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BRAKE ARCHITECTURE FOR PARKING BRAKE BACKUP RESPONSE

Abstract

A vehicle braking system includes a first hydraulic brake assembly associated with a first wheel, a second hydraulic brake assembly associated with a second wheel, a third brake assembly associated with a third wheel, a fourth brake assembly associated with a fourth wheel, a brake control module operably coupled to the first and second hydraulic brake assemblies to control primary operation of the first and second hydraulic brake assemblies and operably coupled to the third and fourth brake assemblies to provide brake torque application for parking brake functionality, and a backup brake actuator operably coupled to a first locking valve disposed in hydraulic lines supplying at least one among the first and second hydraulic brake assemblies and the third and fourth brake assemblies. Responsive to an indication of loss or degradation of the parking brake functionality, the brake control module triggers the backup brake actuator to lock hydraulic pressure in the hydraulic lines supplying the at least one among the first and second hydraulic brake assemblies and the third and fourth brake assemblies for backup parking brake functionality.

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Background/Summary

TECHNICAL FIELD

[0001] Example embodiments generally relate to vehicle braking systems and, more particularly, relate to a system that provides redundant parking braking functionality in response to a loss of or reduction in efficiency of parking brake operation.

BACKGROUND

[0002] Park-by-brake functionality, in which the vehicle relies on the rear brake electric parking actuators to secure the vehicle, has become desirable due to its ability to obviate the use of transmission parking pawls. This is especially true for electric/battery electric vehicles (BEVs), and industry trends in general are moving away from the use of parking pawls.

[0003] In vehicles with park-by-brake functionality, complicated wiring routing or other protection strategies are typically implemented to design against the possibility of a double loss of both rear brakes. Doing so ensures that no single event can take out both rear brake circuits.

[0004] Thus, it may be desirable to develop an architecture that provides an ability to ensure redundant braking capability for a park-by-brake system without complicated wiring strategies.

BRIEF SUMMARY OF SOME EXAMPLES

[0005] In accordance with an example embodiment, a vehicle braking system may be provided. The vehicle braking system may include a first hydraulic brake assembly associated with a first wheel, a second hydraulic brake assembly associated with a second wheel, a third brake assembly associated with a third wheel, a fourth brake assembly associated with a fourth wheel, a brake control module operably coupled to the first and second hydraulic brake assemblies to control primary operation of the first and second hydraulic brake assemblies and operably coupled to the third and fourth brake assemblies to provide brake torque application for parking brake functionality, and a backup brake actuator operably coupled to a first locking valve disposed in hydraulic lines supplying at least one among the first and second hydraulic brake assemblies and the third and fourth brake assemblies. Responsive to an indication of loss or degradation of the parking brake functionality, the brake control module triggers the backup brake actuator to lock hydraulic pressure in the hydraulic lines supplying the at least one among the first and second hydraulic brake assemblies and the third and fourth brake assemblies for backup parking brake functionality.

[0006] In another example embodiment, a method of providing parking brake functionality backup in a vehicle braking system comprising a first hydraulic brake assembly associated with a first wheel, a second hydraulic brake assembly associated with a second wheel, a third brake assembly associated with a third wheel, and a fourth brake assembly associated with a fourth wheel may be provided. The method may include receiving an indication of loss or degradation of the parking brake functionality at a brake control module operably coupled to the first and second hydraulic brake assemblies to control primary operation of the first and second hydraulic brake assemblies, and operably coupled to the third and fourth brake assemblies to provide brake torque application for parking brake functionality. The method may also include actuating a backup brake actuator operably coupled to a first locking valve disposed in hydraulic lines supplying at least one among the first and second hydraulic brake assemblies and the third and fourth brake assemblies to lock hydraulic pressure in the hydraulic lines supplying the at least one among the first and second

hydraulic brake assemblies and the third and fourth brake assemblies for backup parking brake functionality.

Description

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

[0007] Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

[0008] FIG. **1** illustrates a block diagram of a vehicle control system in accordance with an example embodiment;

[0009] FIG. **2** illustrates a block diagram of some components of the vehicle control system of FIG. **1** in accordance with an example embodiment;

[0010] FIG. **3**A illustrates a schematic diagram of a hydraulic brake shut-off valve with a linear actuator in an open position in accordance with an example embodiment;

[0011] FIG. **3**B illustrates a schematic diagram of the hydraulic brake shut-off valve with the linear actuator in a closed position in accordance with an example embodiment;

[0012] FIG. **4**A illustrates a schematic diagram of another hydraulic brake shut-off valve with a rotary actuation in an open position in accordance with an example embodiment;

[0013] FIG. **4**B illustrates a schematic diagram of the hydraulic brake shut-off valve with a rotary actuator in the closed position in accordance with an example embodiment;

[0014] FIG. **4**C illustrates a schematic diagram of another hydraulic brake shut-off valve with a concentric valve in an open position in accordance with an example embodiment;

[0015] FIG. **4**D illustrates a schematic diagram of the hydraulic brake shut-off valve with the concentric valve in the closed position in accordance with an example embodiment; and

[0016] FIG. **5** illustrates a block diagram of a method for providing parking brake functionality backup in a vehicle braking system in accordance with an example embodiment.

DETAILED DESCRIPTION

[0017] Some example embodiments now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all example embodiments are shown. Indeed, the examples described and pictured herein should not be construed as being limiting as to the scope, applicability or configuration of the present disclosure. Rather, these example embodiments are provided so that this disclosure will satisfy applicable requirements. Like reference numerals refer to like elements throughout. Furthermore, as used herein, the term “or” is to be interpreted as a logical operator that results in true whenever one or more of its operands are true. As used herein, operable coupling should be understood to relate to direct or indirect connection that, in either case, enables functional interconnection of components that are operably coupled to each other.

[0018] FIG. **1** illustrates a block diagram of a vehicle control system **100** of an example embodiment. The components of the control system **100** may be incorporated into a vehicle **110** (e.g., via being operably coupled to a chassis of the vehicle **110**, various components of the vehicle **110** and/or electronic control systems of the vehicle **110**). Of note, although the components of FIG. **1** may be operably coupled to the vehicle **110**, it should be appreciated that such connection may be either direct or indirect. Moreover, some of the components of the control system **100** may be connected to the vehicle **110** via intermediate connections to other components either of the chassis or of other electronic and/or mechanical systems or components.

[0019] The control system **100** may include one or more input devices in the form of one or more control pedals. In some embodiments, the control pedals may include a brake pedal **120** that is generally foot operated by an operator **125** to initiate braking forces, or braking torque application at the wheels of the vehicle **110**. The brake pedal **120** may be operably coupled to a set of front hydraulic brakes **130** (e.g., for each of the front wheels) via mechanical, electrical and/or hydraulic

connections under control of an electronic brake booster (EBB) module **135**. The EBB module **135** may also be operably coupled to a set of rear hydraulic brakes **140** (e.g., for each of the rear wheels) that may include an electric actuator. The electric actuator may be used to actuate the rear hydraulic brakes **140** for parking, when actuated. In some cases, rear electromechanical brakes (EMBs) may be substituted for the rear hydraulic brakes **140**, and example embodiments described herein may still be applicable. Moreover, the EBB module **135** may be replaced with any suitable booster or antilock brakes system (ABS) module that employs a hydraulic braking component as described herein. Thus, it should be understood that the EBB module **135** is merely an example of a brake control module (of which the ABS module or other suitable booster are also alternative examples).

[0020] As noted above, given that the electric actuation of the rear hydraulic brakes **140** for parking must normally be redundantly and complexly wired and otherwise constructed. To reduce complexity, and enhance performance, it may be possible to instead employ a backup brake actuator **145**, which may lock hydraulic pressure for brake application to the front and rear hydraulic brakes **130** and **140** in response to a trigger signal **148** from the EBB module **135**, or from any other component of the vehicle **110** (e.g., a vehicle controller or control module). The trigger signal **148** may be provided whenever an indication **149** is received that the parking brake system's operability is compromised or otherwise anything other than operating normally. For example, the trigger signal **148** may be provided if power to the electric actuation of the rear hydraulic brakes **140** (e.g., for parking application). Alternatively or additionally, the indication **149** may take the form of diagnostic codes provided to a vehicle control module (VCM), an electronic control unit (ECU) or other controller of the vehicle **110** (or control system **100**) to indicate lost or reduced capability for the parking brake system may cause the trigger signal **148** to be produced.

[0021] Notably, in some cases, the control system **100** may be configured to perform other tasks related or not related to propulsive and braking control or performance management. However, at least in relation to its functions associated with propulsive and/or braking control, the control system **100** may receive information that is used to determine vehicle status from various components or subassemblies **150** of the vehicle **110**. Additionally or alternatively, various sensors that may be operably coupled to the components or subassemblies **150** may be included, and may provide input to the control system **100** that is used in determining vehicle status. Such sensors may be part of a sensor network **160** and sensors of the sensor network **160** may be operably coupled to the control system **100** (and/or the components or subassemblies **150**) via one or more instances of a vehicle communication bus (e.g., a controller area network (CAN) bus) **170**.

[0022] The components or subassemblies **150** may include, for example, a braking system (of which the parking brake system may be a sub-system), a propulsion system and/or a wheel assembly of the vehicle **110**. The braking system may be configured to provide braking inputs to braking components of the vehicle **110**, and includes the components discussed herein. One or more corresponding sensors of the sensor network **160** that may be operably coupled to the brake system and/or the wheel assembly may provide information relating to brake torque, brake torque rate, vehicle velocity (including rate of change of velocity), front/rear wheel speeds, vehicle pitch, etc. Inputs from the sensors of the sensor network **160** may be provided to the control system **100** to enable the control system **100** to provide various primary and secondary (or backup) control functions related to the components or subassemblies **150**. Accordingly, for example, the control system **100** may be able to receive numerous different parameters, indications and other information that may be related to or indicative of different situations or conditions associated with vehicle status (including providing the indication **149** to the EBB module **135**). The control system **100** may also receive information indicative of the intent of the operator **125** relative to control of various aspects of operation of the vehicle **110** and then be configured to use the information received to provide instructions to control responses to the situations or conditions determined. The control system **100** of FIG. **1** may be similar to conventional systems in many respects, except that,

the control system **100** may be modified to respond to situations in which backup operability is required for the rear hydraulic brakes **140** with respect to parking brake system functionality as described in greater detail in reference to FIGS. **2**-**4**B.

[0023] FIG. **2** illustrates a block diagram of various components of a control system **200**, which may be considered either a specific example of the control system **100** of FIG. **1**, or a portion thereof that is associated with a vehicle braking system. The control system **200** may include the brake pedal **120**, which may have the corresponding brake pedal position sensor (not shown) for determining a position of the brake pedal **120** and providing a signal or input to the EBB module **135** that is indicative of the position determined. However, in other examples, pedal position of the brake pedal **120** may be hydraulically or mechanically communicated to the EBB module **135**.

[0024] The front hydraulic brakes **130** of FIG. **1** may include, for example, a first hydraulic brake assembly **210** associated with a first wheel **212** (e.g., a left front wheel) of the vehicle **110**, and a second hydraulic brake assembly **220** associated with a second wheel **222** (e.g., a right front wheel) of the vehicle **110**. Each of the first and second hydraulic brake assemblies **210** and **220** may include respective instances or a brake caliper or drum for providing frictional braking of the corresponding first and second wheels **212** and **222** associated therewith. Hydraulic power for actuating the first and second hydraulic brake assemblies **210** and **220** may be provided from the EBB module **135** via respective instances of hydraulic lines (e.g., first hydraulic lines **214** and second hydraulic lines **224**). Each of the first and second wheels **212** and **222**, respectively, associated with the first and second hydraulic brake assemblies **210** and **220** may also have a corresponding wheel speed sensor associated therewith to measure the wheel speed of the corresponding ones of the first and second wheels **212** and **222** to provide information on wheel speed measured to the EBB module **135**.

[0025] The control system **200** may also include a third brake assembly **230** associated with a third wheel **232** (e.g., a left rear wheel) and a fourth brake assembly **240** associated with a fourth wheel **242** (e.g., a right rear wheel). The third and fourth brake assemblies **230** and **240** are examples of the rear hydraulic brakes **140** of FIG. **1**. However, as noted above, the third and fourth brake assemblies **230** and **240** may be replaced by respective instances of EMBs in some cases.

[0026] When the third and fourth brake assemblies **230** and **240** are embodied as hydraulic brake assemblies, each of the third and fourth brake assemblies **230** and **240** may include respective instances or a brake caliper or drum for providing frictional braking of the corresponding third and fourth wheels **232** and **242** associated therewith. Hydraulic power for actuating the third and fourth brake assemblies **230** and **240** may be provided from the EBB module **135** via respective instances of hydraulic lines (e.g., third hydraulic lines **234** and fourth hydraulic lines **244**). Each of the third and fourth wheels **232** and **242**, respectively, associated with the third and fourth brake assemblies **230** and **240** may also have a corresponding wheel speed sensor associated therewith to measure the wheel speed of the corresponding ones of the third and fourth wheels **232** and **242** to provide information on wheel speed measured to the EBB module **135**.

[0027] Unlike the first and second hydraulic brake assemblies **210** and **220**, the third and fourth brake assemblies **230** and **240** may each also be operable via an electrical actuation signal that may be used, for example, for applying clamp force as a parking brake. As noted above, this may be an alternative to the use of transmission parking pawls. In such an example, the EBB module **135** may provide the electrical actuation signal via a first electric line **250** to a first electrical actuator **252** associated with the third brake assembly **230**. The EBB module **135** may also provide the electrical actuation signal via a second electric line **254** to a second electrical actuator **256** associated with the fourth brake assembly **240**. The first and second electrical actuators **252** and **256** may, when actuated, may employ a local electrical motor or other motive force provider, to apply brake pressure to the respective instances or the brake caliper or drum for providing frictional braking of the corresponding third and fourth wheels **232** and **242** associated therewith as a parking brake.

[0028] As noted above, redundancy in the event of the loss of the parking brake functionality

associated with the third and fourth brake assemblies **230** and **240** is typically provided for by complex wiring aimed at preventing loss of power to provide the electric actuation signal. This added complexity may be considered inefficient and undesirable. To provide backup braking power for parking brake functionality, example embodiments may employ the backup brake actuator **145** of FIG. **1**, which is also shown in FIG. **2**. As shown in FIG. **2**, the backup brake actuator **145** may be operably coupled to the EBB module **135** to receive the trigger signal **148** from the EBB module **135** (e.g., responsive to the indication **149** of lost or reduced capability for the parking brake system). The backup brake actuator **145** may then actuate a first locking valve **260** associated with the first and second hydraulic lines **214** and **224**, and/or actuate a second locking valve **270** associated with the third and fourth hydraulic lines **234** and **244**.

[0029] When actuated, the first locking valve **260** may lock hydraulic pressure in the first and second hydraulic lines **214** and **224**, and the second locking valve **270** may lock hydraulic pressure in the third and fourth hydraulic lines **234** and **244**. In particular, assuming the operator **125** is already pressing the brake pedal **120**, hydraulic pressure will normally already be built up in the first, second, third and fourth hydraulic lines **214**, **224**, **234**, and **244**. This already built up pressure will simply then be locked in by actuating or closing the first and second locking valves **260** and **270** between the first and second locking valves **260** and **270** and the braking components associated with the first, second, third and fourth wheels **212**, **222**, **232** and **242**. This locking of pressure may provide a backup parking brake functionality (responsive to the indication **149** and trigger signal **148**), and may also be accompanied by a notification **280**, which may be provided to the operator **125**. The notification **280** may indicate to the operator **125** that service should be performed on the parking brake functionality.

[0030] However, if for any reason the operator **125** is not pressing the brake pedal **120** when the indication **149** is received, the EBB module **135** (or some other controller in the system **200**) may cause pressure to be built up in the necessary hydraulic lines before issuing the trigger signal **148** and locking the pressure in the hydraulic lines. In this regard, for example, a threshold pressure may be set above which operation of the locking of pressure in the corresponding hydraulic lines will be enabled to act as a parking brake backup. When the indication **149** is received, the EBB module **135** may first check the current pressure in the hydraulic lines and, if the current pressure is above the threshold pressure, the trigger signal **148** may be issued. However, if the current pressure is below the threshold pressure, then the EBB module **135** may direct the raising of such pressure until the threshold pressure is exceeded. After the threshold pressure is exceeded, the trigger signal **148** may be used to lock the pressure in the corresponding hydraulic lines to act as a backup parking brake.

[0031] Notably, the structure of FIG. **2** indicates that each of the first locking valve **260** and the second locking valve **270** operates to isolate or lock two hydraulic lines (e.g., the first locking valve **260** locks the first and second hydraulic lines **214** and **224**, and the second locking valve **270** locks the third and fourth hydraulic lines **234** and **244**). However, one locking valve could alternatively be provided for each respective one of the hydraulic lines. In such an example, the first locking valve **260** may represent a pair of locking valves that are independently or simultaneously operated with respect to the first and second hydraulic lines **214** and **224**. Similarly, the second locking valve **270** may represent a pair of locking valves that are independently or simultaneously operated with respect to the third and fourth hydraulic lines **234** and **244**.

[0032] Additionally, although FIG. **2** shows both the first and second locking valves **260** and **270** as external valves (with respect to the EBB module **135**), it is also possible for the first and second locking valves to be alternatively embodied as internal valves **290**. In the case of an internal structure, the internal valves **290** are located internal to the EBB module **135**. In this regard, for example, the EBB module **135** may include a header or other hydraulic fluid distribution assembly that distributes hydraulic fluid (and pressure) to the first, second, third and fourth hydraulic lines **214**, **224**, **234** and **244**. The internal valves **290** may be actuated by the backup brake actuator **145**

responsive to the trigger signal **148**, and lock pressure in respective ones of the first, second, third and fourth hydraulic lines **214**, **224**, **234** and **244** that are isolated by the actuation. Thus, the internal valves **290** may isolate or lock respective ones of the first, second, third and fourth hydraulic lines **214**, **224**, **234** and **244** internal to the EBB module **135**.

[0033] Although the specific structures used to implement the first and second locking valves **260** and **270** may vary in different embodiments, some examples of structures that may be employed are shown in FIGS. **3**A, **3**B, **4**A and **4**B. In this regard, FIGS. **3**A and **3**B illustrate a hydraulic brake shut-off valve **300** with a locking body **310** that moves in the direction of arrow **320** in order to lock pressure in the first and second hydraulic lines **214** and **224**. The locking body **310** may include blocking portions **330** that interrupt flow through the first and second hydraulic lines **214** and **224** when in the closed or locked position of FIG. **3**B, but allow flow through the first and second hydraulic lines **214** and **224** when in the open or unlocked position of FIG. **3**A. The locking body **310** of this example embodiment operates similar to a linear actuator in that the locking body **310**, when actuated, moves linearly between the open and closed positions.

[0034] In some embodiments, it may be desirable for the state of the hydraulic brake shut-off valve **300** (and particularly the position of the locking body **310**) to remain unchanged except in response to a specific instruction to change state. Thus, for example, if the vehicle **110** is being held on a slope due to operation of the first and/or second locking valve **260**/**270** and the battery of the vehicle **110** is exhausted such that power is lost, the state of the first and/or second locking valve **260**/**270** will not change. This state stability may be achieved, for example, by implementing the backup brake actuator **145** in the form of a latching solenoid **340**. Thus, if the hydraulic brake shut-off valve **300** is in the open or unlocked state of FIG. **3**A when power is lost, the latching solenoid **340** will maintain the locking body **310** in the position shown in FIG. **3**A until power is restored and the trigger signal **148** can be applied to change state. If instead the hydraulic brake shut-off valve **300** is in the closed or locked state of FIG. **3**B when power is lost, the latching solenoid **340** will maintain the locking body **310** in the position shown in FIG. **3**B until power is restored and the trigger signal **148** can be applied to change state.

[0035] FIGS. **4**A and **4**B illustrate an example of alternative structures that may be employed to implement the first and second locking valves **260** and **270**. Instead of moving linearly responsive to actuation, rotational motion is instead employed in this example. In particular, FIGS. **4**A and **4**B illustrate a hydraulic brake shut-off valve **400** with a locking body **410** that moves rotationally in the direction of arrow **420** about a pivot axis of the locking body **410**. The locking body **410** includes fixed points of connection to blocking portions **430** that are pivoted outward (in FIG. **4**B) or drawn inward (in FIG. **4**A) to transition between states of the hydraulic brake shut-off valve **400**. The blocking portions **430** of FIG. **4**B translate outward on rotation of the locking body **410** in order to lock pressure in the first and second hydraulic lines **214** and **224** when in the closed or locked position of FIG. **4**B, but allow flow through the first and second hydraulic lines **214** and **224** when in the open or unlocked position of FIG. **4**A. As shown in FIG. **4**A, a latching solenoid **440** may be employed to actuate or rotate the locking body **410** so that unwanted state changes are prevented even if power is lost.

[0036] FIGS. **4**A and **4**B illustrate an example in which the rotational movement **420** is tangential and/or perpendicular to the blocking portions **430**. Alternatively, the rotational movement can be concentric with the blocking portions so that the blocking portions rotate **90** degrees to either block or allow flow through the valve depending on control signal logic. An example of such an alternative concept is shown in FIGS. **4**C and **4**D. In this regard, the hydraulic brake shut-off valve **450** of FIGS. **4**C and **4**D includes a lock body **460** that is essentially a cylindrical rotatable body with through-holes **470** that pass entirely through the lock body **460** and align the through-holes **470** with the first and second hydraulic lines **214** and **224** to permit flow when in the open position of FIG. **4**C. However, responsive to an actuation signal from actuator **480**, the lock body **460** rotates about its axis as shown by arrow **490** such that the through-holes **470** are not aligned with

the first and second hydraulic lines **214** and **224** and flow is therefore not permitted through the first and second hydraulic lines **214** and **224** in the closed position of FIG. **4**D. Thus, for example, the hydraulic brake shut-off valve **450** of FIGS. **4**C and **4**D would conceptually operate like an electrically actuated dual (or single) circuit ball or cylinder valve.

[0037] FIG. **5** illustrates a method of providing parking brake functionality backup in a vehicle braking system such as that shown, for example in FIG. **2**. Thus, for example, the system may include a first hydraulic brake assembly associated with a first wheel, a second hydraulic brake assembly associated with a second wheel, a third brake assembly associated with a third wheel, and a fourth brake assembly associated with a fourth wheel. The method may include receiving an indication of loss or degradation of the parking brake functionality at a brake control module (e.g., the EBB module **135**) at operation **500**. The brake control module may be operably coupled to the first and second hydraulic brake assemblies to control primary operation of the first and second hydraulic brake assemblies, and operably coupled to the third and fourth brake assemblies to provide brake torque application for parking brake functionality. Notably, if the third and fourth brake assemblies are also hydraulic in nature, then the brake control module may also provide brake torque application for normal operation of the third and fourth brake assemblies as well. The method may further include actuating a backup brake actuator operably coupled to a first locking valve disposed in hydraulic lines supplying at least one among the first and second hydraulic brake assemblies and the third and fourth brake assemblies to lock hydraulic pressure in the hydraulic lines supplying the at least one among the first and second hydraulic brake assemblies and the third and fourth brake assemblies for backup parking brake functionality at operation **510**. The method may, in some cases, include additional (optional) operations, some of which are shown in dashed lines in FIG. **5**. In this regard, for example, the method may further include determining a current pressure in the first and second hydraulic lines responsive to receipt of the indication at operation **520** and, in response to the current pressure being below a threshold value, raising pressure to greater than the threshold value prior to actuating the first locking valve at operation **530**. The method may also or alternatively include providing a notification to an operator of the vehicle responsive to actuation of the first locking valve at operation **540**.

[0038] A vehicle braking system for a vehicle may therefore be provided. The vehicle braking system may include a first hydraulic brake assembly associated with a first wheel, a second hydraulic brake assembly associated with a second wheel, a third brake assembly associated with a third wheel, a fourth brake assembly associated with a fourth wheel, a brake control module operably coupled to the first and second hydraulic brake assemblies to control primary operation of the first and second hydraulic brake assemblies and operably coupled to the third and fourth brake assemblies to provide brake torque application for parking brake functionality, and a backup brake actuator operably coupled to a first locking valve disposed in hydraulic lines supplying at least one among the first and second hydraulic brake assemblies and the third and fourth brake assemblies. Responsive to an indication of loss or degradation of the parking brake functionality, the brake control module triggers the backup brake actuator to lock hydraulic pressure in the hydraulic lines supplying at least one among the first and second hydraulic brake assemblies and the third and fourth brake assemblies for backup parking brake functionality.

[0039] The system of some embodiments may include additional features, modifications, augmentations and/or the like to achieve further objectives or enhance performance of the system. The additional features, modifications, augmentations and/or the like may be added in any combination with each other. Below is a list of various additional features, modifications, and augmentations that can each be added individually or in any combination with each other. For example, the hydraulic supply lines may include a first hydraulic supply line operably coupled to the first hydraulic brake assembly and a second hydraulic supply line operably coupled to the second hydraulic brake assembly, and the first locking valve, when actuated, may simultaneously lock pressure in both the first and second hydraulic supply lines. In an example embodiment, the

hydraulic supply lines may include a third hydraulic supply line operably coupled to the third brake assembly and a fourth hydraulic supply line operably coupled to the fourth brake assembly, and the vehicle braking system may further include a second locking valve that, when actuated, simultaneously locks pressure in both the third and fourth hydraulic supply lines. In some cases, the first and second locking valves may be internal to the brake control module. However, in some other alternatives, the first and second locking valves may be external to the brake control module. In an example embodiment, the first locking valve comprises a locking body that is repositioned linearly to simultaneously lock pressure in both the first and second hydraulic supply lines. However, in some other alternatives, the first locking valve comprises a locking body that rotates about an axis to simultaneously lock pressure in both the first and second hydraulic supply lines. In an example embodiment, the brake control module determines a current pressure in the first and second hydraulic lines responsive to receipt of the indication and, in response to the current pressure being below a threshold value, raising pressure to greater than the threshold value before actuating the first locking valve. In some cases, the third brake assembly and the fourth brake assembly are each electromechanical brake assemblies, and responsive to the indication, the brake control module triggers the first locking valve to simultaneously lock pressure in both the first and second hydraulic supply lines. In an example embodiment, the brake control module may provide a notification to an operator of the vehicle responsive to actuation of the first locking valve. In some cases, the backup brake actuator may include a latching solenoid.

[0040] Many modifications and other embodiments of the inventions set forth herein will come to mind to one skilled in the art to which these inventions pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the inventions are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Moreover, although the foregoing descriptions and the associated drawings describe exemplary embodiments in the context of certain exemplary combinations of elements and/or functions, it should be appreciated that different combinations of elements and/or functions may be provided by alternative embodiments without departing from the scope of the appended claims. In this regard, for example, different combinations of elements and/or functions than those explicitly described above are also contemplated as may be set forth in some of the appended claims. In cases where advantages, benefits or solutions to problems are described herein, it should be appreciated that such advantages, benefits and/or solutions may be applicable to some example embodiments, but not necessarily all example embodiments. Thus, any advantages, benefits or solutions described herein should not be thought of as being critical, required or essential to all embodiments or to that which is claimed herein. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

Claims

1. A vehicle braking system comprising: a first hydraulic brake assembly associated with a first wheel; a second hydraulic brake assembly associated with a second wheel; a third brake assembly associated with a third wheel; a fourth brake assembly associated with a fourth wheel; a brake control module operably coupled to the first and second hydraulic brake assemblies to control primary operation of the first and second hydraulic brake assemblies, and operably coupled to the third and fourth brake assemblies to provide brake torque application for parking brake functionality; and a backup brake actuator operably coupled to a first locking valve disposed in hydraulic lines supplying at least one among the first and second hydraulic brake assemblies and the third and fourth brake assemblies, wherein, responsive to an indication of loss or degradation of the parking brake functionality, the brake control module triggers the backup brake actuator to lock hydraulic pressure in the hydraulic lines supplying the at least one among the first and second

hydraulic brake assemblies and the third and fourth brake assemblies for backup parking brake functionality.

2. The vehicle braking system of claim 1, wherein the hydraulic supply lines include a first hydraulic supply line operably coupled to the first hydraulic brake assembly and a second hydraulic supply line operably coupled to the second hydraulic brake assembly, and wherein the first locking valve, when actuated, simultaneously locks pressure in both the first and second hydraulic supply lines.

3. The vehicle braking system of claim 2, wherein the hydraulic supply lines include a third hydraulic supply line operably coupled to the third brake assembly and a fourth hydraulic supply line operably coupled to the fourth brake assembly, and wherein the vehicle braking system further includes a second locking valve that, when actuated, simultaneously locks pressure in both the third and fourth hydraulic supply lines.

4. The vehicle braking system of claim 3, wherein the first and second locking valves are internal to the brake control module.

5. The vehicle braking system of claim 3, wherein the first and second locking valves are external to the brake control module.

6. The vehicle braking system of claim 2, wherein the first locking valve comprises a locking body that is repositioned linearly to simultaneously lock pressure in both the first and second hydraulic supply lines.

7. The vehicle braking system of claim 2, wherein the first locking valve comprises a locking body that rotates about an axis to simultaneously lock pressure in both the first and second hydraulic supply lines.

8. The vehicle braking system of claim 2, wherein the brake control module determines a current pressure in the first and second hydraulic lines responsive to receipt of the indication and, in response to the current pressure being below a threshold value, raising pressure to greater than the threshold value before actuating the first locking valve.

9. The vehicle braking system of claim 2, wherein the third brake assembly and the fourth brake assembly are each electromechanical brake assemblies, and wherein responsive to the indication, the brake control module triggers the first locking valve to simultaneously lock pressure in both the first and second hydraulic supply lines.

10. The vehicle braking system of claim 1, wherein the first locking valve is internal to the brake control module.

11. The vehicle braking system of claim 1, wherein the first locking valve is external to the brake control module.

12. The vehicle braking system of claim 1, wherein the brake control module provides a notification to an operator of the vehicle responsive to actuation of the first locking valve.

13. The vehicle braking system of claim 1, wherein the backup brake actuator comprises a latching solenoid.

14. A method of providing parking brake functionality backup in a vehicle braking system comprising a first hydraulic brake assembly associated with a first wheel, a second hydraulic brake assembly associated with a second wheel, a third brake assembly associated with a third wheel, and a fourth brake assembly associated with a fourth wheel, the method comprising: receiving an indication of loss or degradation of the parking brake functionality at a brake control module operably coupled to the first and second hydraulic brake assemblies to control primary operation of the first and second hydraulic brake assemblies, and operably coupled to the third and fourth brake assemblies to provide brake torque application for parking brake functionality; and actuating a backup brake actuator operably coupled to a first locking valve disposed in hydraulic lines supplying at least one among the first and second hydraulic brake assemblies and the third and fourth brake assemblies to lock hydraulic pressure in the hydraulic lines supplying the at least one among the first and second hydraulic brake assemblies and the third and fourth brake assemblies

for backup parking brake functionality.

15. The method of claim 14, wherein the hydraulic supply lines include a first hydraulic supply line operably coupled to the first hydraulic brake assembly and a second hydraulic supply line operably coupled to the second hydraulic brake assembly, and wherein the first locking valve, when actuated, simultaneously locks pressure in both the first and second hydraulic supply lines.

16. The method of claim 15, wherein the hydraulic supply lines include a third hydraulic supply line operably coupled to the third brake assembly and a fourth hydraulic supply line operably coupled to the fourth brake assembly, and wherein a second locking valve is actuated to simultaneously lock pressure in both the third and fourth hydraulic supply lines.

17. The method of claim 15, further comprising: determining a current pressure in the first and second hydraulic lines responsive to receipt of the indication; and in response to the current pressure being below a threshold value, raising pressure to greater than the threshold value prior to actuating the first locking valve.

18. The method of claim 15, further comprising providing a notification to an operator of the vehicle responsive to actuation of the first locking valve.

19. The method of claim 14, wherein actuating the backup brake actuator comprises providing a state change signal to a latching solenoid.

20. The method of claim 14, wherein actuating the backup brake actuator comprises actuating the first locking valve internal to the brake control module or external to the brake control module.