US Patent & Trademark Office
Patent Public Search | Text View

Swash plate braking

Abstract

A vehicle may include an electric motor, a variable displacement hydraulic pump having a swash plate, driven traction members, a transmission operably coupling the electric motor to the driven traction members and to the hydraulic pump, a hydraulic pressure consumer fluidly coupled to an output of the hydraulic pump, a battery to receive energy produced by the electric motor during braking of the driven traction members by the electric motor and a controller. The controller is configured to adjust an angle of the swash plate in response to a sensed state of the battery and braking of the driven traction members.

U.S. Cl.:

CPC **F16H61/46** (20130101); **B60T1/10** (20130101); **F16H61/433** (20130101); B60Y2300/18125 (20130101)

Field of Classification Search

CPC: B60T (1/10); B60T (10/04); B60Y (2300/18125); B60Y (2300/91)

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
6170587	12/2000	Bullock	903/910	B60K 6/365
11052881	12/2020	Chen	N/A	B60K 31/08
2006/0000207	12/2005	Rush	N/A	N/A
2009/0173066	12/2008	Duray	N/A	N/A
2016/0193916	12/2015	Kassube	74/664	B60K 17/354
2017/0335867	12/2016	Meehan et al.	N/A	N/A
2020/0079221	12/2019	Ferri	N/A	B60W 10/06

OTHER PUBLICATIONS

International Search Report and Written Opinion for PCT/US2023/082179; mail date Jun. 6, 2024; 9 pages. cited by applicant

Primary Examiner: Lazo; Thomas E

Attorney, Agent or Firm: Rathe Lindenbaum LLP

Background/Summary

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS (1) The present non-provisional application claims benefit from U.S. provisional patent Application Ser. No. 63/429,190 filed on Dec. 1, 2022, by Karan Kaushi and entitled SWASH PLATE BRAKING, the full disclosure of which is hereby incorporated by reference.

BACKGROUND
(1) Electric vehicles utilize an electric motor to provide torque for propulsion of the vehicle. Some electric vehicles may employ regenerative braking, wherein the electric motor functions as a generator during braking to output electrical energy.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a diagram schematically illustrating portions of an example vehicle having an example vehicle braking system.
(2) FIG. **2** is a flow diagram of an example vehicle braking method.
(3) FIG. **3** is a side view illustrating portions of an example vehicle having an example vehicle

braking system.

(4) Throughout the drawings, identical reference numbers designate similar, but not necessarily identical, elements. The figures are not necessarily to scale, and the size of some parts may be exaggerated to more clearly illustrate the example shown. Moreover, the drawings provide examples and/or implementations consistent with the description; however, the description is not limited to the examples and/or implementations provided in the drawings.

DETAILED DESCRIPTION OF EXAMPLES

(5) Disclosed are example vehicle control systems, vehicles and methods that provide enhanced vehicle braking performance for vehicles driven by an electric motor. Vehicles, especially heavy off-road vehicles, such as agricultural vehicles and tractors, carry a lot of kinetic energy which must be dissipated into a different form of energy for the vehicle to slow down or brake. Vehicles driven within electric motor may employ regenerative braking, wherein the electric motor functions as a generator during braking and wherein the electrical power produced by the generator is used to recharge the vehicle's battery. Such regenerative braking may not be available when the battery is nearly fully charged.

(6) The disclosed example control systems, vehicles and methods facilitate continued braking of the vehicle in circumstances where regenerative braking is not available or is less effective. The disclosed examples dissipate kinetic energy of the vehicle during braking into heat or other forms by using a continuously variable hydraulic pump and adjusting the angle of its swash plate to impose a load upon the electric motor, wherein the resulting pressurized hydraulic fluid is forced through a narrow passage, such as through a variable orifice valve, producing the heat. The load imposed upon the motor assists in slowing the vehicle down in a controlled and smooth manner. This load may also assist in speed control of the vehicle when the vehicle is traveling upon a gradient.

(7) The disclosed examples adjust the angle of the swash plate in response to a sensed state of the battery and braking of driven traction members of the vehicle. The driven traction members may be in the form of wheels or tracks. In some implementations, a controller is used to adjust the angle of the swash plate in response to a state of charge of the battery exceeding a predetermined battery charge level. In some implementations, the predetermined battery charge level comprises 90% of the charge capacity of the battery.

(8) In some implementations, the sensed state of the battery comprises a voltage level of the battery. The controller may be configured to adjust the angle swash plate in response to the voltage level of the battery exceeding a predetermined battery voltage level. In some implementations, the predetermined battery maximum cell voltage level comprises a value of at least 4200 mV, and in some implementations, a value of at least 4250 mV.

(9) In some implementations, the controller adjusts the angle of the swash plate to provide a load up to 25 KW. In some implementations, the controller adjust the angle of the swash plate to provide a load up to 28 KW. Such load depends upon the motor RPM and the plate angle.

(10) In some implementations, the hydraulic pump is mechanically connected to the electric motor which serves as a traction motor. In some implementations, the hydraulic pump may be used to drive forward or front steered wheels, and to power and hydraulically drive hydraulic subsystems, such as attachments (i.e., a front loader) or implements associated with the vehicle.

(11) In circumstances where no hydraulic flow is being used to drive such attachments or implements, the swash plate may remain a 0% travel, imposing no or little load upon the traction motor. During braking, in response to the state of charge or voltage level of the battery exceeding a predetermined threshold, such that regenerative braking may not be available or may be inefficient, the angle of the swash plate may be controlled or adjusted against the internal hydraulic circuit without actuating any hydraulic subsystems. In circumstances where hydraulic subsystems are utilizing hydraulic flow, a first portion of the pressurized hydraulic fluid flow produced by the hydraulic pump during such braking may be used to hydraulically power the hydraulic subsystems

and a second portion of the pressurized hydraulic fluid flow produced by the hydraulic pump during such braking may be directed (with the valve or the like) through the narrow restriction or main relief.

(12) For purposes of this application, the term "processing unit" shall mean a presently developed or future developed computing hardware that executes sequences of instructions contained in a non-transitory memory. Execution of the sequences of instructions causes the processing unit to perform steps such as generating control signals. The instructions may be loaded in a random-access memory (RAM) for execution by the processing unit from a read only memory (ROM), a mass storage device, or some other persistent storage. In other embodiments, hard wired circuitry may be used in place of or in combination with software instructions to implement the functions described. For example, a controller may be embodied as part of one or more application-specific integrated circuits (ASICs). Unless otherwise specifically noted, the controller is not limited to any specific combination of hardware circuitry and software, nor to any particular source for the instructions executed by the processing unit.

(13) For purposes of this disclosure, unless otherwise explicitly set forth, the recitation of a "processor", "processing unit" and "processing resource" in the specification, independent claims or dependent claims shall mean at least one processor or at least one processing unit. The at least one processor or processing unit may comprise multiple individual processors or processing units at a single location or distributed across multiple locations.

(14) For purposes of this disclosure, the phrase "configured to" denotes an actual state of configuration that fundamentally ties the stated function/use to the physical characteristics of the feature proceeding the phrase "configured to".

(15) For purposes of this disclosure, unless explicitly recited to the contrary, the determination of something "based on" or "based upon" certain information or factors means that the determination is made as a result of or using at least such information or factors; it does not necessarily mean that the determination is made solely using such information or factors. For purposes of this disclosure, unless explicitly recited to the contrary, an action or response "based on" or "based upon" certain information or factors means that the action is in response to or as a result of such information or factors; it does not necessarily mean that the action results solely in response to such information or factors.

(16) For purposes of this, unless explicitly recited to the contrary, recitations reciting that signals "indicate" a value or state means that such signals either directly indicate a value, measurement or state, or indirectly indicate a value, measurement or state. Signals that indirectly indicate a value, measure or state may serve as an input to an algorithm or calculation applied by a processing unit to output the value, measurement or state. In some circumstances, signals may indirectly indicate a value, measurement or state, wherein such signals, when serving as input along with other signals to an algorithm or calculation applied by the processing unit may result in the output or determination by the processing unit of the value, measurement or state.

(17) For purposes of this disclosure, the term "coupled" shall mean the joining of two members directly or indirectly to one another. Such joining may be stationary in nature or movable in nature. Such joining may be achieved with the two members, or the two members and any additional intermediate members being integrally formed as a single unitary body with one another or with the two members or the two members and any additional intermediate member being attached to one another. Such joining may be permanent in nature or alternatively may be removable or releasable in nature. The term "operably coupled" shall mean that two members are directly or indirectly joined such that motion may be transmitted from one member to the other member directly or via intermediate members.

(18) FIG. **1** schematically illustrates an example electrically driven or propelled vehicle **420** comprising an example a vehicle braking control system **422** for carrying out an example steering control method **500** (shown in FIG. **7**). Vehicle **420** may be in the form of an agricultural vehicle (a

tractor, a harvester, self-propelled sprayer or the like), a passenger vehicle (car or truck) or another self-propelled vehicle.

(19) Vehicle braking control system **422** facilitates continued braking of the vehicle in circumstances where regenerative braking is not available or is less effective. Vehicle braking control system **422** dissipates kinetic energy of the vehicle **420** during braking into heat or other forms by using a continuously variable hydraulic pump and adjusting the angle of its swash plate to impose a load upon the electric motor, wherein the resulting pressurized hydraulic fluid is forced through a narrow constriction or a main relief, producing the heat. The load imposed upon the motor assists in slowing the vehicle down in a controlled and smooth manner. This load may also assist in speed control of the vehicle when the vehicle is traveling upon a gradient.

(20) Vehicle **420** comprises frame **424**, driven traction members **426** electric traction motor **428**, transmission **430**, battery **432**, variable displacement hydraulic pump **434**, hydraulic subsystems **436**, compensator/relief **438** and controller **440**. Frame **424** rotatably or movably supports ground engaging or traction members **426** which may be in the form of wheels or tracks. In some implementations, driven traction members **426** are located at a rearward portion of vehicle **420**. In other implementations, driven traction members **426** are located at a forward portion of vehicle **420**.

(21) Electric traction motor **428** comprises an electric motor operably coupled to driven traction members **426** by transmission **430** and operably coupled to variable displacement hydraulic pump **434** by transmission **430**. Transmission **430** transmits torque from motor **428** to drive or propel traction members **426**. In circumstances, transmission **430** further transmits torque from motor **428** to pump **434** to drive pump **434**. Electric traction motor **428** is supplied with electrical power energy from battery **432**. Battery **432** may comprise a battery pack comprising several sets of rechargeable batteries of sufficient power and sized to electrically power motor **428** so as to generate sufficient torque for propelling vehicle **420**. Transmission **430** is configured such that during braking of vehicle **420**, electric traction motor **428** functions as a generator producing electrical power which may be used to recharge battery **432** (referred to as regenerative braking).

(22) Variable displacement hydraulic pump **434** comprises a pump configured to supply pressurized hydraulic fluid flow to hydraulic subsystems **436** and/or compensator/relief **438**. Hydraulic pump **434** comprises a swash plate **442** which is operably coupled to motor **428** so as to be rotatably driven by torque output by motor **428**. This load is imposed by adjusting the oil flow and the pressure drop of the hydraulic fluid flowing through the output of pump **434**.

(23) Hydraulic subsystems **436** comprise systems of vehicle **420** or external systems powered by the hydraulic pump **434** of vehicle **420**. Such hydraulic subsystems may include hydraulic cylinder-piston assemblies for physically moving, raising and/or lowering components. One example of a hydraulic subsystem **436** are hydraulic cylinder-piston assemblies used to actuate a bucket, fork or other attachment of a front or rear loader. In some implementations, hydraulic subsystems **436** may be such as where pump **434** is solely used for braking.

(24) Compensator/relief **438** is fluidly coupled to pump **434** comprise a series of valves and a pressure loop. Hydraulic fluid flow from pump **434** may be directed (with valves of the like) through a pressure loop of compensator/relief **438**. In some circumstances, the hydraulic fluid flow is forced through a narrow constriction of the pressure loop, wherein energy of the hydraulic fluid is dissipated as heat prior to returning to the hydraulic reservoir.

(25) Controller **440**, pump **434** and compensator/relief **438** serve as part of the vehicle braking control system **422**. Controller **440** comprises a processing unit **446** and a non-transitory computer-readable medium **448**. Processing unit **446** is configured to receive data signals, analyze such data signals, and output data and control signals. Medium **448** may comprise instructions (in the form of hard-wired circuitry or software) for directing processing unit **446** to carry out method **500** (shown in FIG. **2**).

(26) FIG. **2** is a flow diagram of an example steering control method **500** that may be carried out by

processor **446** of controller **440** based upon instructions provided in memory **448**. As indicated by decision block **502**, controller **440** determines whether vehicle **420** is undergoing braking. Such a determination may be made based upon the current state of motor **428**, whether motor **428** is carrying out regenerative braking, functioning as a generator where electrical charge is being produced or output by motor **428**. Such a determination may also or alternatively be made based upon signals from various sensors on vehicle **420** indicating such braking. For example, such braking may be determined based upon changes in the speed of vehicle **420** and the slope of the terrain upon which vehicle **420** is traveling (based upon signals from a camera, inertial motion unit or the like. Determination of braking is carried out by comparing the target speed request either from the hand or the foot throttle and the measured speed on the motor shaft and the wheels using sensors along with the check on the amount of regenerative torque allowed from the motor.

(27) As indicated by block **504**, in response to a determination that vehicle **420** is undergoing braking, controller **440** determines the current state of battery **432**. In some implementations, the current state of battery **432** may be sensed, such as through the use of a battery sensor **452** (shown in broken lines in FIG. **1**). In some implementations, the current state of battery **432** may be determined/estimated by controller **440** based upon a prior historical state of battery **432** and prior historical power draws from battery **432**.

(28) As indicated by block **506**, controller **440** (processing unit **446** following instructions contained in memory **448**) whether the current battery state BS satisfies a predetermined battery state threshold BS TH. As indicated by block **508**, in response to the battery state threshold being satisfied, controller **440** automatically outputs control signals causing an adjustment to the angle of swash plate **442** to move the swash plate to an angle that applies a load to motor **4282** facilitate enhanced braking. Increasing the angle of the swash plate increases the load placed upon motor **428**. In some implementations, swash plate angle may be adjusted such that a load of at least 25 kW, and in some implementations at least 28 kW, is placed upon motor **428** so as to brake traction members **426** and vehicle **420**. The increased angle of swash plate **442** results in pump **434** outputting hydraulic flow at a greater pressure.

(29) In some circumstances, the greater pressure (greater energy) may be at least partially consumed by the hydraulic subsystems **436**. As indicated by block **510**, any excess pressure or energy is dissipated by the hydraulic flow being directed through compensator/relief **438**. In some implementations, hydraulic flow is dead headed against the compensator/relief **438** to dissipate the energy as heat. In some implementations, such hydraulic subsystems **436** may not be consuming any energy or may be disconnected, wherein all of the hydraulic flow produced by pump **434** is directed to compensator **438** for energy dissipation and heat generation. The flow of hydraulic may be controlled by controller **440** outputting control signals to one or more valves which selectively direct the pressurized fluid to the hydraulic subsystems **436** and/or compensator/relief **438**.

(30) In some implementations, the state of the battery comprises a state of charge of battery **432**. For example, in some implementations, the battery state threshold may comprise a 90% of the capacity of battery **432**. In response to battery **432** having a charge of at least 90% of its charging capacity, controller **440** may output control signals increasing the angle of swash plate **442** and increasing the load of pump **434** upon motor **428** to assist with braking of vehicle **420**.

(31) In some implementations, the state of the battery comprises a battery maximum cell voltage level. For example, in some implementations, the battery state threshold may comprise a predetermined battery maximum cell voltage level having a value of at least 4250 mV. In response to battery **432** having a voltage of at least 4250 mV, controller **440** may output control signals increasing the angle of swash plate **442** and increasing a load of pump **434** upon motor **428** to assist with braking of vehicle **420**.

(32) In some implementations, the state of the battery (BS) determined in block **504** and used as a criteria in block **506** may be a combination of multiple factors, such as a combination of both the current state of charge of battery **432** and the current voltage level of battery **432**. In some

implementations, the multiple factors may be differently weighted with respect to a determination of whether a battery state threshold value has been satisfied or exceeded. In some implementations, criteria other than state of charge and voltage level may be used in block **504** and **506**.

(33) As indicated by block **512**, during such braking assistance provided by pump **434**, controller **440** monitors the current braking state of vehicle **420**. For example, controller **440** may monitor the charge output or input of motor **428**. Controller **440** may evaluate operator controls or commands for such braking to determine when such braking has been ended. Controller **440** may evaluate whether such braking is continuing as discussed above with respect to block **502**.

(34) As indicated by block **514**, in response to determining that such braking has ended, controller **440** may output control signals to pump **434** causing the angle of swash plate **442** to be once again adjusted to a non-braking angle. The non-braking angle is an angle at which the angle swash plate **442** is such that pump **434** produces sufficient hydraulic flow for powering any of hydraulic subsystems **436**, but wherein excess hydraulic flow that might otherwise be directed to compensator/relief **438** is reduced or eliminated. In circumstances where the hydraulic subsystems **436** are not consuming any energy from hydraulic flow, swash plate **442** may be actuated to a zero angle.

(35) FIG. **3** is a side view of an example electrically driven or propelled vehicle **620** comprising an example a vehicle braking control system **622** for carrying out an example steering control method **500** (shown in FIG. **2**). Vehicle **620** is in the form of an agricultural vehicle (a tractor).

(36) Vehicle braking control system **622** facilitates continued braking of the vehicle **620** in circumstances where regenerative braking is not available or is less effective. Vehicle braking control system **622** dissipates kinetic energy of the vehicle **620** during braking into heat or other forms by using a continuously variable hydraulic pump and adjusting the angle of its swash plate to impose a load upon the electric motor, wherein the resulting pressurized hydraulic fluid is forced through a narrow constriction or a main relief, producing the heat. The load imposed upon the motor assists in slowing the vehicle down in a controlled and smooth manner. This load may also assist in speed control of the vehicle when the vehicle is traveling upon a gradient.

(37) Vehicle **620** comprises frame **624**, driven traction members **626**, electric traction motor **628**, transmission **630**, battery **632**, battery sensor **633**, variable displacement hydraulic pump **634**, hydraulic subsystems **636-1**, **636-2** and **636-3** (collectively referred to as subsystems **636**), compensator/relief **638** and controller **640**. Electric traction motor **628**, transmission **630**, battery **632**, pump **634**, hydraulic subsystems **636** and compensator/relief **638** comprise commercially available components and are schematically illustrated for ease of illustration. Frame **624** rotatably or movably supports ground engaging or traction members **626** which may be in the form of wheels or tracks. In the illustrated example, driven traction members **626** are located at a rearward portion of vehicle **620**. In other implementations, driven traction members **626** are located at a forward portion of vehicle **620**.

(38) Electric traction motor **628** comprises an electric motor operably coupled to driven traction members **626** by transmission **630** and operably coupled to variable displacement hydraulic pump **634** by transmission **630**. Transmission **630** transmits torque from motor **628** to drive or propel traction members **626**. In the illustrated example, transmission **630** further transmits torque from motor **628** to pump **634** to drive pump **634**. Electric traction motor **628** is supplied with electrical power or energy from battery **632**.

(39) Battery **632** may comprise a battery pack comprising several sets of rechargeable batteries of sufficient power and sized to electrically power motor **628** so as to generate sufficient torque for propelling vehicle **620**. Transmission **630** is configured such that during braking of vehicle **620**, electric traction motor **628** functions as a generator producing electrical power which may be used to recharge battery **632** (referred to as regenerative braking).

(40) Battery sensor comprises at least one sensor configured to output signals indicating a state of battery **632**. The state of the battery **632** comprises a battery maximum cell voltage level. For

example, in some implementations, the battery state threshold may comprise a predetermined battery maximum cell voltage level for battery **632** and may have a value of at least 4250 mV. Examples of battery sensor **633** include: negative temperature coefficient (NTC) thermistors, hall effect current sensors and voltage measurement circuits.

(41) Variable displacement hydraulic pump **634** comprises a pump configured to supply pressurized hydraulic fluid flow to hydraulic subsystems **636** and/are compensator/relief **638**. Hydraulic pump **634** comprises a swash plate **642** (schematically illustrated) which is operably coupled to motor **428** so as to be rotatably driven by torque output by motor **428**. This load is imposed by adjusting the oil flow and the pressure drop of the hydraulic fluid flowing through the output of pump **434**.

(42) Hydraulic subsystems **436** comprise systems of vehicle **620** or external systems powered by the hydraulic pump **634** of vehicle **620**. Hydraulic subsystem **636-1** comprises at least one hydraulic coupling port configured to supply pressurized hydraulic fluid to external vehicles or components. For example, the hydraulic ports of hydraulic subsystems **636-1** may be connectable to hydraulic hoses which transmit pressurized hydraulic fluid to a hydraulic motor or hydraulic jacks (hydraulic cylinder-piston assemblies) on an implement that is to be pulled by vehicle **620**.

(43) Hydraulic subsystem **636-2** comprises ports or other fluid connections for connection to a hydraulic jacks associate with vehicle **620**. For example, in some implementations, vehicle **620** may be equipped with lift arms for releasable connection to functional tools such as a bucket, a pallet fork, a bale spear or the like. Such lift arms may be raised and lowered with hydraulic jacks supplied with hydraulic fluid by hydraulic subsystem **636-2**.

(44) Hydraulic subsystems **636-3** comprises a hydraulic motor. The hydraulic motor generates torque. In the example illustrated, hydraulic motor of hydraulic subsystems **636-3** is operably coupled to front traction members **627** by transmission **631** to rotatably drive the front traction members **627**. In the example illustrated, this provides vehicle **620** with four-wheel-drive. In some implementations, one or more of subsystem **636** may be omitted or may be supplied with hydraulic power by a separate additional hydraulic pump that is driven by a separate additional electric motor. In some implementations, each of such subsystem **636** may be omitted, wherein pump **634** is used solely for braking.

(45) Compensator/relief **638** is fluidly coupled to pump **634** are provided as part of pump **634**. Compensator/relief **638** comprises a series of valves and a pressure loop. Hydraulic fluid flow from pump **634** may be directed (with valves of the like) through a pressure loop of compensator/relief **638**. In some circumstances, the hydraulic fluid flow is forced through a narrow constriction of the pressure loop, wherein energy of the hydraulic fluid is dissipated as heat prior to returning to the hydraulic reservoir.

(46) Controller **640**, pump **634** and compensator/relief **638** serve as part of the vehicle braking control system **622**. Controller **640** comprises a processing unit **646** and a non-transitory computer-readable medium **648**. Processing unit **646** is configured to receive data signals, analyze such data signals, and output data and control signals. Medium **648** may comprise instructions (in the form of hard-wired circuitry or software) for directing processing unit **646** to carry out method **500** (shown in FIG. **2**).

(47) As indicated by decision block **502** in FIG. **2**, controller **640** determines whether vehicle **620** is undergoing braking. Such a determination may be made based upon the current state of motor **628**, whether motor **628** is carrying out regenerative braking, functioning as a generator where electrical charge is being produced or output by motor **628**. Such a determination may also or alternatively be made based upon signals from various sensors on vehicle **620** indicating such braking. In the example illustrated, vehicle **620** comprises various sensors in the form of braking sensor **660**, camera **662** and inertial measurement units **664**.

(48) Braking sensor **660** (schematically illustrated) comprises one or more sensors that sense braking of traction members **626**. Braking sensor **660** may comprise one or more sensors that detect actuation of braking pads. Braking sensor **60** may comprise one or sensors that sense torque

or strain experience by traction members **626** or transmission **630**. Camera **662** may capture be used by controller **640** to identify vehicle **620** is undergoing braking. Inertial measurement units **634** include accelerometers and gyroscopes, wherein signals from the accelerometer may indicate a deceleration that exceeds a predetermined threshold so as to indicate vehicle **620** in a braking state. Signals from inertial measurement units **634** may further indicate a pitch of vehicle **620** (or a corresponding slope of the underlying terrain) that exceeds a predetermined threshold, wherein the indicated pitch along with other factors may result in controller **640** determining that vehicle **620** is in a braking state. Determination of braking may also be determined by controller **640** by comparing the target speed request either from the hand or the foot throttle and the measured speed on the motor shaft and the wheels using sensors along with the check on the amount of regenerative torque allowed from the motor.

(49) As indicated by block **504** in FIG. **2**, in response to a determination that vehicle **620** is undergoing braking, controller **640** determines the current state of battery **632**. In some implementations, the current state of battery **632** may be sensed, such as through the use of a battery sensor **633**. In some implementations, the current state of battery **632** may be determined/estimated by controller **640** based upon a prior historical state of battery **632** and prior historical power draws from battery **632**.

(50) As indicated by block **506** in FIG. **2**, controller **440** (processing unit **646** following instructions contained in memory **648**) whether the current battery state BS satisfies a predetermined battery state threshold BS TH. As indicated by block **508**, in response to the battery state threshold being satisfied, controller **640** automatically outputs control signals causing an adjustment to the angle of swash plate **642** covering the adjustment is to move the swash plate to an angle that applies a load to motor **628** to facilitate enhanced braking. Increasing the angle of the swash plate increases the load placed upon motor **628**. In some implementations, swash plate angle may be adjusted such that a load of at least 25 KW, and in some implementations at least 28 KW, is placed upon motor **628** so as to brake traction members **626** and vehicle **620**. The increased angle of swash plate **642** results in pump **634** outputting hydraulic flow at a greater pressure.

(51) In some circumstances, the greater pressure (greater energy) may be at least partially consumed by the hydraulic subsystems **636**. As indicated by block **510**, any excess pressure or energy is dissipated by the hydraulic flow being directed through compensator/relief **638**. In some implementations, hydraulic flow is dead headed against the compensator/relief **638** to dissipate the energy as heat. In some implementations, such hydraulic subsystems **636** may not be consuming any energy or may be disconnected, wherein all of the hydraulic flow produced by pump **634** is directed to compensator **638** for energy dissipation and heat generation. The flow of hydraulic may be controlled by controller **640** outputting control signals to one or more valves which selectively direct the pressurized fluid to the hydraulic subsystems **636** and/or compensator/relief **638**.

(52) In some implementations, the state of the battery comprises a state of charge of battery **632**. For example, in some implementations, the battery state threshold may comprise a 90% of the capacity of battery **632**. In response to battery **632** having a charge of at least 90% of its charging capacity, controller **640** may output control signals increasing the angle of swash plate **642** and increasing the load of pump **634** upon motor **628** to assist with braking of vehicle **620**.

(53) In some implementations, the state of the battery comprises a battery maximum cell voltage level. For example, in some implementations, the battery state threshold may comprise a predetermined battery maximum cell voltage level having a value of at least 4250 mV. In response to battery **632** having a voltage of at least 4250 mV, controller **640** may output control signals increasing the angle of swash plate **642** and increasing a load of pump **634** upon motor **628** to assist with braking of vehicle **620**.

(54) In some implementations, the state of the battery (BS) determined in block **504** and used as a criteria in block **506** may be a combination of multiple factors, such as a combination of both the current state of charge of battery **632** and the current voltage level of battery **632**. In some

implementations, the multiple factors may be differently weighted with respect to a determination of whether a battery state threshold value has been satisfied or exceeded. In some implementations, criteria other than state of charge and voltage level may be used in block **504** and **506**.

(55) As indicated by block **512** in FIG. **2**, during such braking assistance provided by pump **634**, controller **640** monitors the current braking state of vehicle **620**. For example, controller **640** may monitor the charge output or input of motor **628**. Controller **640** may evaluate operator controls or commands for such braking to determine when such braking has been ended. Controller **640** may evaluate whether such braking is continuing as discussed above with respect to block **502**.

(56) As indicated by block **514** in FIG. **2**, in response to determining that such braking has ended, controller **640** may output control signals to pump **634** causing the angle of swash plate **642** to be once again adjusted to a non-braking angle. The non-braking angle is an angle at which the angle swash plate **642** is such that pump **634** produces sufficient hydraulic flow for powering any of hydraulic subsystems **636**, but wherein excess hydraulic flow that might otherwise be directed to compensator/relief **638** is reduced or eliminated. In circumstances where the hydraulic subsystems **436** are not consuming any energy from hydraulic flow, swash plate **642** may be actuated to a zero angle.

(57) Although the present disclosure has been described with reference to example implementations, workers skilled in the art will recognize that changes may be made in form and detail without departing from the scope of the claimed subject matter. For example, although different example implementations may have been described as including features providing benefits, it is contemplated that the described features may be interchanged with one another or alternatively be combined with one another in the described example implementations or in other alternative implementations. Because the technology of the present disclosure is relatively complex, not all changes in the technology are foreseeable. The present disclosure described with reference to the example implementations and set forth in the following claims is manifestly intended to be as broad as possible. For example, unless specifically otherwise noted, the claims reciting a single particular element also encompass a plurality of such particular elements. The terms "first", "second", "third" and so on in the claims merely distinguish different elements and, unless otherwise stated, are not to be specifically associated with a particular order or particular numbering of elements in the disclosure.

Claims

1. A vehicle comprising: an electric motor; a variable displacement hydraulic pump having a swash plate; driven traction members; a transmission operably coupling the electric motor to the driven traction members and to the hydraulic pump; a hydraulic pressure consumer fluidly coupled to an output of the hydraulic pump; a battery to receive energy produced by the electric motor during braking of the driven traction members by the electric motor; a controller configured to adjust an angle of the swash plate in response to a sensed state of the battery and braking of the driven traction members.

2. The vehicle of claim 1, wherein the sensed state of the battery comprises a state of charge of the battery, wherein the controller is configured to adjust the angle of the swash plate in response to the state of charge of the battery exceeding a predetermined battery charge level.

3. The vehicle of claim 2, wherein the predetermined battery charge level comprises 90% battery.

4. The vehicle of claim 1, wherein the sensed state of the battery comprises a maximum cell voltage level of the battery, wherein the controller is configured to adjust the angle of the swash plate in response to the maximum cell voltage level of the battery exceeding a predetermined battery voltage level.

5. The vehicle of claim 4, wherein the maximum cell voltage level of the battery comprises a value of at least 4250 mV.

6. The vehicle of claim 1, wherein the controller adjusts the angle swash plate to provide a load up to 25 KW to the electric motor.

7. The vehicle of claim 1, wherein the hydraulic pump comprises a compensator having an internal pressure loop and a relief valve against which hydraulic fluid flow from the hydraulic pump is forced through a narrow passage provided by the pressure loop to generate a heat load.

8. The vehicle of claim 1, wherein the hydraulic pump is fluidly disconnected from the hydraulic pressure consumer during braking of the driven traction members by the hydraulic pump.

9. The vehicle claim 1, wherein the hydraulic pump is fluidly connected to the hydraulic pressure consumer during braking of the driven traction members by the hydraulic pump.

10. The vehicle of claim 1, wherein the hydraulic pressure consumer comprises a hydraulic cylinder-piston assembly for raising and lowering an attachment of the vehicle.

11. The vehicle of claim 1, wherein the sensed state of the battery comprises a combination of a current state of charge of the battery and a current voltage level of the battery.

12. The vehicle claim 1 further comprising a battery sensor selected from a group of battery sensors consisting of: a negative temperature coefficient thermistor, a Hall effect current sensor and a voltage measurement circuit.

13. The vehicle of claim 1, wherein the hydraulic pressure consumer comprises a hydraulic coupling port configured to supply pressurized hydraulic fluid to external vehicles or components.

14. A vehicle braking method comprising: determine braking by a vehicle; determine a battery state of a battery used to propel the vehicle; in response to the battery state satisfying a predetermined threshold, adjusting a swashplate angle of a variable displacement hydraulic pump to a braking angle; and in response to the battery state satisfying the predetermined threshold, directing flow from the variable displacement hydraulic pump to a compensator/relief.

15. The vehicle braking method of claim 14 further comprising: determining an end to the braking by the vehicle; and in response to the braking by the vehicle ending, adjusting the swashplate angle of the variable displacement hydraulic pump to a non-braking angle.

16. A non-transitory computer-readable medium containing instructions to direct the processor to: determine braking by a vehicle; determine a battery state of a battery used to propel the vehicle; in response to the battery state satisfying predetermined threshold, output control signals to adjust a swashplate angle of a variable displacement hydraulic pump to a braking angle; and in response to the battery state satisfying the predetermined threshold, output control signals directing flow from the variable displacement hydraulic pump to a compensator/relief.

17. The medium of claim 16, wherein the instructions are further configured to direct the processor to: determine an end to the braking by the vehicle; and in response to the braking by the vehicle ending, output control signals to adjust the swashplate angle of the variable displacement hydraulic pump to a non-braking angle.