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Pedal modulating valve assembly including multiple gain states

Abstract

A valve assembly is provided. The valve assembly includes a valve body defining a bore. The valve assembly further includes a plunger adjacent the valve body. The valve assembly further includes a modulating biasing member abutting the plunger. The valve assembly further includes a spool disposed in the bore and adjacent the plunger with the modulating biasing member disposed therebetween. The plunger is configured to move the spool between a neutral position and an energized position. The spool defines a socket. The valve assembly further includes a piston disposed in the socket and configured to move between a first piston position and a second piston position within the socket.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION (1) This application claims priority to and all advantages of U.S. Application No. 62/942,052, filed on Nov. 29, 2019, the contents of which are incorporated herein by reference.

TECHNICAL FIELD

(1) The present disclosure generally relates to a pedal modulating valve assembly including a first gain state and a second gain state, and systems including the same, for working units and other applications.

BACKGROUND

(2) Due to the increasing weights of vehicles, such as off highway vehicles, the brake energy required to stop these vehicles has also increased. To account for these increases, modern off highway vehicles include large and robust wheel brakes designed to be prepared for worst case conditions including an ability to apply the maximum brake pressure needed to bring the vehicle to the shortest possible stop in an emergency situation. While these wheel brakes are effective in worst case conditions, high fidelity control of the wheel brakes during lower pressure braking scenarios is difficult.

(3) A wide variety of electrohydraulic proportional pressure control valves are used to provide controlled pressure to working units, such as wheel brakes. Some typical valves are designed for use with an actuator, such as a pedal actuator, in which force is applied to by a user. These pressure control valves provide a linear output characteristic for pressure versus force applied by the user to the actuator.

(4) While this linear output characteristic permits braking at both the lower percentage of the brake pressure range and the higher percentage of the braking pressure range, a majority of the braking occurs in the lower percentage of the braking pressure range. Thus, a majority of the braking occurs without high fidelity control of the wheel brakes thereby resulting in abrupt or aggressive braking of the vehicle which affects control of the vehicle and operator comfort.

(5) Accordingly, it is desirable to provide an improved valve assembly and a system including the same. Furthermore, other desirable features and characteristics will become apparent from the subsequent summary and detailed description and the appended claims, taken in conjunction with the foregoing technical field and background.

BRIEF SUMMARY

(6) In one embodiment, a valve assembly is provided. The valve assembly includes a valve body defining a bore. The valve assembly further includes a plunger adjacent the valve body. The valve assembly further includes a modulating biasing member disposed in the bore and abutting the plunger. The valve assembly further includes a spool disposed in the bore and adjacent the plunger with the modulating biasing member disposed therebetween. The plunger is configured to move the spool between a neutral position and an energized position. The spool defines a socket. The valve assembly further includes a piston disposed in the socket and configured to move between a first piston position and a second piston position within the socket.

(7) In this and other embodiments, by moving the piston from the first piston position to the second piston position, fluid within the socket is limited to a predefined force and therefore no longer acts to further oppose movement of the spool by the plunger. As a result, force required to move the spool toward the energized position by the plunger when the piston is in the second piston position is decreased relative to the force required when the piston is in the first piston position.

(8) In this and other embodiments, the valve assembly has a first gain state and a second gain state. The valve assembly is in the first gain state when the piston is in the first piston position, and the valve assembly is in the second gain state when the piston is in the second piston position. The valve assembly having the first gain state and the second gain state provides the user improved fidelity at lower pressures while still allowing a working unit to reach higher pressures. For working units, such as wheel brakes of a vehicle, lower pressures are typically utilized during a majority of the braking of the vehicle. Thus, improving fidelity of the wheel brakes at lower pressures can improve overall usability of the vehicle. However, higher pressures may be necessary in emergency situations. Therefore, multiple gain states are important to allow the working unit to

reach higher pressures while still exhibiting improved fidelity at lower pressures.
(9) In another embodiment, a system having a first gain state and a second gain state is also provided. The system includes, but is not limited to, a fluid source configured to provide a fluid force (e.g., hydraulic fluid pressure). The system further includes, but is not limited to, a valve assembly in fluid communication with the fluid source. The valve assembly includes, but is not limited to, a plunger. The valve assembly further includes, but is not limited to, a modulating biasing member abutting the plunger. The valve assembly further includes, but is not limited to, a spool. The spool is adjacent the plunger with the modulating biasing member disposed therebetween. The plunger is configured to move the spool between a neutral position and an energized position. The valve assembly further includes, but is not limited to, a piston. The piston is in fluid communication with the fluid source. The piston is configured to move between a first piston position and a second piston position. The system further includes, but is not limited to, a working unit in fluid communication with the valve assembly and configured to activate in response to the fluid force. The system is in the first gain state when the piston is in the first piston position and the system is in the second gain state when the piston is in the second piston position.

Description

BRIEF DESCRIPTION OF THE DRAWING(S)
(1) Other advantages of the disclosed subject matter will be readily appreciated, as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:
(2) FIGS. **1**A and **1**B are a cross-sectional plan views illustrating a non-limiting embodiment of a valve assembly;
(3) FIG. **2** is another cross-sectional plan view illustrating a non-limiting embodiment of the valve assembly;
(4) FIG. **3** is another cross-sectional plan view illustrating a non-limiting embodiment of the valve assembly; and
(5) FIG. **4** is a graph illustrating gain states of a non-limiting embodiment of the valve assembly as compared to the prior art.
DETAILED DESCRIPTION
(6) Except in the examples, or where otherwise expressly indicated, all numerical quantities in this description indicating amounts of material or conditions of reaction and/or use are to be understood as modified by the word “about” in describing the broadest scope of the invention. Practice within the numerical limits stated is generally preferred. Also, unless expressly stated to the contrary: percent, “parts of,” and ratio values are by weight; the description of a group or class of materials as suitable or preferred for a given purpose in connection with the invention implies that mixtures of any two or more of the members of the group or class are equally suitable or preferred; description of constituents in chemical terms refers to the constituents at the time of addition to any combination specified in the description, and does not necessarily preclude chemical interactions among the constituents of a mixture once mixed; the first definition of an acronym or other abbreviation applies to all subsequent uses herein of the same abbreviation and applies mutatis mutandis to normal grammatical variations of the initially defined abbreviation; and, unless expressly stated to the contrary, measurement of a property is determined by the same technique as previously or later referenced for the same property.
(7) It must also be noted that, as used in the specification and the appended claims, the singular form “a,” “an,” and “the” comprise plural referents unless the context clearly indicates otherwise. For example, reference to a component in the singular is intended to comprise a plurality of components.

(8) The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. Furthermore, there is no intention to be bound by any theory presented in the preceding background or the following detailed description.
(9) A valve assembly is provided herein. In various embodiments, the valve assembly is suitable for controlling a working unit of a vehicle. A system for controlling a working unit of a vehicle is also provided herein.
(10) FIGS. **1-3** are cross-sectional plan views illustrating a non-limiting embodiment of a valve assembly **10**. The valve assembly **10** includes a valve body **12** and a plunger **14** adjacent the valve body **12**. In certain embodiments, a user applies a force to the plunger **14** and the plunger **14** is configured to receive the force from the user. In various embodiments, the valve assembly **10** is utilized with a fluid source **16** (e.g., hydraulic pressure unit or hydraulic pump), a tank **18** (e.g., a hydraulic reservoir), and a working unit **20** (e.g., a hydraulic cylinder or wheel brake). In various embodiments, the fluid source **16** is configured to provide fluid force (e.g. hydraulic fluid pressure) to the valve assembly **10**. For purposes of clarification, the valve body **12** will be described as having a first body end **22** and a second body end **24**.
(11) The valve body **12** of the valve assembly **10** defines a bore **26**. The bore **26** may be manufactured as a through bore extending through the valve body **12**. It is contemplated that the bore **26** may also be configured as a blind bore. The valve body **12** further defines a pressure port **28**, a work port **30**, and a tank port **32**. The bore **26** typically extends through the valve body **12** between the first body end **22** and the second body end **24**. Each of the ports **28**, **30**, and **32** may be in fluid communication with the bore **26**. As shown in a non-limiting embodiment of FIG. **1**, the pressure port **28** is disposed proximate the second body end **24** and the tank port **32** is disposed proximate the first body end **22**. The work port **30** is disposed intermediate the pressure port **28** and the tank port **32**. In certain embodiments, the ports **28**, **30**, and **32** provide connection locations for establishing fluid communication between the valve body **12** and the hydraulic pump **16**, the working unit **20**, and the tank **18**. Typical port connections include standard SAE straight threads or other configurations for allowing hoses or other conduits to be connected between the components. However, it is to be appreciated that other port configurations are contemplated, for example, the pressure port **28** may be disposed proximate the first body end **22** and the tank port **32** may be disposed proximate the second body end **24**.
(12) The bore **26** may include a first annular surface **34** and a second annular surface **36**. These surfaces **34**, **36** may be utilized to provide fluid communication between the ports **28**, **30**, and **32**. The bore **26** may also include a countersink region **38**. In various embodiments, the countersink region **38** is proximate the first body end **22**.
(13) The valve assembly **10** further includes a spool **40** disposed in the bore **26**. The spool **40** is adjacent and operatively coupled to the plunger **14**. The plunger **14** is configured to move the spool **40** between a neutral position (see FIG. **1**A) and an energized position (see FIG. **3**). In various embodiments, the plunger **14** is configured to move the spool **40** to an intermediate position (see FIG. **2**) between the neutral position and the energized position. In certain embodiments, the valve assembly **10** further includes a retaining member **42** operatively coupled to the spool **40** for moving the spool **40** between the neutral position and the energized position. The valve assembly **10** may further includes a ball bearing member **94** as a universal joint between the retaining member **42** and the spool **40**. In various embodiments, the spool **40** includes a first spool end **44** and a second spool end **46** with the retaining member **42** operatively coupled to the first spool end **44**.
(14) In certain embodiments, the spool **40** includes a first annular portion **48** and a second annular portion **50**. The first annular portion **48** and the second annular portion **50** may be configured to cooperate with the first annular surface **34** and the second annular surface **36** of the bore **26**, respectively, for manipulating fluid communication between the ports **28**, **30**, and **32**. The spool **40** may further includes a flow portion **52** having a decreased diameter relative to the first annular portion **48** and the second annular portion **50** for providing fluid communication to the work port

30. The spool **40** may also include a shoulder **100** proximate the first spool end **44** and configured to cooperate with the countersink region **38** of the valve body **12**.

(15) With reference to FIGS. **1**A and **1**B, when the spool **40** is in the neutral position, fluid communication may be provided between the work port **30** and the tank port **32**. Further, when the spool **40** is in the neutral position, fluid communication may be prevented between the pressure port **28** and the work port **30**. In particular, when the spool **40** is in the neutral position, the second annular portion **50** may be engaged with the second annular surface **36** thereby preventing fluid to flow between the pressure port **28** and the work port **30**.

(16) With reference to FIGS. **2** and **3**, when the spool **40** is in the intermediate position or the energized position, respectively, fluid communication may be provided between the pressure port **28** and the work port **30**. Further, when the spool **40** is in the intermediate position or the energized position, fluid communication may be prevented between the work port **30** and the tank port **32**. In particular, when the spool **40** is in the intermediate position or the energized position, the first annular portion **48** may be engaged with the first annular surface **34** thereby preventing fluid to flow between the work port **30** and the tank port **32**.

(17) It is to be appreciated that the valve assembly **10** may operate in a different manner. For example, the energized position of a spool may provide fluid communication between a work port and a tank port and the neutral position of the spool may provide fluid communication between a pressure port and the work port.

(18) With continuing reference to FIGS. **1-3**, the spool **40** may define a cavity **56** between the first annular portion **48** and the second annular portion **50**. In certain embodiments, the cavity **56** is in fluid communication with the work port **30** and the tank port **32** through an orifice **102** when the spool **40** is in the neutral position. Further, in these embodiments, the cavity **56** is in fluid communication with the pressure port **28** and the work port **30** through the orifice **102** when the spool **40** is in the energized position.

(19) In certain embodiments, the spool **40** defines a socket **62** between the second spool end **46** and the cavity **56**. The socket **62** may extend through the second spool end **46**. The spool **40** may have a socket face **65** opposite the second spool end **46** and within the socket **62**. The spool **40** may define a channel **64** extending between the socket **62** and the cavity **56** such that the socket **62** is in fluid communication with the cavity **56**. In various embodiments, fluid provided between the work port **30** and the tank port **32** is also provided to the socket **62** through the orifice **102**, then through the cavity **56**, and then through the channel **64** when the spool **40** is in the neutral position. Likewise, fluid provided between the pressure port **28** and the work port **30** is also provided to the socket **62** through the orifice **102**, then through the cavity **56**, and then through the channel **64** when the spool **40** is in the energized position.

(20) The valve assembly **10** further includes a piston **66** disposed in the socket **62**. The piston **66** is configured to move between a first piston position (see FIGS. **1**A and **2**) and a second piston position (see FIG. **3**) in response to the fluid. In certain embodiments, the first piston position and the second piston position are relative to the spool **40**. The piston **66** includes a first piston end **68** and a second piston end **70** spaced from the first piston end **68** with a void **72** defined therebetween.

(21) With continuing reference to FIGS. **1-3**, the valve assembly **10** may further include a dowel **84** extending through the spool **40** and the piston **66**. In various embodiments, the dowel **84** extends through the void **72** of the piston **66**, the socket **62** of the spool **40**, and the channel **64** of the spool **40**. The valve assembly **10** may further include a plug **86** disposed proximate the second body end **24** of the valve body **12** within the bore **26**. The dowel **84** may be adapted to abut the plug **86** to prevent the dowel **84** from moving beyond the plug **86** toward the second body end **24**. The spool **40** may be operatively arranged with the dowel **84** so as to slide relative to the dowel **84**. The piston **66** may also be operatively arranged with the dowel **84** so as to slide relative to the dowel **84**.

(22) The spool **40** may have a spool face **58** and the dowel **84** may have a dowel face **60** with the

spool face **58** and the dowel face **60** flanking the cavity **56**. As the spool **40** moves from the neutral position to the energized position, fluid provided between the pressure port **28** and the work port **30** acts on the spool face **58** and the dowel face **60**. To this end, the spool face **58** and the dowel face **60** create an imbalanced pressure load on the spool **40** in the presence of the force of the fluid due to the dowel **84** being prevented from moving beyond the plug **86**. In various embodiments, this imbalanced pressure load biases the spool **40** toward the first body end **22** (e.g., toward the neutral position) and the piston **66** may have a piston face **74** with the socket face **65** and piston face **74** flanking the socket **62**. As the spool **40** moves from the neutral position to the energized position, fluid provided between the pressure port **28** and the work port **30** communicates through channel **64** of the piston **66**. To this end, the socket face **65** and the position face **74** create an imbalanced force load on the spool **40** in the presence of the pressure of the fluid. The sum of the pressure force acting on the spool face **58** and the piston face **74** combine to react against the applied force at the plunger **14**.

(23) The second piston end **70** includes an extension **76** configured to cooperate with the second spool end **46** to prevent fluid communication between the socket **62** and pressure port **28** when the piston **66** is in the first piston position. As the spool **40** moves from the neutral position to the energized position, fluid provided between the pressure port **28** and the work port **30** through the channel **64** acts on the piston face **74** when the piston **66** is in the first piston position. When the piston **66** is in the second piston position, the piston **66** and the spool **40** cooperate to define a relief passage **78** to limit the force of the fluid acting on the piston face **74** and socket face **65** thereby preventing the piston **66** from absorbing additional force by the fluid. To this end, by moving the piston **66** from the first piston position to the second piston position, force acting on the piston face **74** and socket face **65** due to fluid within the socket **66** is limited to the pressure at which the relief passage **78** begins to meter flow out of socket **66** to oppose movement of the spool **40** by the plunger **14**. As a result, the force required to move the spool **40** toward the energized position by the plunger **14** when the piston **66** is in the second piston position is decreased relative to the force required when the piston **66** is in the first piston position. In various embodiments, the relief passage **78** is in fluid communication with the pressure port **28** due to disengagement of the extension **76** from the second spool end **46**. Thus, when the piston **66** is in the second position, the channel **64** is in fluid communication with the pressure port **28** through the passage **78** such that fluid pressure in channel **64** is limited to the pressure at which the passage **78** started fluid communication to the pressure port **28**. As a result when the piston **66** is in the second position, fluid may flow from the channel **64**, through the socket **62**, around the piston **66**, through the relief passage **78**, and to the pressure port **28**.

(24) The valve assembly **10** may further include a first compensating biasing member **80** exhibiting a first force on the spool **40** to bias the spool **40** toward the first body end **22** (e.g., toward the neutral position). The valve assembly **10** may further include a second compensating biasing member **82** exhibiting a second force on the piston **66** to bias the piston **66** to the first piston position. In certain embodiments, the piston **66** is configured to move to the second piston position prior to the spool **40** moving to the energized position due to a ratio of the first force and the second force. The first compensating biasing member **80** and the second compensating biasing member **82** may, independently, include any standard spring commonly used and known by those having skill in the art or any other feed-back device such as pneumatic struts, electromagnets, or elastomeric force feed-back devices. Alternatively, the first compensating biasing member **80** and/or the second compensating biasing member **82** may be omitted in applications where the imbalanced work port pressure alone is used to return the spool to the neutral position and/or return the piston **66** to the first piston position.

(25) FIG. **4** is a graph illustrating gain states of a non-limiting embodiment of the valve assembly **10** as compared to the prior art. The valve assembly **10** has a first gain state **88** and a second gain state **90**. The valve assembly **10** may be in the first gain state **88** when the piston **66** is in the first

piston position. The valve assembly **10** may be in the second gain state **90** when the piston **66** is in the second piston position. It is to be appreciated that the valve assembly **10** may be configured to have more than two gain states. When the valve assembly **10** is in the first gain state **88**, a greater amount of force by the plunger **14** on the spool **40** is necessary to move the spool **40** toward the second body end **24** as compared to when the valve assembly **10** is in the second gain state **90**. When the valve assembly **10** is in the second gain state **90**, a reduced amount of force by the plunger **14** on the spool **40** is necessary to move the spool **40** toward the second body end **24** as compared to when the valve assembly **10** is in the first gain state **88**.

(26) With continuing reference to FIG. **4**, multiple gain states, such as the first gain state **88** and the second gain state **90** of the valve assembly **10** provide the user improved fidelity at lower pressures while still allowing the working unit **16** to reach higher pressures. For wheel brakes of a vehicle, lower pressures are typically utilized during a majority of the braking of the vehicle. Thus, improving fidelity of the wheel brakes at lower pressures can improve overall usability of the vehicle. However, higher pressures may be necessary in emergency situations. Therefore, multiple gain states are important to allow the working unit **16** to reach higher pressures while still exhibiting improved fidelity at lower pressures.

(27) When the valve assembly **10** is in the first gain state **88**, the force of the fluid from the work port **30** acts on the dowel **84** and the piston **66**. This force biases the dowel **84** against the plug **86**. However, this force on the piston **66** is not sufficient to overcome the second force of the second compensating biasing member **82** thereby maintaining the piston **66** in the first piston position. In various embodiments, the piston **66** is adapted to generate a force to oppose movement of the spool **40** by the plunger **14**. In some of these embodiments, the force is in accordance with the second force of the second compensating biasing member **82**. In certain embodiments, the force is equal to the second force of the second compensating biasing member **82**. The pressure force acting on the spool face **58** and the socket face **65** may also act on the spool **40** in a similar amount. Pressure force acting on piston face **74** opposes force from the second compensating member **82**. To this end, the combined pressure force on spool face **58** and the socket face **65**, the first compensating biasing member **80**, and the second compensating biasing member **82** via the piston **66**, are biasing the spool **40** toward the first body end **22** (e.g., toward the neutral position), opposing the force generated by the plunger **14**. Thus, when the valve assembly **10** is in the first gain state **88**, a greater amount of force opposes movement of the spool **40** toward the second body end **24** thereby reducing the force of the fluid acting on the work port **30** relative to the amount of force generated by the plunger **14**. With reference to FIG. **4**, the first gain state **88** exhibits a lower slope for pressure at the work port **30** relative to the force applied by the user to the plunger **14** as compared to the second gain state **90**.

(28) When the valve assembly **10** is in the second gain state **90**, the force of the fluid from the work port **30** continues to act on the spool face **58** and to a reduced amount to the piston face **74** and socket face **65**. In contrast to the first gain state **88**, where fluid from the work port **30** continues to act fully on spool face **58** and the socket face **65** this force on the piston **66** is sufficient to overcome the second force at a second pressure, piston **66** moves to the second piston position and defining the relief passage **78**. With the relief passage **78** defined, via the piston **66** pressure in socket **62** is limited to a maximum pressure. Pressure force acting on the socket face **65** is limited to bias the spool **40** toward the first body end **22**. A pre-defined force in accordance with the force of the biasing member **82** acts on piston **66**. In other words, the force generated by the socket face **65** may be limited to a pre-defined force when the piston **66** is in the second piston position and the pre-defined force may be in accordance with the second force of the second compensating biasing member **82** when the piston **66** is in the second piston position. In certain embodiments, the pre-defined force is equal to the second force of the second compensating biasing member **82** when the piston **66** is in the second piston position. To this end, the force acting on spool face **58** and the limited force acting on the socket face **65**, and the first compensating biasing member **80** are

biasing the spool **40** toward the first body end **22** (e.g., toward the neutral position), opposing the force generated by the plunger **14**. Thus, when the valve assembly **10** is in the second gain state **90** as opposed to the first gain state **88**, a reduced amount of force opposes movement of the spool **40** toward the second body end **24** thereby increasing the force of the fluid acting on the work port **30** relative to the amount of force generated by the plunger **14**. With reference to FIG. **4**, the second gain state **90** exhibits a higher slope for pressure at the work port **30** relative to the force applied by the user to the plunger **14** as compared to the first gain state **88**.

(29) The valve assembly **10** may further include a modulating biasing member **92** disposed in the bore **26** and abutting the plunger **14**. In certain embodiments, the modulating biasing member **92** is disposed between the plunger **14** and the retaining member **42** proximate the first body end **22**. The modulating biasing member **92** may be positioned within the countersink region **38** of the bore **26**. The modulating biasing member **92** may include a variety of compression spring configurations. Other spring types that may be used include bevel springs, torsion springs with levers, leaf springs, and the like.

(30) The retaining member **42** may be configured with an interior shoulder **54**. The modulating biasing member **92** may be positioned longitudinally between the plunger **14** and the interior shoulder **54** of the retaining member **42**. The retaining member **42** may be configured to transfer force from the modulating biasing member **92** to the spool **40** when the modulating biasing member **92** is compressed by the plunger **14**. In various embodiments, the retaining member **42** includes an extended portion **96** having an inside diameter adapted to guide the modulating biasing member **92**. The extended portion **96** maintains the modulating biasing member **92** in a longitudinal orientation.

(31) In various embodiments, a return spring **104** is disposed between the plunger **14** and the valve body **12**. The plunger **14** may be configured to move into the bore **26** against the resistance of the return spring **104**. When pressure is removed from the plunger **14**, the return spring **104** is configured to return the plunger **14** to a normal position.

(32) In certain embodiments, a washer **98** is disposed between the shoulder **100** of the spool **40** and the retaining member **42**. The washer **98** may define the neutral position of the spool **40** by providing a mechanical stop to prevent movement of the spool **40** beyond neutral position toward the first body end **22**. As shown in FIG. **1**, the washer **98** contacts the countersink region **38** due to tension from the retaining member **42** acting on the washer **98**. The washer **98** also contacts the shoulder **100** of the spool **40** when the spool **40** is in the neutral position due tension from the first compensating biasing member **80** acting on the spool **40**. The tension from the first compensating biasing member **80** may also be lower than the tension provided by modulating biasing member **92** when the spool **40** is in the neutral position.

(33) It is to be understood that spring compression may be adapted to various applications by modifying the length of the spring retaining member, the thickness of the washer, the stiffness of the spring, or other various structural features as would be obvious to one of ordinary skill in the art.

(34) In various embodiments, a check valve passage **106** extends between the tank port **32** and the bore **26**. A check valve **108** may be configured to control flow through the check valve passage **106** between the tank port **32** and the bore **26**.

(35) With reference back to FIGS. **1-3**, non-limiting embodiments of operation of the valve assembly **10** are depicted therein. In certain embodiments, when fluid is desired to operate the working unit **20**, the valve assembly **10** is energized. A user applies a force to the plunger **14** begins developing axial force from the neutral state shown in FIG. **1**. The plunger **14** moves the spool **40** toward the second body end **24** to the first gain state **88** of the valve assembly **10** shown in FIG. **2**. In the first gain state **88**, fluid is permitted to flow from the pressure port **28** around the flow portion **52** having a decreased diameter and through cavity **56** of the spool **40**, and to the work port **30** for operation of the working unit **20**. At the same time, fluid flow to the tank port **32** is

obstructed by cooperation between the first annular surface **34** of the valve body **12** and the first annular portion **48** of the spool **40**. As described above, when the valve assembly **10** is in the first gain state **88**, a greater amount of force opposes movement of the spool **40** toward the second body end **24** thereby reducing the force of the fluid acting on the work port **30** relative to the amount of force acting on the spool **40** by the plunger **14** due to the force acting on the spool **40** at the spool face **58** and the socket face **65**. In other words, a greater amount of force acting on the spool **40** by the plunger **14** is necessary to move the spool **40** toward the second body end **24** as compared to when the valve assembly **10** is in the second gain state **90**.

(36) As the plunger **14** continues providing axial force during the first gain state **88** as shown in FIG. **2**, the plunger **14** continues to move the spool **40** toward the second body end **24** to the second gain state **90** of the valve assembly **10** as shown in FIG. **3**. In the second gain state **90**, fluid is still permitted to flow from the pressure port **28** around the flow portion **52** having a decreased diameter and through cavity **56** of the spool **40**, and to the work port **30** for operation of the working unit **20**. At the same time, fluid flow to the tank port **32** is still obstructed by cooperation between the first annular surface **34** of the valve body **12** and the first annular portion **48** of the spool **40**. As described above, when the valve assembly **10** is in the second gain state **90**, a reduced amount of force opposes movement of the spool **40** toward the second body end **24** thereby increasing the force of the fluid acting on the work port **30** relative to the amount of force applied to the spool **40** by the plunger **14** due to the relief passage **78** of the piston **66** being defined when the piston **66** is in the second position. In other words, a reduced amount of force by the plunger **14** on the spool **40** is necessary to move the spool **40** toward the second body end **24** as compared to when the valve assembly **10** is in the first gain state **88**.

(37) The force of the fluid acts on the surface areas of the spool face **58** and the socket face **65** of the spool **40**. As the force increases, the force approaches the force applied by the plunger **14** and the spool **40** begins to move toward the first body end **22**. Movement of the spool **40** toward the first body end **22** increases fluid communication with the tank port **32** and decreases fluid communication with the pressure port **28**, thereby causing the force at the work port **30** to stabilize or drop. With force drop, net force of the spool **40** toward the second body end **24** exceeds net force of the spool **40** toward the first body end **22** causing movement of the spool **40** toward the second body end **24**. Movement of the spool **40** toward the second body end **24** decreases fluid communication with the tank port **32** and increases fluid communication with the pressure port **28**. This cycling of movement causes “modulation” (i.e. back and forth movement) of spool **40**. During modulation, the user continues to apply pressure to plunger **14**. The spool **40** modulates until the pressure force and the force of the modulating biasing member **92** is balanced against the force of the plunger **14**. At steady state equilibrium, (when the kinematic energy forces resulting from a changes in the force applied by the plunger **14** or force from the working unit **20** have subsided) the spool **40** will attain a stabilized position where fluid flow from the pressure port **28** to the work port **30** equals the fluid flow from the work port **30** to the tank port **32**.

(38) Upon desired release of the fluid, the user reduces pressure to the plunger **14** and no longer generates a force toward the second body end **24**. The spool **40** moves in the toward the first body end **22** to the neutral position by the imbalance of force of the fluid and the force from the first compensating biasing member **80**. In the neutral position, fluid is permitted to flow from the work port **30** around the flow portion **52** of the spool **40** and to the tank port **32**.

(39) Flow rate from the work port **30** to the tank port **32** is determined by the amount of flow required in the application, for example, the amount of flow necessary to disengage a hydraulic actuator or hydraulic brake within an acceptable amount of time. For a given spool configuration, the open area or gap providing for fluid communication between ports is a function of spool stroke or spool travel. Greater flow rates require greater cross-sectional flow areas or gaps and therein require the spool **40** to travel farther to increase the area of the gap. Similarly, when the plunger **14** is first energized, the required flow rate from the pressure port **28** to the work port **30** is determined

by the amount of flow required in the application, for example, the amount of flow necessary to actuate a hydraulic brake within an acceptable amount of time.

(40) As introduced above, a system for controlling the working unit **20** is also provided herein. The system has the first gain state **88** and the second gain state **90**. The system includes a fluid source **16** configured to provide the fluid force. The system further includes the valve assembly **10** with the valve assembly **10** in fluid communication with the fluid source **16**. The valve assembly **10** includes the plunger **14**. The valve assembly further includes the modulating biasing member abutting the plunger **14**. The valve assembly **10** further includes the spool **40**. The spool **40** operatively coupled to the plunger **14**. The plunger **14** is configured to move the spool **40** between the neutral position and the energized position. The valve assembly **10** further includes the piston **66**. The piston **66** is in fluid communication with the fluid source **16**. The piston **66** is configured to move between the first piston position and the second piston position. The system further includes a working unit **20** in fluid communication with the valve assembly **10** and configured to activate in response to the fluid force. The system is in the first gain state **88** when the piston **66** is in the first piston position and the system is in the second gain state **90** when the piston **66** is in the second piston position.

(41) Although the invention has been described in connection with specific preferred embodiments, it should be understood that the invention as claimed should not be unduly limited to these specific embodiments. While at least one exemplary embodiment has been presented in the foregoing detailed description of the disclosure, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the invention in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing an exemplary embodiment of the invention. It being understood that various changes may be made in the function and arrangement of elements described in an exemplary embodiment without departing from the scope of the disclosure as set forth in the appended claims.

(42) Further, any ranges and subranges relied upon in describing various embodiments of the present invention independently and collectively fall within the scope of the appended claims, and are understood to describe and contemplate all ranges including whole and/or fractional values therein, even if such values are not expressly written herein. One of skill in the art readily recognizes that the enumerated ranges and subranges sufficiently describe and enable various embodiments of the present invention, and such ranges and subranges may be further delineated into relevant halves, thirds, quarters, fifths, and so on. As just one example, a range "of from 0.1 to 0.9" may be further delineated into a lower third, i.e., from 0.1 to 0.3, a middle third, i.e., from 0.4 to 0.6, and an upper third, i.e., from 0.7 to 0.9, which individually and collectively are within the scope of the appended claims, and may be relied upon individually and/or collectively and provide adequate support for specific embodiments within the scope of the appended claims. In addition, with respect to the language which defines or modifies a range, such as "at least," "greater than," "less than," "no more than," and the like, it is to be understood that such language includes subranges and/or an upper or lower limit. As another example, a range of "at least 10" inherently includes a subrange of from at least 10 to 35, a subrange of from at least 10 to 25, a subrange of from 25 to 35, and so on, and each subrange may be relied upon individually and/or collectively and provides adequate support for specific embodiments within the scope of the appended claims. Finally, an individual number within a disclosed range may be relied upon and provides adequate support for specific embodiments within the scope of the appended claims. For example, a range "of from 1 to 9" includes various individual integers, such as 3, as well as individual numbers including a decimal point (or fraction), such as 4.1, which may be relied upon and provide adequate support for specific embodiments within the scope of the appended claims.

(43) The present invention has been described herein in an illustrative manner, and it is to be

understood that the terminology which has been used is intended to be in the nature of words of description rather than of limitation. Many modifications and variations of the present invention are possible in light of the above teachings. The present invention may be practiced otherwise than as specifically described within the scope of the appended claims. The subject matter of all combinations of independent and dependent claims, both single and multiple dependent, is herein expressly contemplated.

INDUSTRIAL APPLICABILITY

(44) While the present invention is not limited to a particular end application, use or industry, vehicles often rely on valve assemblies to provide fluid to working units, such as wheel brakes. The valve assembly is configured to move between a first piston position and a second piston position for providing multiple gain states for the valve assembly.

Claims

1. A valve assembly, comprising: a valve body defining a bore; a plunger adjacent to the valve body; a modulating biasing member disposed in the bore and abutting the plunger; a spool disposed in the bore and adjacent the plunger with the modulating biasing member disposed therebetween, the plunger configured to move the spool between a neutral position and an energized position, and the spool defining a socket; a piston disposed in the socket and configured to move between a first piston position and a second piston position within the socket; and a dowel extending through the spool and the piston with the spool and piston operatively arranged with the dowel so as to slide relative to the dowel.

2. The valve assembly of claim 1, wherein movement of the spool from the neutral position to the energized position generates a fluid force and wherein the piston is adapted to move to the second piston position in the presence of the fluid force.

3. The valve assembly of claim 1, wherein the plunger is configured to receive a force from a user to move the spool from the neutral position to the energized position, and wherein the force by the user required to move the spool toward the energized position when the piston is in the second piston position is decreased relative to the force required when the piston is in the first piston position.

4. The valve assembly of claim 1, wherein the spool has a spool face, the dowel has a dowel face, and the spool defines a cavity between the spool face and the dowel face.

5. The valve assembly of claim 4, wherein the spool and the dowel cooperate to define a channel extending between the socket and the cavity such that the socket is in fluid communication with the cavity.

6. The valve assembly of claim 5, wherein the channel is adapted to partially restrict a fluid moving from the cavity to the socket.

7. The valve assembly of claim 1, wherein the spool and the piston cooperate to define a relief passage when the piston is in the second piston position.

8. The valve assembly of claim 1 further comprising: a first compensating biasing member exhibiting a first force on the spool to bias the spool to the neutral position; and a second compensating biasing member exhibiting a second force on the spool to bias the spool to the neutral position and on the piston to bias the piston to the first piston position; wherein the piston is configured to move to the second piston position prior to the spool moving to the energized position due to a ratio of the first force and the second force.

9. The valve assembly of claim 8, wherein the piston is adapted to generate a force to oppose the second force of the second compensating biasing member.

10. The valve assembly of claim 9, wherein the force generated by the piston is limited to a pre-defined force acting on the piston when the piston is in the second piston position, and wherein the pre-defined force is in accordance with the second force of the second compensating biasing

member when the piston is in the second piston position.

11. The valve assembly of claim 1, wherein the valve assembly has a first gain state and a second gain state, the valve assembly is in the first gain state when the piston is in the first piston position, and the valve assembly is in the second gain state when the piston is in the second piston position.

12. The valve assembly of claim 1, wherein the first piston position and the second piston position of the piston are relative to the spool.

13. A system having a first gain state and a second gain state, the system comprising: a fluid source configured to provide a fluid force; a valve assembly in fluid communication with the fluid source, the valve assembly comprising: a plunger, a modulating biasing member abutting the plunger; a spool adjacent the plunger with the modulating biasing member disposed therebetween, the plunger configured to move the spool between a neutral position and an energized position; a piston in fluid communication with the fluid source via a port, the piston configured to move between a first piston position and a second piston position; and a dowel extending through the spool and the piston with the spool and piston operatively arranged with the dowel so as to slide relative to the dowel; and a working unit in fluid communication with the valve assembly and configured to activate in response to the fluid force; wherein the system is in the first gain state when the piston is in the first piston position and the system is in the second gain state when the piston is in the second piston position.

14. The system of claim 13, wherein movement of the spool from the neutral position to the energized position generates the fluid force and wherein the piston is adapted to move to the second piston position in the presence of the fluid force.

15. The system of claim 13, wherein the spool has a spool face, the dowel has a dowel face, and the spool defines a cavity between the spool face and the dowel face.

16. The system of claim 15, wherein the spool defines a socket in which the piston is disposed, and the spool defines a channel extending between the socket and the cavity such that the socket is in fluid communication with the cavity.

17. The system of claim 13, wherein the valve assembly further comprises: a first compensating biasing member exhibiting a first force on the spool to bias the spool to the neutral position; and a second compensating biasing member exhibiting a second force on the piston to bias the piston to the first piston position; wherein the piston is configured to move to the second piston position prior to the spool moving to the energized position due to a ratio of the first force and the second force.

18. The valve assembly of claim 17, wherein the spool defines a socket in which the piston is disposed, the piston is adapted to limit pressure in the socket.
