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Linton et al.

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(54) **FUEL PUMP ASSEMBLY WITH MULTIPLE PUMPS AND VARIABLE OUTPUT**

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(51) **Int. Cl.**

F02M 37/10	(2006.01)
F02M 37/08	(2006.01)
F02M 51/04	(2006.01)

(52) **U.S. Cl.**

CPC ***F02M 37/10*** (2013.01); ***F02M 51/04*** (2013.01); *F02M 2037/085* (2013.01)

(58) **Field of Classification Search**

CPC ... F02M 37/10; F02M 51/04; F02M 2037/085

See application file for complete search history.

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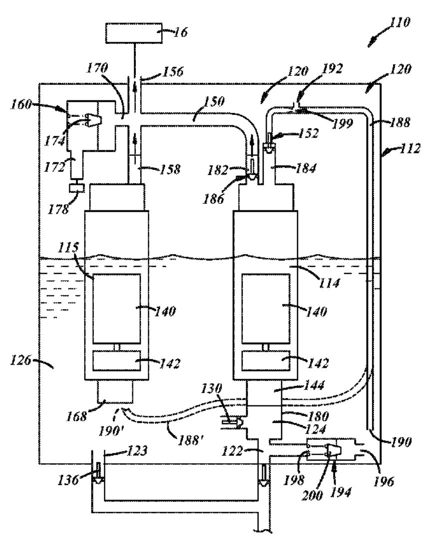
(57) **ABSTRACT**

In at least some implementations, a fuel system includes a first fuel pump and a first switch adapted to be coupled to a power supply, and a second fuel pump adapted to be coupled to the power supply. A conductor is provided between a first node between the first fuel pump and the first switch and a second node to which the second fuel pump is electrically coupled or electrically communicated so that depending upon the state of the first switch power may be supplied to the first fuel pump and second fuel pump in series or in parallel.

19 Claims, 5 Drawing Sheets



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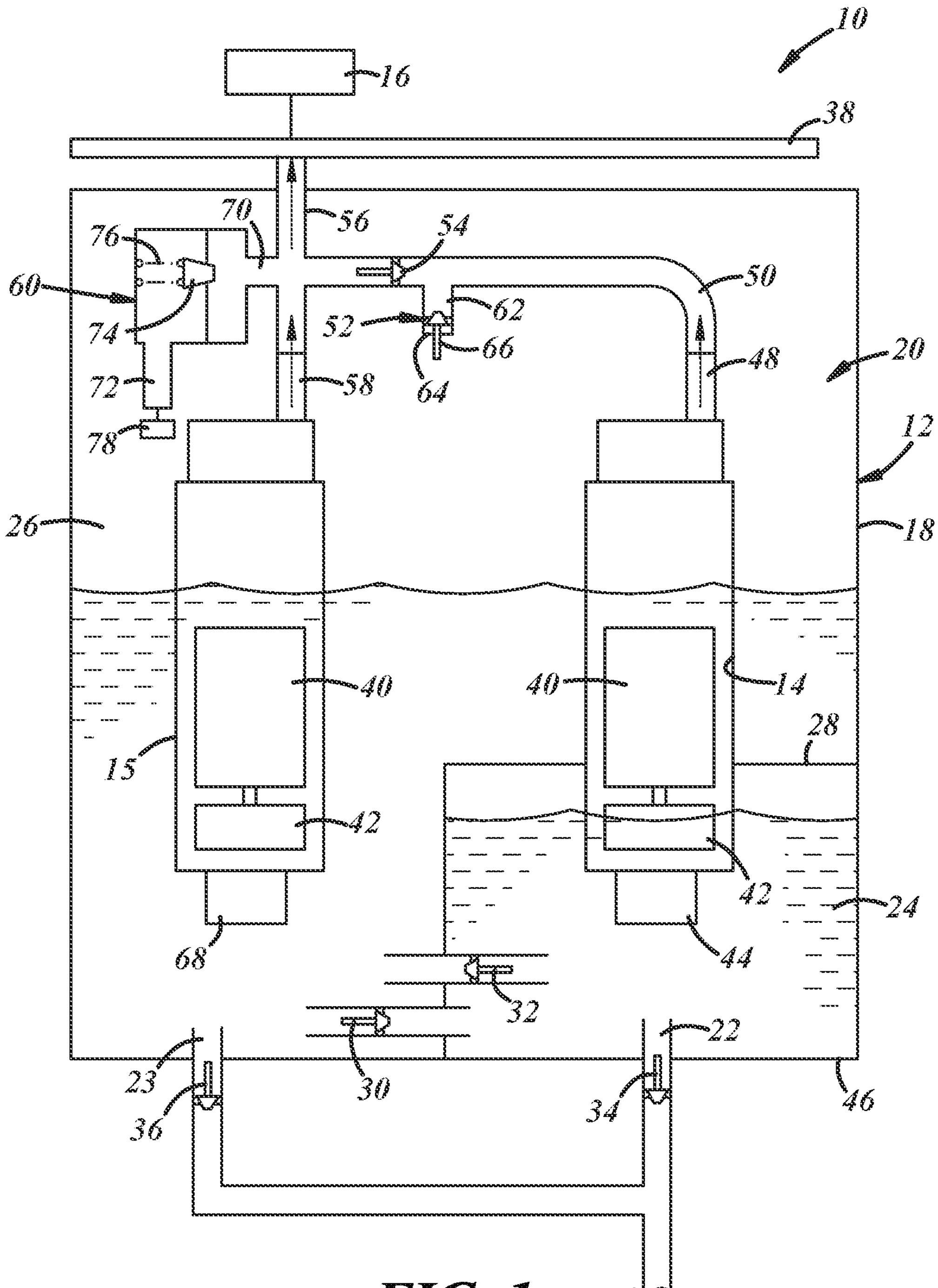
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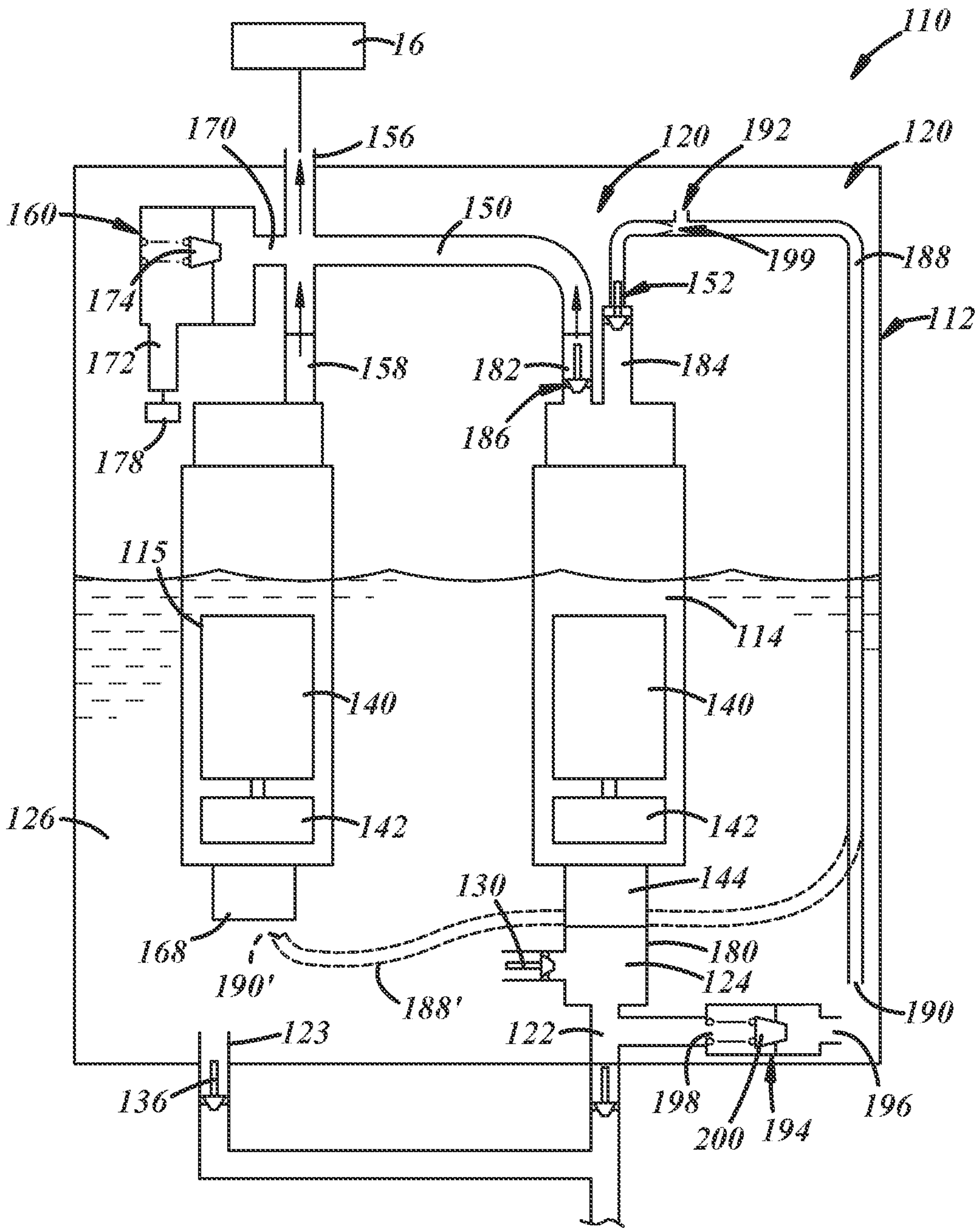
FIG. 1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114
140
140
126
142
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144
130
180
168
124
190'
188'
122
190
123
136
198
200
194
196

FIG. 2

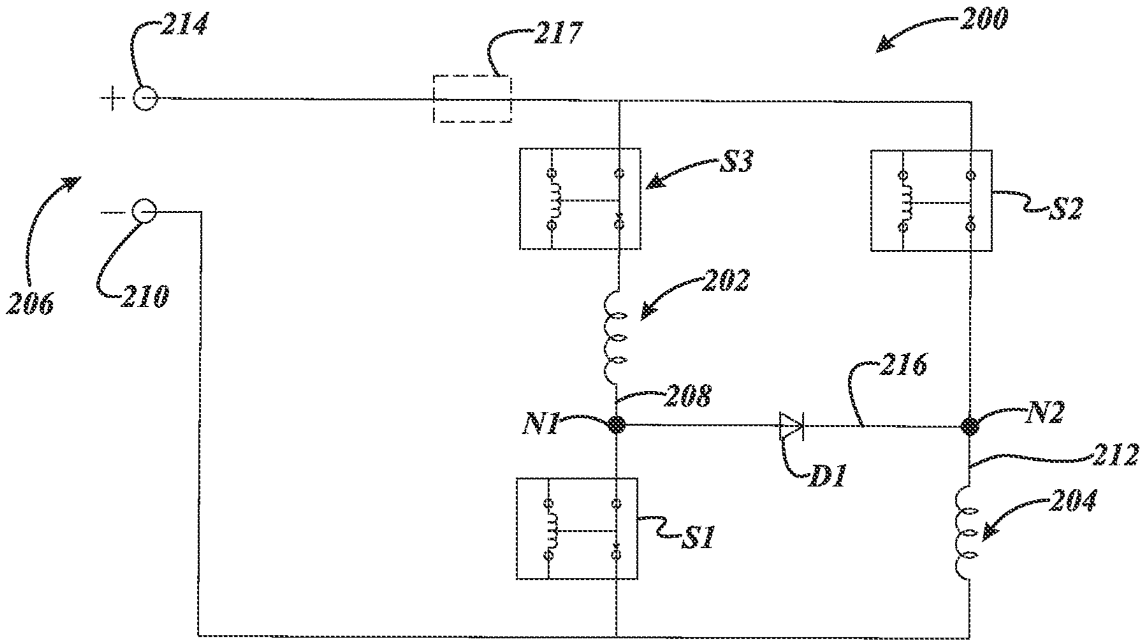
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FIG. 3

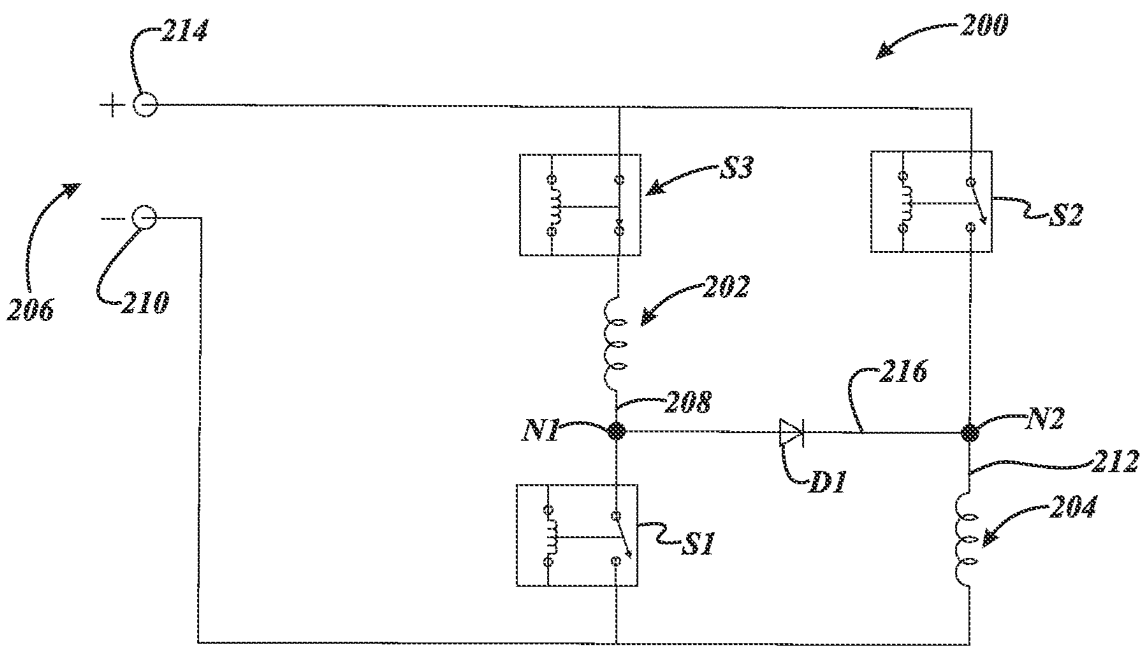
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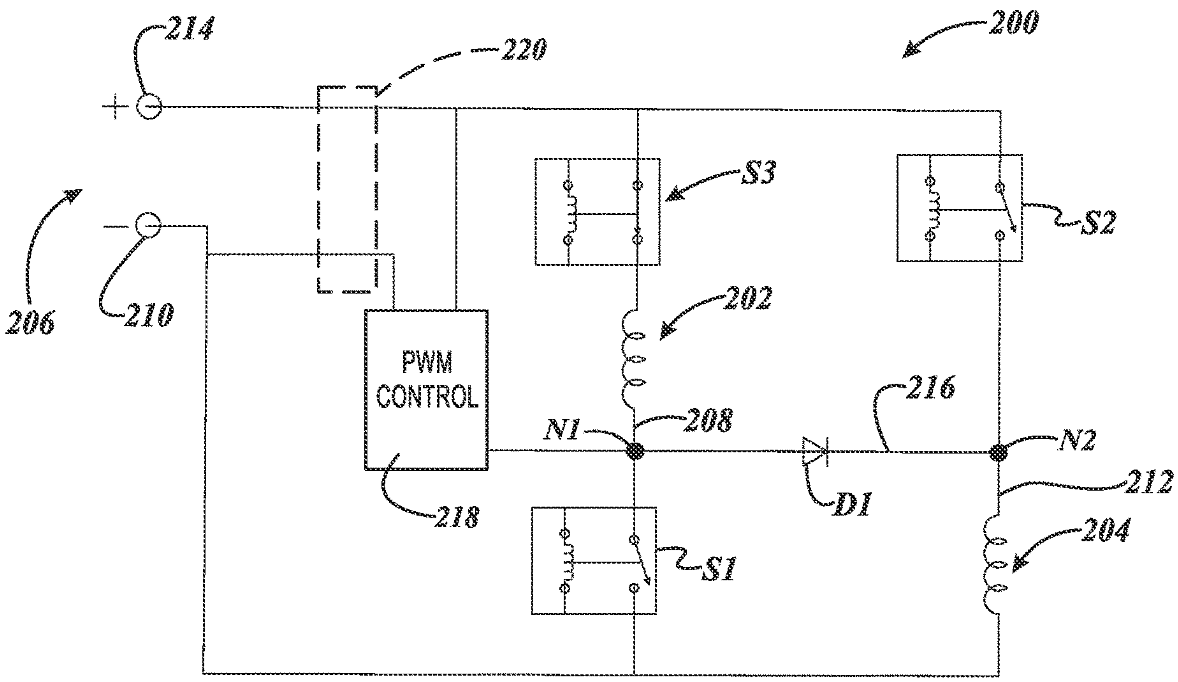
FIG. 4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CONTROL
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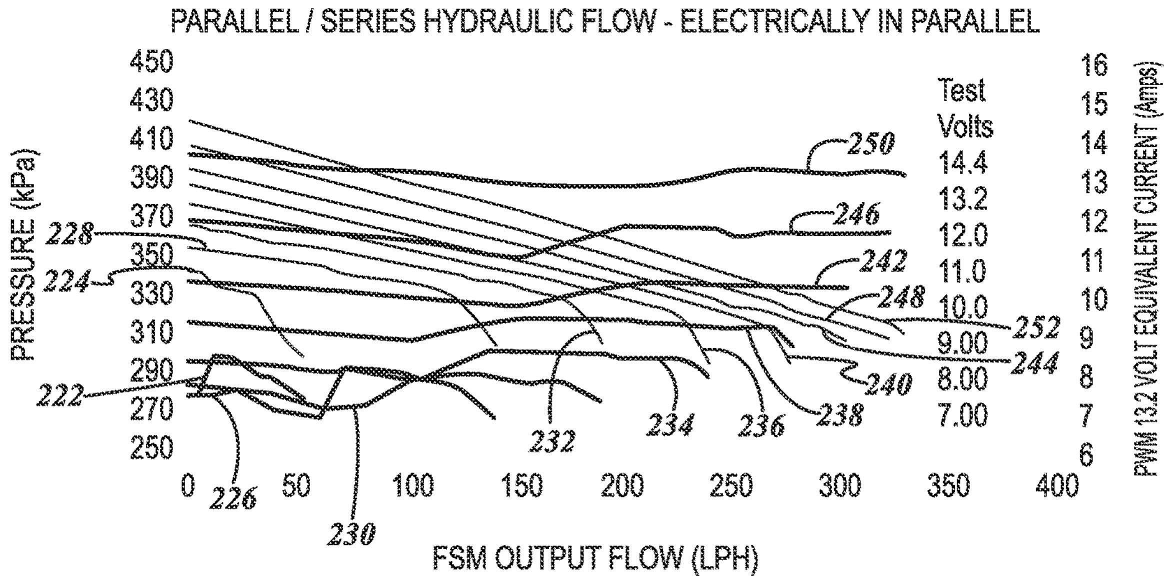
S1

FIG. 5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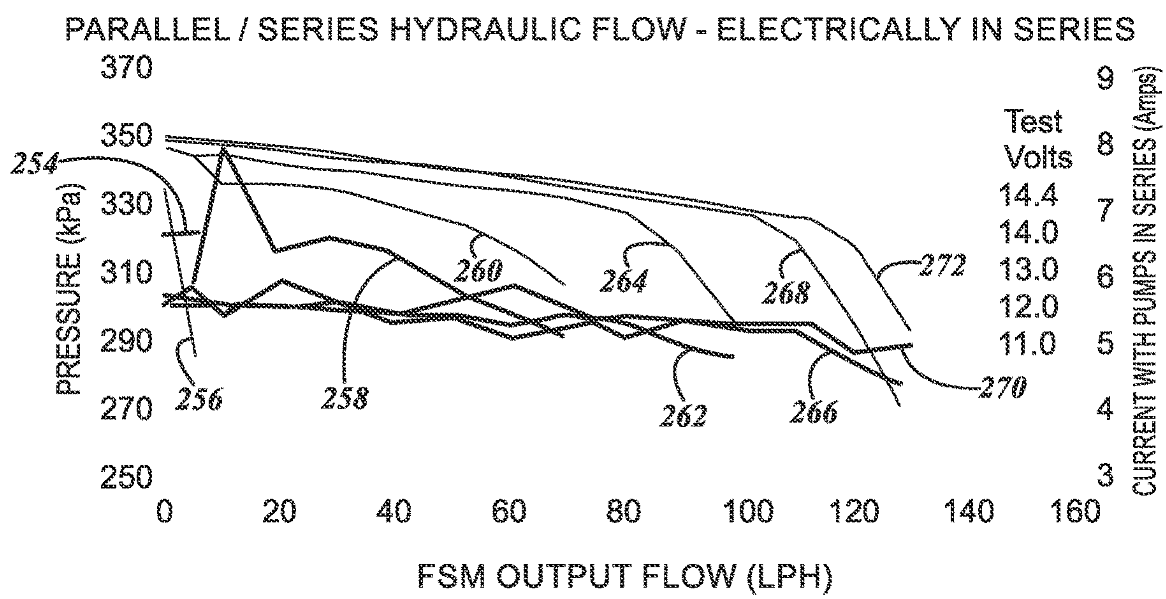
PRESSURE (kPa)
450
430
410
390
370
350
330
310
290
270
250
Test Volts
14.4
13.2
12.0
11.0
10.0
9.00
8.00
7.00
16
15
14
13
12
11
10
9
8
7
6
PWM 13.2 VOLT EQUIVALENT CURRENT (Amps)
0
50
100
150
200
250
300
350
400
FSM OUTPUT FLOW (LPH)
222
224
226
228
230
232
234
236
238
240
242
244
246
248
250
252

FIG. 6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PRESSURE (kPa)
370
350
330
310
290
270
250
Test Volts
14.4
14.0
13.0
12.0
11.0
9
8
7
6
5
4
3
CURRENT WITH PUMPS IN SERIES (Amps)
0
20
40
60
80
100
120
140
160
FSM OUTPUT FLOW (LPH)
254
256
258
260
262
264
266
268
270
272

FIG. 7

FUEL PUMP ASSEMBLY WITH MULTIPLE PUMPS AND VARIABLE OUTPUT

REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application Ser. No. 63/216,741 filed on Jun. 30, 2021 the entire content of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

The present disclosure relates generally to a fuel system that has more than one fuel pump.

BACKGROUND

Fuel systems sometimes have two fuel pumps with a lift pump providing fuel under relatively low pressure from a fuel tank to a high pressure fuel pump that provides fuel under higher pressure to an engine, to support engine operation. In this system, full electrical power or voltage is provided to both the lift pump and high pressure fuel pump all the time. Fuel delivered in excess of the engine's demand for fuel is returned to the fuel tank, and the fuel pump and the pumped fuel can become heated. Further, these systems do not have a valve mechanism to allow the fuel pump outputs to combine in series, so the output is determined by the output of the high pressure fuel pump.

SUMMARY

In at least some implementations, a fuel system includes a first fuel pump and a first switch adapted to be coupled to a power supply, and a second fuel pump adapted to be coupled to the power supply. A conductor is provided between a first node between the first fuel pump and the first switch and a second node to which the second fuel pump is electrically coupled or electrically communicated so that depending upon the state of the first switch power may be supplied to the first fuel pump and second fuel pump in series or in parallel.

In at least some implementations, when the first switch is open the first fuel pump and second fuel pump are electrically in series. In at least some implementations, when the first switch is closed the first fuel pump and second fuel pump are electrically in parallel. In at least some implementations, the first switch is a semiconductor switch including one of a SCR, MOSFET, BJT, MCT, IGCT or IGBT.

In at least some implementations, a second switch is arranged so that when the second switch is open current does not flow to either the first fuel pump or second fuel pump, and when the second switch is closed, current may flow to the first fuel pump and second fuel pump. In at least some implementations, the second switch is coupled between a positive lead of the second pump and a positive terminal adapted to be coupled to a power supply.

In at least some implementations, the first switch is connected between a negative lead of the first pump and a negative terminal adapted to be coupled to a power supply. In at least some implementations, a controller is coupled to the first switch and capable of changing the state of the first switch. In at least some implementations, the controller provides a pulse width modulated signal to the first switch.

In at least some implementations, a second switch is arranged so that when the second switch is open and the first switch is open, power is supplied in series to the first fuel

pump and to the second fuel pump. In at least some implementations, a second switch is arranged so that when the second switch is closed and the first switch is closed, power is supplied in parallel to the first fuel pump and to the second fuel pump.

In at least some implementations, a controller is coupled to the first node to change the voltage at the first node, and a diode is coupled to the conductor between the first node and the second node, and the diode conducts electricity from a negative terminal of the first pump to a positive terminal of the second pump. In at least some implementations, the controller is a pulse width modulated controller.

In at least some implementations, a fuel system includes a first fuel pump and a first switch adapted to be coupled to a power supply, and a second fuel pump and a second switch adapted to be coupled to the power supply. A conductor is provided between a first node between the first fuel pump and the first switch and a second node between the second switch and the second fuel pump. When the second switch is open and the first switch is open, power is supplied in series to the first fuel pump and to the second fuel pump. And when the second switch is closed and the first switch is closed, power is supplied in parallel to the first fuel pump and to the second fuel pump. In at least some implementations, the first switch is coupled between the negative lead of the first fuel pump and a negative power supply terminal, and the second switch is coupled between the positive lead of the second fuel pump and a positive power supply terminal.

In at least some implementations, a controller is coupled to the first switch and capable of changing the state of the first switch. In at least some implementations, the controller provides a pulse width modulated signal to the first switch.

In at least some implementations, a controller is coupled to the first node to change the voltage at the first node, and which also includes a diode coupled to the conductor between the first node and the second node, the diode conducting electricity from a negative terminal of the first pump to a positive terminal of the second pump. And the controller may be a pulse width modulated controller.

BRIEF DESCRIPTION OF THE DRAWINGS

The following detailed description of certain embodiments and best mode will be set forth with reference to the accompanying drawings, in which:

FIG. **1** is a schematic view of a fuel pump assembly including two fuel pumps received within a container in which a supply of fuel is maintained;

FIG. **2** is a schematic view of another fuel pump assembly;

FIG. **3** is a schematic of a circuit through which power is supplied to fuel pumps, showing power supplied to the fuel pumps in parallel;

FIG. **4** is the circuit of FIG. **3** showing power supplied in series to the fuel pumps;

FIG. **5** is a schematic of a circuit like that shown in FIG. **4**, and including a pulse width modulated controller;

FIG. **6** is graph of output flow, pressure and current for different test of fuel pumps operated electrically in parallel; and

FIG. **7** is graph of output flow, pressure and current for different test of fuel pumps operated electrically in series.

DETAILED DESCRIPTION

Referring in more detail to the drawings, FIG. **1** illustrates a fuel pump assembly **10** having a container or reservoir **12** in which a supply of fuel is contained, and multiple fuel pumps, shown as a first fuel pump **14** and a second fuel pump **15**, arranged to pump fuel from the reservoir **12** for use by an engine **16**. During times of high engine fuel demand, each fuel pump (i.e. both pumps **14** and **15** in the illustrated example) may provide fuel to the engine together, and during times of lesser engine fuel demand, fewer than all pumps (i.e. only one pump **15** in the illustrated example) provides fuel to the engine. In this way, the maximum flow rate of fuel from the fuel pump assembly **10** to the engine **16** may be greater than the maximum output flow rate from any one fuel pump **14** or **15**, but such maximum flow rate of fuel to the engine may be selectively provided from the fuel pumps **14**, **15** when demanded by the engine rather than continuously. Various valves and/or other flow controllers may be used to control the routing of fuel in and from the fuel assembly, as set forth in more detail below.

The reservoir **12** may include or be defined at least in part by a main body **18** that defines at least part of an internal volume or interior **20** in which liquid fuel is retained. A first inlet **22** of the reservoir **12** may be communicated with a first portion **24** of the interior **20**, and a second inlet **23** of the reservoir may be communicated with a second portion **26** of the interior **20**. The first and second portions **24**, **26** of the reservoir interior **20** may be separated from each other by a wall **28** or other divider (with the first portion **24** on one side of the divider and the second portion **26** on the other side of the divider), and may communicate with each other through one or more valves provided in the wall **28** or divider, to ensure at least some fuel is present in each portion **24**, **26** so long as there is fuel in either portion at or above the height/level of one of the valves (or the only valve when only one valve is provided). In at least some implementations, two oppositely acting check valves **30**, **32** are provided to control fuel flow between the first portion **24** and the second portion **26**. Inlet check valves **34** and **36** may be provided in the first and second inlets **22**, **23**, respectively, to prevent flow of fuel out of the reservoir through the first and second inlets, and to control flow into the first portion **24** and the second portion **26** as a function of pressure differentials across the inlet check valves **34**, **36**. With the valve **30** permitting flow from the first portion **24** to the second portion **26**, the second inlet check valve **36** and second inlet **23** may be omitted, as the second pump **15** may draw fuel into the reservoir interior **20** through the first inlet **22** and the valve **30**, in at least some circumstances. In at least some implementations, the reservoir main body **18** may be supported by a mounting flange **38** that is sealed to a fuel tank, to support the fuel pump assembly **10** within the fuel tank. Of course, other arrangements may be used, including arrangements in which the fuel pump assembly **10** is mounted outside of the fuel tank (e.g. not within an interior of the fuel tank) in which case the reservoir **12** may include a lid or second body coupled to the main body **12** to enclose the interior **20**.

The first and second fuel pumps **14** and **15** may each include an electric motor **40** and a pumping element **42** driven by the motor **40**. The pumping elements **42** may be a of a positive displacement type, like a gerotor or screw pump, or a centripetal pump like a turbine type pump with an impeller, as is known in the art. The fuel pumps **14** and **15** may be identical in construction (i.e. size, motor, output capability, etc) or they may be different, as desired for a particular application.

The first fuel pump **14** may be arranged to move fuel from a fuel supply (e.g. an interior of a fuel tank) into the reservoir interior **20** through the first inlet **22** of the reservoir, and to move fuel from the first portion **24** to the second portion **26** and/or to the engine **16**. To draw fuel into the first portion **24** and to take fuel from the first portion **24** into the fuel pump **14**, the fuel pump **14** has an inlet **44** communicated with the pumping element **42** and in or at which a subatmospheric or decreased pressure is caused by rotation of the pumping element **42**. A low pressure fuel pump could instead be used to move fuel from the fuel tank to the first portion **24** of the reservoir **12** communicated with the fuel pump inlet. That is, in at least some implementations, a third pump may be used to deliver fuel to the fuel pump assembly **10**, if desired. The first pump inlet **44** may be arranged in the first portion **24** so that it is relatively close to a bottom wall **46** of the reservoir **12**, for example, within one-half of an inch to facilitate drawing in fuel even when relatively little fuel is within the first portion **24**. In this position, the first pump inlet **44** may be submerged in liquid fuel during normal operation of the assembly **10**, which may include all or nearly all instances except where the fuel supply is low on fuel and when the reservoir **12** has a low level of or no fuel therein. This may maintain a head of liquid at the first pump inlet **44**, and the first pump inlet **44** wetted to improve the performance and efficiency of the first pump **14**. The first fuel pump **14** has an outlet **48** through which fuel is discharged from the pump **14** and from the first portion **24** of the interior **20**. The first pump outlet **48** is communicated with a passage **50** that routes the fuel away from the first pump **14**.

The passage **50** may be defined by one or more conduits or bodies that may carry one or more components that control fuel flow through the passage. In the example shown, the passage **50** includes or communicates with, to direct fuel flow to, one or more of a flow control valve **52**, a check valve **54**, a fuel assembly outlet **56** through which fuel is discharged from the fuel assembly **10** (e.g. to the engine **16**), an outlet **58** of the second pump **15**, and a fuel pressure regulator **60**. The flow control valve **52** has an inlet **62** in communication with the passage **50**, an outlet **64** in communication with the second portion **26** of the reservoir **20** and a valve body **66** that controls flow through the valve **52**. The valve body **66** is movable between first and second positions. When the valve body **66** is in a first position, the valve body **66** permits fuel flow through the valve outlet **64** to direct fuel discharged from the first pump **14** into the second portion **26** of the reservoir interior **20**. When the valve body **66** is in a second position, the valve element prevents fuel flow through the valve outlet **64** and fuel discharged from the first fuel pump **14** flows past the flow control valve **52** and through the check valve **54**. The check valve **54** may be arranged to permit fluid flow from the first fuel pump **14** to the fuel assembly outlet **56**, but to prevent the reverse flow through the passage **50** so that fuel downstream of the check valve **54** is not drained through the fuel control valve **52** or first fuel pump **14**.

The second fuel pump **15** may be arranged to do one or both of move fuel from a fuel supply into the second portion **26** of the reservoir interior **20** through the second inlet **23**, and move fuel from the second portion **26** of the reservoir interior **20** to the fuel pump assembly outlet **56** for delivery to the engine **16**. To draw fuel into the second portion **26** and to take fuel from the second portion **26** into the second fuel pump **15**, the second fuel pump **15** has an inlet **68** communicated with the pumping element **42** and in or at which a subatmospheric or decreased pressure is caused by rotation of the pumping element **42**. The second pump inlet **68** may be arranged in the second portion **26** so that it is relatively close to the bottom wall **46** of the reservoir **12**, for example, within one-half of an inch to facilitate drawing in fuel even when relatively little fuel is within the second portion **26**. In this position, the second pump inlet **68** may be submerged in liquid fuel during normal operation of the assembly **10**, which may include all or nearly all instances except where the fuel supply is low on fuel and when the reservoir **12** has a low level of or no fuel therein. This may maintain a head of liquid at the second pump inlet **68**, and the second pump inlet **68** wetted to improve the performance and efficiency of the second pump **15**. Fuel is discharged from the second pump **15** and from the second portion **26** of the reservoir interior **20** through the second pump outlet **58**.

The second pump outlet **58** is communicated with the passage **50** and the fuel pump assembly outlet **56**. In at least some implementations, the check valve **54** and the fuel control valve **52** are between the outlets **48**, **58** of the first and second pumps **14**, **15**, and relative to the second pump **15**, the flow control valve **52** is downstream of the check valve **54** such that the check valve **54** prevents fuel discharged from the second pump **15** from flowing to the flow control valve **52**. The fuel discharged from the second pump **15** may be communicated with the pressure regulator **60**. The pressure regulator **60** may include an inlet **70**, an outlet **72** and a valve body **74** between the inlet **70** and outlet **72**. When the fuel pressure at the valve inlet is below a threshold (which may be defined at least in part by a spring **76** that biases the valve body **74**), the valve body **74** prevents fuel flow through the valve outlet **72** and the fuel flows through the fuel pump assembly main outlet **56** for delivery to the engine **16**. When the fuel pressure at the valve inlet **70** is above the threshold pressure, the valve body **74** is moved to an open position to permit some fuel flow out of the valve outlet **72** and into the second portion **26** of the reservoir interior **20** (and/or first portion **24**, if desired). This reduces the pressure of the fuel so that the pressure of fuel delivered to the engine **16** may be regulated, in known manner. Fuel discharged from the first pump **14** that does not flow through the fuel control valve **52** to the second portion **26** of the reservoir interior **20**, is combined with fuel discharged from the second pump **15**, and the pressure of the combined fuel flows is regulated by pressure regulator **60** in the same manner and the combined fuel flow is discharged from the fuel pump assembly **10** through the main outlet **56**, in at least some operating conditions.

Thus, both fuel pumps **14** and **15** may draw fuel into the reservoir interior **20** and both fuel pumps **14**, **15** may discharge fuel from the reservoir interior **20** for delivery to the engine **16**. In this way, the amount that may be taken into the reservoir interior **20** to support pumping fuel to the engine **16** is not limited by the intake capacity of just one pump **14** or **15**, as both pumps **14** and **15** draw fuel into the reservoir **12**. Similarly, the flow rate of fuel delivered from the fuel pump assembly **10** is not limited to the output flow rate of just one pump **14** or **15** as both pumps **14** and **15** may simultaneously provide fuel to the engine **16**. In this way, the maximum fuel flow rate from the assembly **10** may be greater than the flow rate possible from either fuel pump **14** or **15** by itself.

In at least some implementations, when the engine fuel demand is less than or equal to the maximum fuel output of the second pump **15**, the output from the first pump **14** may be directed into the second portion **26** of the reservoir interior **20** to provide fuel for the second pump **15**, and the first pump **14** can boost or increase pressure of fuel provided to the second pump **15**. The check valve **36** through which fuel enters the second portion **26** of the reservoir interior **20** will close when there is a positive pressure in the second portion **26**. Also, the check valve **30** will close and the check valve **32** will open if there is a positive pressure in the second portion **26** of the reservoir interior **20**. When the engine fuel demand exceeds the maximum fuel output of the second pump **15**, the fuel control valve **52** may reduce the flow rate of or prevent fuel flow through the control valve outlet **64** so that at least a portion and up to all of the fuel discharged from the first pump **14** is combined with the fuel discharged from the second pump **15** for delivery to the engine **16**. Of course, at least some output from the first pump **14** can be used to supplement the fuel pressure provided to the second pump **15** when the engine fuel demand is below the maximum fuel output of the second pump **15**, as desired. In at least some implementations, some of the fuel from both pumps **14** and **15** may be used to satisfy the engine's fuel demand over a wide range of fuel flow rates up to and including all fuel flow rate demands of the engine **16**. In at least some implementations, when the engine fuel demand can be met by either pump, the other pump may be shut off or not powered. That is, the engine fuel demand up to a threshold could be met by only the first fuel pump **14**, or by only the second fuel pump **15**, in at least some implementations.

The motor **40** of either or both of the first and second pumps **14**, **15** can be operated by a pulse width modulated signal to vary the electrical power provided to the pump motor **40** and thereby vary the pump output to support the engine fuel demand. The fuel control valve **52** can be responsive to a fuel output flow rate, for example with a flow rate sensor providing a signal used to close the fuel control valve **52** which may be, for example, an electro-mechanical valve such as a solenoid valve. For example, when the output of the first fuel pump **14** is above a threshold level, for example but not limited to 100 liters per hour, the fuel control valve **52** may be closed to route the output of the first fuel pump **14** to the engine **16** (subject to some fuel being bypassed by the pressure regulator **60**, if provided). At lower flow rates, the fuel control valve **52** may be opened and all or at least some of the fuel discharged from the first pump **14** may be routed through the control valve **52** to the second portion **26** of the reservoir interior **20**. If the output of the first pump **14** is constant, then the fuel control valve **52** can be opened and closed based upon the engine fuel demand and the flow rate of fuel needed to support engine operation in combination with the fuel discharged from the second fuel pump **15**.

The engine fuel demand can be determined in different ways. For example, the flow rate of fuel discharged from the regulator outlet **72** may be monitored and used to determine the engine fuel demand as a function of the output of the second pump **15** and/or first pump **14**. This information may be used to determine the power provided to either or both pumps **14**, **15** (e.g. via PWM drive) and/or to control opening and closing of the fuel control valve **52**. A flow switch **78** could be used that, when there is fuel flow out of the pressure regulator outlet **72**, provides a signal to control the fuel control valve **52** and/or provides a signal that one or the other of the fuel pumps **14**, **15** can be shut off until such time as the engine demands a greater fuel flow rate. Alternatively, when there is no fuel flow from the regulator outlet **72**, or if the flow out of the regulator outlet **72** is below a threshold, the flow switch **78** may provide a signal to indicate that the fuel flow from one or both fuel pumps **14**, **15** should be increased, and/or to close the fuel control valve **52** to increase fuel flow from the first pump **14** that reaches the regulator **60** and main outlet **56** of the fuel pump assembly **10**. As an alternative, a valving arrangement such as is shown in U.S. Pat. No. 4,683,864 may be used to mechanically open or close the flow control valve as a function of the flow through the flow control valve.

The fuel control valve **52** may be biased or normally in an open position. In this position, fuel vapors and air in the reservoir interior **20** may be allowed to flow into and through the fuel control valve outlet **64**, and such gasses may flow out of the fuel pump **14** through the outlet **48** when the valve **52** is opened, either by fuel flow or by pressure within the pump **14**. Further, the first pump outlet **48** could be separately routed from the fuel pump assembly **10**, such as through a second outlet of the assembly that is separate from the main outlet **56** already described. That is, the first fuel pump **14** may be communicated with the flow control valve **52** and output from the first fuel pump **14** may flow through the control valve **52** and/or through a second output of the assembly **10** separate from any output from the second pump **15**. A second pressure regulator may be used, if desired, in the pump assembly **10** or a pressure regulator may be provided downstream of the assembly **10** with a return line used to return fuel to the reservoir that was discharged from the assembly **10** in excess of engine fuel demand. Thus, the fuel pumps **14**, **15** may be arranged in a parallel relationship, and may separately draw fuel into the reservoir interior **20** and separately discharged fuel to the engine **16**. The output of the pumps **14**, **15** may be combined a in single flow path that exits a single outlet **56** of the assembly **10**, or the output of the pumps **14**, **15** may be discharged through separate outlets of the assembly.

The fuel pump assembly **110** shown in FIG. **2** has many similar features and components as in the fuel pump assembly **10** shown in FIG. **1**. To facilitate the description of the fuel pump assembly **110**, components will be given the reference numerals offset by one hundred from the reference numerals given to similar components in the fuel pump assembly **10**, and the following description will focus on the differences between the two assemblies **10** and **110**.

The fuel pump assembly **110** also includes a first pump **114** and a second pump **115** that are received in an interior **120** of a reservoir **112**, to pump fuel into the reservoir **112** and out of the reservoir **112** for delivery to an engine. The second fuel pump **115** has an inlet **168** that draws in fuel and an outlet **158** through which fuel is discharged. The outlet **158** of the second fuel pump **115** may be communicated with a fuel pressure regulator **160** arranged as set forth with regard to the fuel pump assembly **10**, and communicated with or routed to the main outlet **156** of the fuel pump assembly **110** for delivery to the engine **16**. The second fuel pump **115** may operate as set forth with regard to the second pump **15** in the fuel pump assembly **10**, including drawing fuel into the reservoir interior **120** via a second inlet **123** and associated check valve **136**, or an optional check valve **130** carried by an inlet body **180** of the first fuel pump **114** to draw fuel in through the first inlet **122**, the first portion **124** and the optional check valve **130** (in the latter instance, no second inlet **123** is needed). The inlet body **180** defines the divider in the interior **120**, with the first portion **124** of the interior **120** inside the inlet body **180** and the second portion of the interior **120** outside of the inlet body **180**.

The first fuel pump **114** has its inlet **144** received in the inlet body **180** and in communication with the first portion **124** defined by the inlet body **180**. The first pump **114** draws fuel into the reservoir **112** via the first inlet **122** which leads to the first portion **124**, and the first pump **114** then pumps fuel from the first portion **124** and discharges that fuel through one or both of two outlets **182**, **184**. A first outlet **182** is coupled to or communicated with the outlet **158** of the second pump **115**, the fuel pressure regulator **160** and the main outlet **156**, as in the fuel pump assembly **10**. A check valve **186** prevents fuel flow from the second pump **115**, or back flow when the engine **16** is off, from flowing through the first outlet **182** and first pump **114**. One difference is that the first outlet **182** is not communicated with the fuel control valve **152**, which is instead communicated with a second outlet **184** of the first pump **114**.

The second outlet **184** of the first pump **114** directs fuel to the (optional) flow control valve **152**, which when open, allows fuel flow through the valve **152** and/or a reduced flow area orifice **199** (sometimes called a jet) and an optional conduit **188** having an outlet **190** within the reservoir interior **120** (e.g. the second portion **126** in communication with the second pump inlet **168**). A vent **192** in the conduit **188** prevents a syphoning action from occurring through the conduit **188** when the pumps **114**, **115** are off to prevent draining or emptying of fuel from the reservoir **112** if the flow control valve **152** is not utilized. The conduit outlet **190** may be located near the bottom of the reservoir interior **120** so that it is usually submerged in liquid fuel and to direct fuel to the bottom or inlet of the second pump **115**. The flow control valve **152** can be opened to direct fuel to the interior **120** of the reservoir **112** and to reduce the flow rate of fuel provided from the first pump **114** to the main outlet **156**. The flow control valve **152** can be controlled in the same manner(s) as set forth above with regard to the fuel pump assembly **10**.

In a pressurized or enclosed/sealed reservoir, a second fuel pressure regulator **194** may be provided that has an inlet **196** communicating with the second portion **126** of the reservoir interior **120**, an outlet **198** communicating with the first portion **124** of the reservoir interior **120**, and a valve body **200** between them that is normally closed to prevent fuel flow through the second regulator **194**. When the pressure at the inlet **196** of the regulator **194** is equal to or greater than the pressure at which the valve body **200** opens, the valve body **200** will open. This permits fuel flow through the fuel pressure regulator **194** from the second portion **126** and into the first portion **124** of the interior **120** so that fuel from the second portion **126** will be drawn into and pumped by the first pump **114**. This diverts fuel from liquid fuel in the second portion **126** of the reservoir interior **120** and thereby controls the pressure therein. Until a certain level of fuel or pressure is present within the second portion **126** of the reservoir interior **120**, fuel may be drawn only or primarily from the fuel source (e.g. a fuel tank), and only when the threshold pressure exists at the second regulator inlet **196** does fuel flow from the second portion **126** to the first portion **124** and into the first pump inlet **144**. Of course, other arrangements are possible and will be understood to persons skilled in this art in view of this disclosure.

The second outlet **184** of the first pump **114** and conduit **188** may divert output fuel flow from the first pump **114**, and may allow the first pump **114** to operate at a pressure that is below system pressure, and may allow air flow through the first pump **114** at a pressure that is below system pressure. The flow control valve **152** may be controlled to increase or decrease the diverted fuel flow. The jet or restrictive orifice **199** may also be used to control the flow rate of fuel from the first pump **114** through the second outlet **184** and conduit **188**. The jet may be part of a jet pump that uses the flow of output fuel therethrough to entrain air, vapor and/or liquid fuel into the jet pump. This may be used to evacuate or vent air and vapor from the reservoir interior **120** by moving such fluids to the bottom of the reservoir interior **120** wherein they may be drawn into the second pump **115** (e.g. by the alternate routing of the conduit **188'** shown in dashed lines in FIG. **2** with outlet **190'**).

Like the second pump **115**, the first pump **114** may be operated in the same manner(s) as described above with regard to the fuel pump assembly **10**. For example, the first pump **114** could be operated at full duty all the time and the flow control valve **152** and fuel pressure regulator **194** may divert some of the first pump output flow back into the reservoir interior **120**. As another example, the first pump **114** could be operated at less than full duty including not being powered at all and relying on the operation of the second pump **115** in at least some circumstances, as desired (likewise, the second pump **115** may be shut down and the first pump **114** may provide all fuel flow from the assembly **110**, in at least some instances, if desired. This may lower the total system current draw). Alternatively, both pumps could be run at partial duty with the fuel output just matching the engine fuel demand. If so, the pressure from the first pump **114** will provide a boost pressure to the second pump **115**, which may enhance performance of the second pump **115**.

Further, the assemblies **10**, **110** having two or more pumps described herein may meet higher fuel flow rate engine demands with lower current consumption than use of both a single, higher flow rate pump and a lower pressure lift pump that simply moves fuel from a tank to the reservoir **12**, **112**, or by use of both pumps working in series to provide an increased flow in comparison to either pump's output by itself. The pump assemblies **10**, **110** should also prove more efficient and more capable of dry priming the system as both pumps **14**, **15** and **114**, **115** are able to divert air from the input side to the output side of the fuel pump assembly **10**, **110** (as opposed to only one pump being able to pump to the output side/main outlet of the assembly).

Further, even if one pump fails, the other pump can provide at least some fuel to the engine **16** to provide a failsafe mode in which at least some engine fuel demand can be satisfied to support at least some level of engine operation. The still operating pump can also more easily draw fuel into the reservoir interior **20**, **120** due to the parallel arrangement of the fuel pumps. In prior arrangements, the fuel pumps were arranged in series with only the lift pump drawing fuel into the reservoir and only the high pressure pump delivering fuel to the engine. If the high pressure pump failed, there was little or no fuel flow to the engine. If the lower pressure lift pump failed, the high pressure pump would have to draw fuel through the lift pump to get fuel into the reservoir which either resulted in no flow into the reservoir or a low flow rate which then negatively impacted the output flow rate of the high pressure pump.

FIGS. **3** and **4** illustrate an electrical schematic diagram of a circuit **200** that may be used to selectively control operation of two or more pumps, with two pumps **202**, **204** shown. In this circuit **200**, a power supply, such as a battery **206**, is coupled to both the first pump **202** and the second pump **204**. The first pump **202** may have a higher pressure output fluid flow than the second pump **204**, although the pumps could be the same or the second pump may have a higher pressure output fluid flow than the first pump. The pumps **202**, **204** may be arranged as shown in and described with reference to FIGS. **1** and **2**, with regard to fluid flow paths, valves and the like.

As shown in FIG. **3**, the power supply **206** is connected to the first pump **202** with a first switch S**1** connected between the negative lead **208** of the first pump **202** and the negative power supply terminal or lead **210**. The power supply **206** is also connected to the second pump **204** with a second switch S**2** between the positive lead **212** of the second pump **204** and the positive terminal **214** of the power supply **206**. A conductor **216** may extend between a node N**1** provided between the first pump **202** and first switch S**1** and a node N**2** provided between the second pump **204** and second switch S**2**. A diode D**1** controls the direction of current flow through the conductor **216**.

In the example shown, a control switch or relay (not shown) may be provided by a system to which the pumps **202**, **204** and circuit **200** are connected, for example, a vehicle control system which may include a relay or other switch that enables power supply to the pumps **202**, **204** only when, for example, a vehicle ignition is activated or other action is taken to start an engine to which the pumps supply fuel. By way of example, some vehicles enable use of the power supply **206** even without the engine running, such as to enable use of a radio or other devices or accessories. So that fuel is provided only when the engine needs fuel, the control switch may be open until an activation step is detected. With the control switch open, no power is provided from the power supply **206** to either the first pump **202** or second pump **204**. When the control switch is closed, power is provided to both the first and second pumps **202**, **204**.

The first switch S**1** and second switch S**2** are shown as single pole relays, but could be any desired type of switch or relay including, but not limited to, semiconductor switches like a SCR, MOSFET, BJT, MCT, IGCT or IGBT. Changing the state of the switches S**1**, S**2** changes the current flow within the circuit **200**. In the example shown in FIG. **3**, the first switch S**1** and second switch S**2** are both closed (e.g. conductive) and current flows in parallel to the first pump **202** and the second pump **204**. As shown in FIG. **4**, when the first switch S**1** and second switch S**2** are both open (e.g. not conductive), current flows in series to the first pump **202** and to the second pump **204**, through the conductor **216** and its diode D**1**.

A third switch S**3** may also be provided, and when open, may prevent power from being supplied to one or both pumps. In the example shown, when the third switch S**3** is open, power can be provided to the second pump **204** only when the second switch S**2** is closed. The third switch S**3** could be located elsewhere, for example in the location shown by the dashed line box **217** in FIG. **3**, and when open, could prevent power from being supplied to either pump **202**, **204**. Other options for controlling the power supply to the pumps may be used, as desired. For example, the diode D**1** could be replaced with a single pole relay or a switch, and the third switch S**3** could be eliminated. As another example, the first switch S**1** and the diode D**11** could be replaced with a single throw double pole relay. Further, the pumps could be powered individually as needed, and different switch/relay arrangements may be used to accomplish the desired pump operation.

Further, as shown in FIG. **5**, a controller **218** may be provided to increase or decrease the voltage at, for example, node N**1**. This configuration of the circuit can be used to adjust the electrical match point of the fuel pumps **202**, **204** so that the operating points of the individual pumps can be matched or optimized to meet system requirements under idle or partial load conditions. As the diode would be forward biased it would conduct electricity from the negative terminal of the first pump **202** to the positive terminal of the second pump **204**. If another switching device were to be used in place of the diode the intent would be that it is on or set to a closed circuit status. In the example shown, the controller **218** is a pulse width modulated (PWM) control which may enable more precise control of the voltage. A benefit associated with adding PWM control to the node **N1** is that the amount of current that the controller **218** has to provide or consume will only be the amount required to shift the voltage of one pump up or down, and the remaining current is consumed by or provided to the second pump. As an option, a circuit, device or controller **220** (FIG. **5**) may also provide reverse battery protection between the power supply **206** and the pumps **202**, **204** or such protection, if desired, can be provided on the vehicle side of the system.

One exemplary implementation of the circuit **200** was tested with two fuel pumps. The two pumps, when operated at 13 volts and coupled in a standard parallel only power supply circuit, produced a total fuel flow of about 340 liters per hour at a system pressure of 500 kPa, and consumed 22.9 amps and 298 watts. Thus, the power consumption was high and the output flow rate was high. The output flow rate in such a system is set to satisfy the maximum engine fuel demand and so, when the engine has a lesser fuel demand, the pumped fuel is recirculated within the reservoir. Only a small percent of that fuel flow may be needed at low engine speed and low load operation, such as at idle and near idle speed operation. Thus, the power consumed, heat generated and fuel flow rate in the system are considerably more than is needed to support engine operation. Next, the pumps were connected in series instead of in parallel, and the first pump (e.g. the higher pressure pump) was operated with a PWM at 10% to 30% duty cycle. When powered by a 13-volt power source, the pumps produced a flow rate of 117 liters/hour at 500 kPa, and consumed 8.29 amps and 108 watts. Next, the two pumps were operated with the circuit **200** of FIG. **3** including the first switch **S1** in its closed state and the second switch **S2** open such that the pumps were provided power in series. When powered by a 13-volt power source, the pumps produced a flow rate of 117 liters/hour at 500 kPa, and consumed 8.12 amps and 106 watts.

Thus, when the engine has a fuel demand equal to or less than 117 liters/hour, the pumps can be operated in this fashion which greatly reduces the electrical demand from the system and conserves power. Further, less fuel is pumped which means a greater percentage of the pumped fuel is delivered to the engine and less fuel is heated and recirculated within the reservoir. In other words, less energy is wasted and less heat is generated in the fuel and in the fuel system generally. In many engine applications, the lower fuel flow rate is sufficient to support engine operation from idle up to about 50% of maximum engine fuel demand. Of course, some higher performance engines require a higher flow rate and this lower fuel flow rate would be sufficient for less of a range of engine speeds, perhaps only up to about 30% of maximum engine fuel demand. When a higher fuel flow rate is required, the first switch **S1** and second switch **S2** can be closed to provide power to both pumps in parallel and provide a higher fuel flow rate with greater energy consumption.

Further, by controlling the state of the first switch **S1**, the system can be used to achieve intermediate fuel flows between the high fuel flow and high electrical energy consumption of the parallel power supply scenario and the lower fuel flow and low electrical energy consumption of the series power supply. That is, the system can be operated with the first switch **S1** opened for part of the time and closed for part of the time to control the system fuel flow rate and also tailor the energy consumption more closely to the engine fuel demand. This can more closely match the system's ability to provide electrical power. For example, in systems with an alternator, the alternator might struggle to supply power sufficient to operate both pumps when the engine speed is low and hence, the alternator is driven at a lower speed. However, at higher engine speeds, the alternator is driven at a higher speed and can more readily supply power to both pumps.

Also, in some systems or in some situations, only a lesser voltage is provided from the power supply **206**. This may occur, for example, during a cold start and initial cold operation of an engine. Accordingly, the system can be operated to ensure a sufficient fuel supply even when only a limited electrical energy supply is available. In one test, the system achieved up to 275 liters/hour flow rate at over 330 kPa, when operated at 11 volts and took 9 amps to operate with the pumps powered in parallel.

A representative graph of pump performance with the pump operated electrically in parallel is shown in FIG. **6**. In this graph, pump performance at 7 volts is indicated by line **222** which shows output pressure and fuel flow rate and line **224** which shows the current draw in amps, pump performance at 8 volts is indicated by line **226** which shows output pressure and fuel flow rate and line **228** which shows the current draw, pump performance at 9 volts is indicated by line **230** which shows output pressure and fuel flow rate and line **232** which shows the current draw, pump performance at 10 volts is indicated by line **234** which shows output pressure and fuel flow rate and line **236** which shows the current draw, pump performance at 11 volts is indicated by line **238** which shows output pressure and fuel flow rate and line **240** which shows the current draw, pump performance at 12 volts is indicated by line **242** which shows output pressure and fuel flow rate and line **244** which shows the current draw, pump performance at 13.2 volts is indicated by line **246** which shows output pressure and fuel flow rate and line **248** which shows the current draw, and pump performance at 14 volts is indicated by line **250** which shows output pressure and fuel flow rate and line **252** which shows the current draw. Thus, lines **238** and **240** illustrate the pump performance at 11 volts described in the preceding paragraph.

A representative graph of pump performance with the pump operated electrically in series is shown in FIG. **7**. In this graph, pump performance at 11 volts is indicated by line **254** which shows output pressure and fuel flow rate and line **256** which shows the current draw, pump performance at 12 volts is indicated by line **258** which shows output pressure and fuel flow rate and line **260** which shows the current draw, pump performance at 13 volts is indicated by line **262** which shows output pressure and fuel flow rate and line **264** which shows the current draw, pump performance at 14 volts is indicated by line **266** which shows output pressure and fuel flow rate and line **268** which shows the current draw, and pump performance at 14.4 volts is indicated by line **270** which shows output pressure and fuel flow rate and line **272** which shows the current draw.

Thus, the fluid flow output of a multiple pump system can be controlled, for example, as shown in FIGS. **1** and **2** and described above. In addition or instead, the pumps may be electrically powered in series or parallel, and this may be done in combination with a PWM control, if desired, as shown in FIG. **3** and described above. In this way, the fluid flow characteristics can be controlled in accordance with engine fuel demand, and the electrical energy required can be reduced in many engine operating conditions to provide a more efficient system. Further, with the improved control of the fuel pumps, pumps having lower maximum output ratings may be used and these pumps are often much less expensive than higher performance pumps.

For example, a conventional high output fuel system uses a fill pump to move fuel into a reservoir and a high pressure pump takes in this fuel from the reservoir, increases the pressure of the fuel and sends the higher pressure fuel to the engine. In this system, full electrical power or voltage is provided to both the lift pump and high pressure fuel pump all the time. Further, the system does not have a valve mechanism to allow the fuel pump outputs to combine in series. In the system disclosed herein, relays are used to operate the pumps in series at engine idle so that full electrical power is not always provided to the fuel pumps. Further, the system disclosed herein allows the fuel flows from two fuel pumps to combine via automatic switching of valves to produce a higher output fuel flow rate. In this system, the fuel pump outputs can be combined to allow higher output in higher engine fuel demand situations. In lower engine fuel demand situations, the controller can reduce the voltage to the fuel pumps supporting reductions in the flow rate and or pressure to further support hydraulic actuation of a valve or valves that automatically change the flow circuit from combining in parallel to operating in series.

It is to be understood that the foregoing description is not a definition of the invention, but is a description of one or more preferred embodiments of the invention. The invention is not limited to the particular embodiment(s) disclosed herein, but rather is defined by the claims below. Furthermore, the statements contained in the foregoing description relate to particular embodiments and are not to be construed as limitations on the scope of the invention or on the definition of terms used in the claims, except where a term or phrase is expressly defined above. Various other embodiments and various changes and modifications to the disclosed embodiment(s) will become apparent to those skilled in the art. For example, a method having greater, fewer, or different steps than those shown could be used instead. All such embodiments, changes, and modifications are intended to come within the scope of the appended claims.

As used in this specification and claims, the terms "for example," "for instance," "e.g.," "such as," and "like," and the verbs "comprising," "having," "including," and their other verb forms, when used in conjunction with a listing of one or more components or other items, are each to be construed as open-ended, meaning that that the listing is not to be considered as excluding other, additional components or items. Other terms are to be construed using their broadest reasonable meaning unless they are used in a context that requires a different interpretation.

The invention claimed is:

1. A fuel system, comprising:

a first fuel pump and a first switch adapted to be coupled to a power supply;

a second fuel pump adapted to be coupled to the power supply; and

a conductor between a first node between the first fuel pump and the first switch and a second node to which the second fuel pump is electrically coupled or electrically communicated so that depending upon the state of the first switch power may be supplied to the first fuel pump and second fuel pump in series or in parallel.

2. The system of claim **1**, wherein when the first switch is open the first fuel pump and second fuel pump are electrically in series.

3. The system of claim **1**, wherein when the first switch is closed the first fuel pump and second fuel pump are electrically in parallel.

4. The system of claim **1**, further comprising a second switch arranged so that when the second switch is open current does not flow to either the first fuel pump or second fuel pump, and when the second switch is closed, current may flow to the first fuel pump and second fuel pump.

5. The system of claim **1**, wherein the first switch is connected between a negative lead of the first pump and a negative terminal adapted to be coupled to a power supply.

6. The system of claim **4**, wherein the second switch is coupled between a positive lead of the second pump and a positive terminal adapted to be coupled to a power supply.

7. The system of claim **1**, further comprising a controller coupled to the first switch configured to repeatedly open the first switch for a period of time and subsequently close the first switch for a period of time to control a fluid flow rate of the system to output an intermediate fluid flow rate from the system.

8. The system of claim **7**, wherein the controller provides a pulse width modulated signal to the first switch.

9. The system of claim **1**, further comprising a second switch arranged so that when the second switch is open and the first switch is open, power is supplied in series to the first fuel pump and to the second fuel pump.

10. The system of claim **1**, further comprising a second switch arranged so that when the second switch is closed and the first switch is closed, power is supplied in parallel to the first fuel pump and to the second fuel pump.

11. The system of claim **1**, further comprising a pulse width modulated controller coupled to the first node to change the voltage at the first node, and which also includes a diode coupled to the conductor between the first node and the second node, the diode conducting electricity from a negative terminal of the first pump to a positive terminal of the second pump.

12. The system of claim **1**, further comprising:

a fuel reservoir defining an interior having a first portion and a second portion;

an interior divider disposed within the fuel reservoir, and sectioning off the second portion from the first portion of the fuel reservoir, the first fuel pump position within the first portion and the second fuel pump positioned within the second portion;

two oppositely acting check valves coupled to the divider for controlling fuel flow between the first portion and the second portion of the interior;

a conduit communicating an output of the second fuel pump to an engine;

a passage communicating an output of the first fuel pump to the conduit, the passage having a check valve configured to permit fluid flow from the first fuel pump to the engine and to prevent reverse flow through the passage, the passage also having a relief valve configured to discharge fuel flow from the passage into the fuel reservoir; and

a pressure regulator connected to the conduit to regulate a pressure of fuel delivered to the engine.

13. A fuel system, comprising:

a first fuel pump and a first switch adapted to be coupled to a power supply;

a second fuel pump and a second switch adapted to be coupled to the power supply; and

a conductor between a first node between the first fuel pump and the first switch and a second node between the second switch and the second fuel pump, wherein when the second switch is open and the first switch is open, power is supplied in series to the first fuel pump and to the second fuel pump to output a low level fluid flow rate, and when the second switch is closed and the first switch is closed, power is supplied in parallel to the first fuel pump and to the second fuel pump to output a high level fluid flow rate.

14. The system of claim **13**, further comprising a controller coupled to the first switch and configured to repeatedly open the first switch for a period of time and subsequently close the first switch for a period of time to output an intermediate fluid flow rate of the system.

15. The system of claim **14**, wherein the controller provides a pulse width modulated signal to the first switch.

16. The system of claim **13**, further comprising a pulse width modulated controller coupled to the first node to change the voltage at the first node, and which also includes a diode coupled to the conductor between the first node and the second node, the diode conducting electricity from a negative terminal of the first pump to a positive terminal of the second pump.

17. The system of claim **13**, wherein the first switch is coupled between the negative lead of the first fuel pump and a negative power supply terminal, and the second switch is coupled between the positive lead of the second fuel pump and a positive power supply terminal.

18. The system of claim **13**, further comprising:

a fuel reservoir defining an interior having a first portion and a second portion;

an interior divider disposed within the fuel reservoir, and sectioning off the second portion from the first portion of the fuel reservoir, the first fuel pump position within the first portion and the second fuel pump positioned within the second portion;

two oppositely acting check valves coupled to the divider for controlling fuel flow between the first portion and the second portion of the interior;

a conduit communicating an output of the second fuel pump to an engine;

a passage communicating an output of the first fuel pump to the conduit, the passage having a check valve configured to permit fluid flow from the first fuel pump to the engine and to prevent reverse flow through the passage, the passage also having a relief valve configured to discharge fuel flow from the passage into the fuel reservoir; and

a pressure regulator connected to the conduit to regulate a pressure of fuel delivered to the engine.

19. A fuel system, comprising:

a fuel reservoir defining an interior having a first portion and a second portion;

an interior divider disposed within the fuel reservoir, and sectioning off the second portion from the first portion of the fuel reservoir;

two oppositely acting check valves coupled to the divider for controlling fuel flow between the first portion and the second portion of the interior;

a first fuel pump positioned within the first portion of the interior;

a second fuel pump positioned within the second portion of the interior;

a conduit communicating an output of the second fuel pump to an engine;

a passage communicating an output of the first fuel pump to the conduit, the passage having a check valve configured to permit fluid flow from the first fuel pump to the engine and to prevent reverse flow through the passage, the passage also having a relief valve configured to discharge fuel flow from the passage into the fuel reservoir;

a pressure regulator connected to the conduit to regulate a pressure of fuel delivered to the engine;

a power supply connected to the first and second pump;

a first switch connected between a negative lead of the first pump and a negative power supply terminal of the power supply;

a second switch connected between a positive lead of the second pump and a positive power supply terminal of the power supply;

a first node disposed between the first fuel pump and the first switch;

a second node disposed between the second switch and the second fuel pump;

a conductor configured to flow current:

in series to the first and second fuel pump when the first and second switches are open for a low output to the engine, and

in parallel to the first and second fuel pump fuel pump when the first and second switches are closed for a high output to the engine; and

a controller configured to increase or decrease the voltage at the first node, thus adjusting an electrical match point of the first and second fuel pumps so that the operating points of the individual pumps can be optimized to meet engine requirements under idle or partial load conditions.

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