March 27, 1962 D. L. PHILLIPS ET AL 3,026,928

FUEL DELIVERY SYSTEM

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Fig. 1

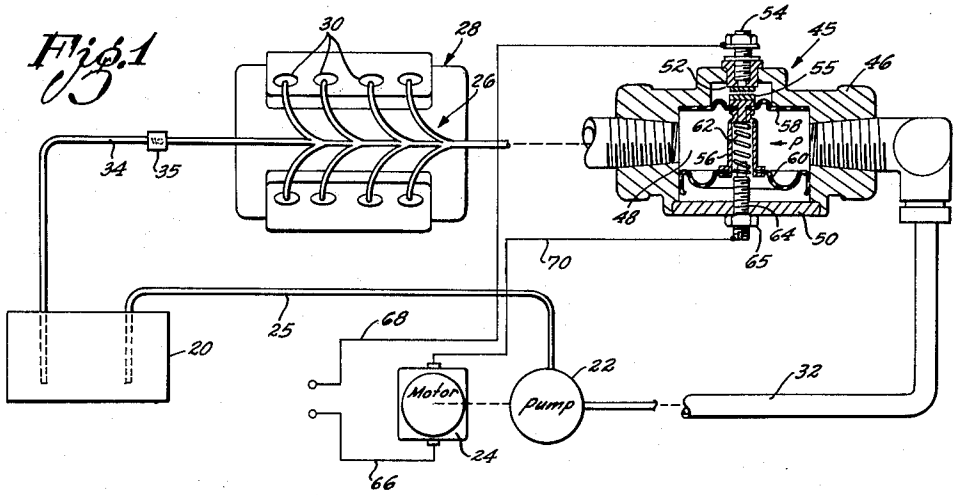


Fig. 2

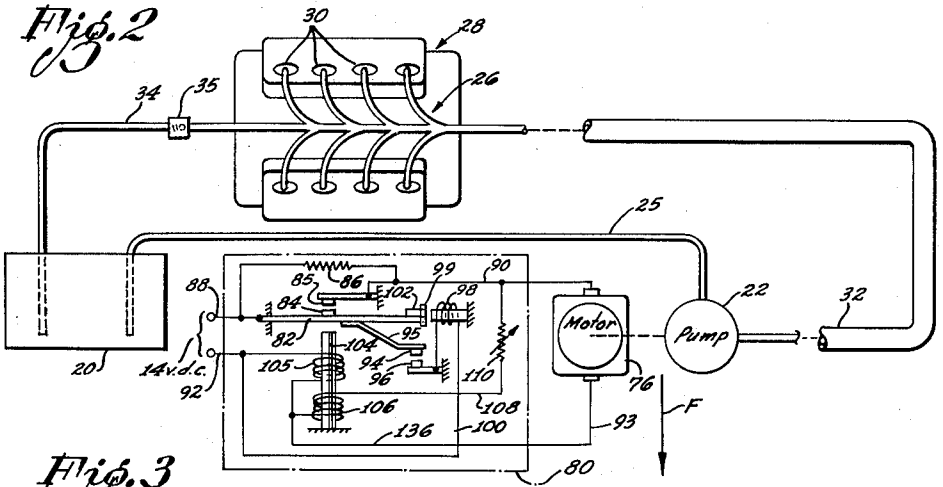
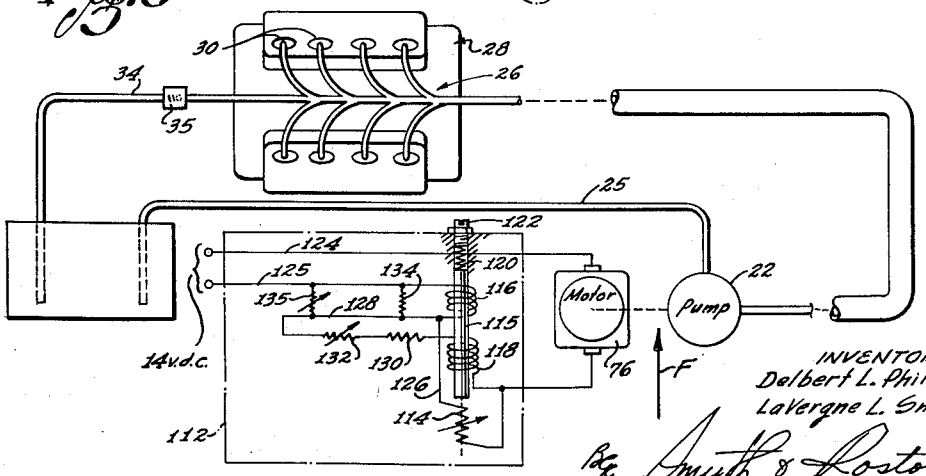


Fig. 3



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Fig. 4

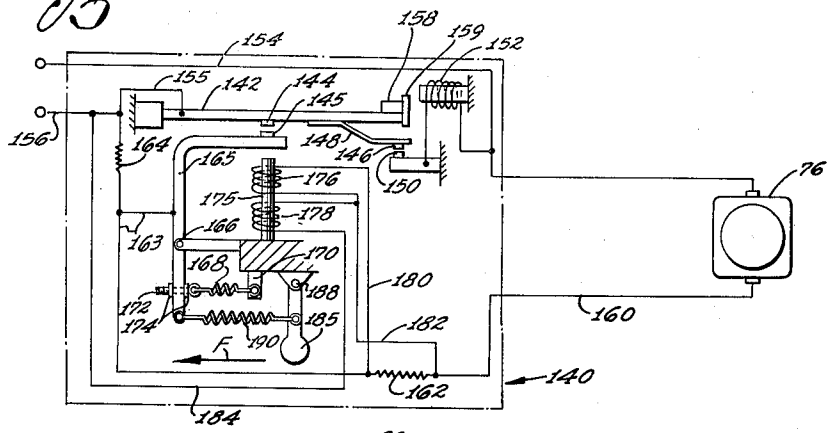
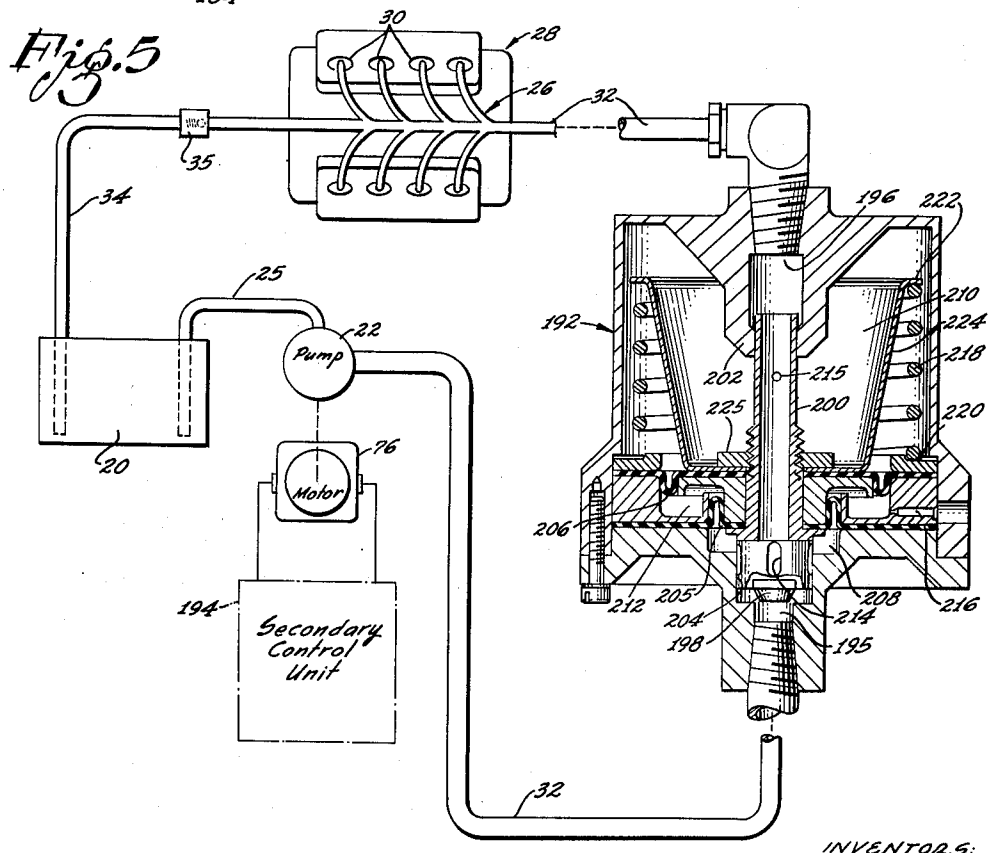


Fig. 5



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FUEL DELIVERY SYSTEM

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Fig. 6

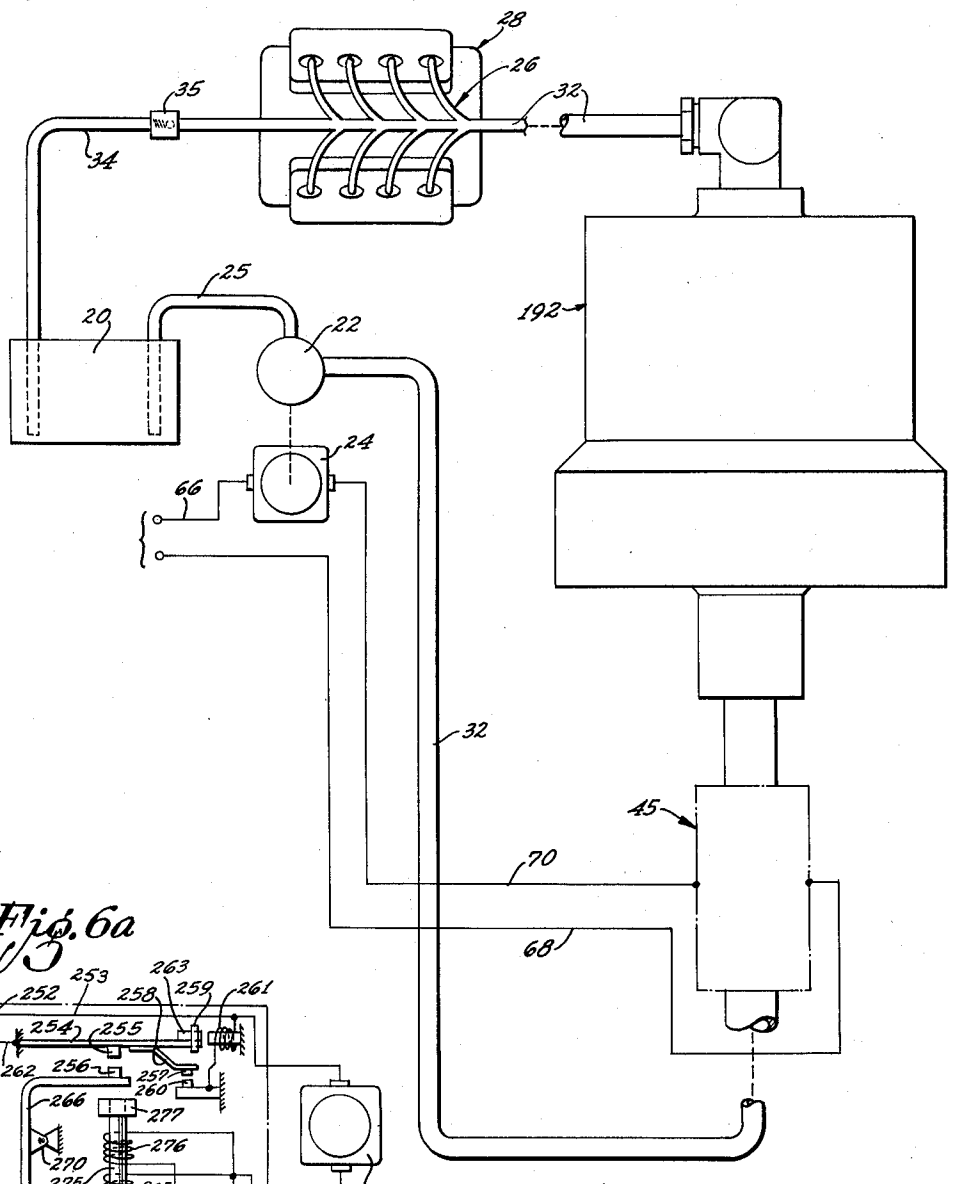
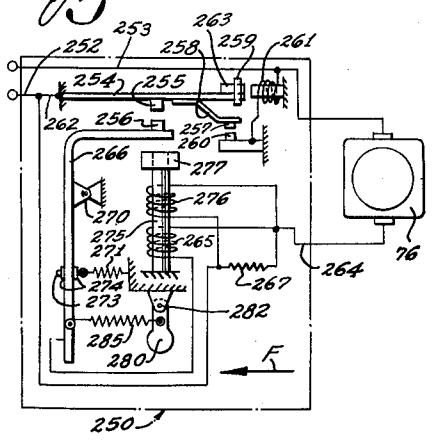


Fig. 6a



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FUEL DELIVERY SYSTEM

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Fig. 7

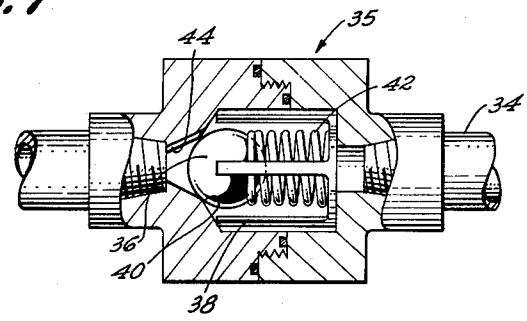


Fig. 8

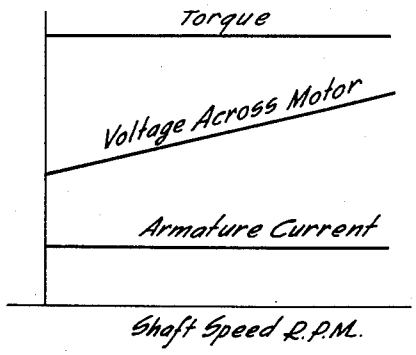


Fig. 9

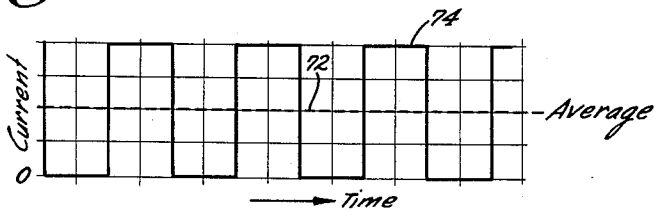
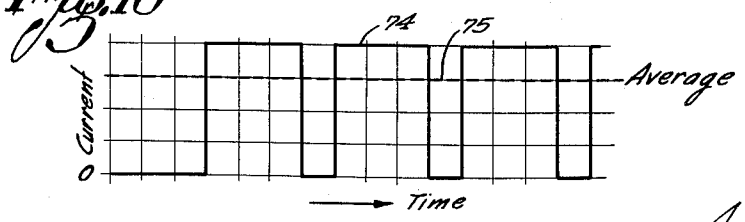


Fig. 10



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United States Patent Office 3,026,928
Patented Mar. 27, 1962

3,026,928
FUEL DELIVERY SYSTEM

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Filed Aug. 16, 1957, Ser. No. 678,616
20 Claims. (Cl. 158—36.3)

This invention relates to fuel systems wherein fuel is pumped through a fuel line from a fuel source directly to a fuel injection system of an engine or to the carburetor or carburetors of an engine or to the fuel distribution system of a turbine. The present practice of the invention refers particularly to such a fuel system for an internal combustion engine wherein the fuel is maintained under pressure for injection directly into the engine, with the periods of injection timed with the engine cycle and with the duration of the periods varied for control of the engine in accord with various conditions. Such a fuel system is disclosed in a paper published by the Society of Automotive Engineers, entitled "Electrojector Bendix Electronic Fuel Injection System" by A. H. Winkler and R. W. Sutton presented at the SAE annual meeting January 14–18, 1957. This published disclosure is hereby incorporated into the present disclosure by reference.

In the above-mentioned "Bendix" system, the injection of fuel into the plurality of cylinders of the engine is controlled by a corresponding plurality of solenoid injection valves which are operated by timed pulses of electric current. The duration of the pulses of current is not only varied for control of the power output of the engine but is also influenced by a number of automatic means to compensate for various factors under various operating conditions.

The fuel is delivered to the engine through a fuel line from a fuel tank and the fuel line is ordinarily of substantial length. In a typical present day automobile the fuel line may be of a length on the order of 15 to 20 feet. The fuel is forced into the fuel line by a pump between the fuel source and the engine and this pump functions to maintain the fuel line under the required pressure for injection of the fuel by the solenoid valves. For example, the required pressure at the solenoid injection valves in the "Bendix" system is 20 p.s.i.±½ p.s.i.

In the "Bendix" system, accurate control of the engine air to fuel ratio by variation of the duration of the pulses of electric current to the injection valves requires accurate maintenance of substantially constant pressure in the fuel line at the engine. The present invention is directed to this particular problem of maintaining the fuel pressure constant at the engine end of the fuel line by appropriate control of the relatively remote fuel pump near the inlet end of the fuel line. This problem arises primarily because the pressure drop in the fuel line between the pump and the engine varies with the rate of flow in the fuel line, the fuel pressure at the injection valves tending to drop whenever the fuel demand by the engine increases.

In general the invention meets this problem by varying the power applied to the pump in accord with changes in the rate of fuel flow through the fuel line to compensate for the changes in pressure drop in the fuel line. Thus, the pump applies a minimum input pressure to the fuel in the fuel line to maintain a predetermined fuel pressure at the engine under conditions of minimum fuel demand and increases this minimum input pressure with increasing fuel flow to maintain the desired predetermined fuel pressure at the engine.

One practice of the invention includes means to detect changes in pressure of the fuel at the engine together with means to vary the power applied to the pump in response

to the detected pressure changes. In other practices of the invention, the desired control is based on the speed of operation of the pump which, in turn, varies with the head against which the pump operates, which, in turn, varies with the rate of fuel consumption.

With reference to control of the power applied to the pump based on the speed of operation of the pump, a feature of the invention is the concept of actuating the pump by an electric motor in an arrangement in which the distribution of voltage in the motor circuit, including the voltage drop across the motor, varies with the motor speed and the further concept of varying the power applied to the motor in response to changes in this voltage distribution. Thus, when the motor speeds up with increased fuel flow, the power input to the motor is automatically increased to boost the motor torque in compensation for the increased pressure drop at the higher rate of flow through the fuel line. Preferably, the fuel pump is of the positive displacement type for maximum sensitivity to changes in the fuel demand by the engine.

Another feature of some practices of the invention is the concept of energizing the pump motor in a periodic manner with the periodicity of the motor energization varied in accord with changes in fuel consumption to compensate for changes in pressure drop in the fuel line. In one such control arrangement a vibratory switch is employed and the vibratory operation of the switch is varied in direct response to changes in the fuel pressure at the engine end of the fuel line. In another control arrangement, means is provided to vary the operation of the vibratory switch in response to changes in the motor speed.

The problem of maintaining substantially constant pressure at the engine end of the fuel line of an automotive vehicle is further complicated by the effect of inertia on the fuel in the fuel line when the vehicle is accelerated or decelerated. The mass of fuel in the fuel line resists such acceleration or deceleration with consequent effect on the fuel pressure at the engine end of the fuel line. At an acceleration loading of ½ G, the pressure change at the end of an 18-foot fuel line is in excess of 3 p.s.i. A further teaching of the invention in this regard is the provision of inertia-sensitive means for creating compensating changes in the power applied to the fuel pump. While such an inertia-sensing means may be a separate control component, for example, a pendulum, a feature of the invention is the further concept of employing a vibratory control switch for the pump motor, which switch is oriented for inherent responsiveness to inertia.

The various features and advantages of the different practices of the invention may be further understood by reference to the following detailed description and the accompanying drawings.

In the drawings, which are to be regarded as merely illustrative:

FIGURE 1 is a diagrammatic view illustrating one practice of the invention that employs a motor-controlling switch that senses the pressure in the fuel line at the engine, this switch being shown in section;

FIGURE 2 is a similar diagram illustrating a second embodiment of the invention wherein the motor is controlled by a vibratory switch that responds to changes in the voltage distribution in the motor circuit;

FIGURE 3 illustrates a third embodiment of the invention in which the current to the motor is controlled by a carbon pile resistance and the carbon pile resistance, in turn, responds to changes in the distribution of the voltage in the motor circuit;

FIGURE 4 is a diagram of a control unit for the motor that is employed in a fourth embodiment of the invention. A vibratory control switch in the motor circuit not only responds to changes in voltage distribution in the motor

circuit but also responds to inertia forces that tend to vary the pressure in the fuel line at the engine;

FIGURE 5 is a diagrammatic view illustrating another practice of the invention wherein a fine control is a pressure reducing valve near the end of the fuel system and a course control unit is any one of the electrical control units shown in FIGURES 2, 3 and 4;

FIGURE 6 is a diagram representing another practice of the invention which also employs a fine control in combination with a course control, the fine control being the pressure reducing valve of FIGURE 5 and the course control being the pressure sensitive switch of FIGURE 1;

FIGURE 6*a* is a diagram of a modification of the control unit shown in FIGURE 4;

FIGURE 7 is a view largely in cross section showing the construction of a relief valve with a bleeder by-pass that may be employed in the various practices of the invention;

FIGURE 8 is a graph indicating the characteristics of the motor that is employed in the preferred practices of the invention;

FIGURE 9 is a graph illustrating the cyclic operation of a vibratory motor switch when the fuel demand of the engine is relatively low; and

FIGURE 10 is a similar diagram indicating the behavior of the vibratory switch when the fuel demand of the engine is relatively high.

In the first practice of the invention illustrated by FIGURE 1, the fuel system includes: a fuel tank **20** containing a liquid fuel; a pump **22** driven by a motor **24**; a fuel passage means **25** from the fuel tank **20** to the intake of the pump **22**; a fuel distribution system or manifold **26** mounted on an internal combustion engine **28**; suitably controlled injection valves **30** for the various cylinders of the engine; a fuel line **32** for the discharge side of the pump **22** to the manifold **26**; a fuel passage means **34** from the manifold **26** for return flow to the fuel tank **20**; and suitable means **35** in the fuel passage means **34** to control or restrict the return of fuel to the tank. The means **35** to control return flow to the fuel tank **20** may be a bleeder means and/or a pressure relief valve.

Preferably the means **35** for controlling return flow to the fuel tank comprises a relief valve with a bleeder by-pass. FIGURE 7 shows by way of example a relief valve **35** that may be used in the fuel passage means **34**. The relief valve **35** is of a well known type in which a ball valve member **36** is confined by a cage **38** for movement relative to a valve seat **40**, the valve member being urged towards the valve seat by a suitable spring **42**. The bleeder by-pass consists simply of a small groove **44** in the valve seat **40** for leakage flow at an exceedingly small rate when the ball valve member is seated.

In a typical practice of the invention, the desired regulated fuel pressure at the manifold **26** may be, for example, 20 p.s.i. In such an installation the spring **42** in the relief valve **35** will be selected to yield at a somewhat higher pressure, say 20½ p.s.i., to open automatically whenever the pressure at the manifold **26** surges to that magnitude. The size of the groove **44** for the bleeder by-pass flow may, for example, be equivalent to a bore of a diameter of .013 inch. The main function of the bleeder by-pass is to purge the fuel line **32** of vapor and/or incondensable gases and an important advantage of employing a groove in a check valve for this purpose is that the bleeder by-pass is flushed every time the check valve opens in response to a pressure surge.

In this first practice of the invention, the motor **24** is controlled by a vibratory switch, generally designated **45**, the cyclic behavior of which responds to the pressure in the fuel line **32** at the manifold **26** in a manner to maintain the pressure substantially constant. For example, where the desired pressure level is approximately 20 p.s.i., the vibratory switch **45** will limit the range of pressure variation to ½ p.s.i., under normal operating conditions.

The vibratory pressure-sensitive switch **45** has a pipe-fitting body **46** forming a chamber **48** for flow of fuel therethrough, the chamber being accessible by removal of a closure member **50**. The vibratory switch has a fixed contact **52** that is insulated from the surrounding structure and is provided with a terminal screw **54** for connection to the motor circuit. A movable contact **55** for cooperation with the fixed contact **52** is carried by the end of a tubular member **56**. The tubular member **56** interconnects and is carried by a pair of diaphragms **58** and **60** that form opposite sides of the chamber **48** and these two diaphragms differ in their effective areas to cause the contact **55** to respond to pressure changes in the chamber **48**.

The diaphragm **58** has a relatively small pressure-responsive area and the diaphragm **60** has a substantially larger pressure-responsive area so that rise in the fluid pressure in the chamber **48** causes the contact **55** to move away from the fixed contact **52**. The movement of the contact **55** in the direction away from the fixed contact **52** is resisted by a suitable spring **62** that extends into the tubular member **56** and is in abutment against the end of a screw **64** for adjustment by the screw. The adjustment screw **64**, which is adapted for connection to the motor circuit, is mounted in the closure member **50** and is releasably retained at adjusted positions by a suitable lock nut **65**. The movable contact **55** is electrically connected with the adjustment screw **64** by the tubular member **56** and the spring **62**. Assuming that the pressure desired in the fuel line at the manifold **26** is 20 p.s.i., the spring **62** is adjusted to cause the two contacts **52** and **55** to close whenever the pressure in the chamber **48** drops below the selected magnitude and to open when the pressure rises above the selected magnitude.

Preferably the pump **22** is of a rotary positive displacement type that operates in a substantially pulsation-free manner so that the pressure in the chamber **48** at any given moment is determined by the torque of the motor **24** and the rate of fuel consumption by the various injection valves **30**. It is further contemplated that the motor **24** when continuously energized will be capable of delivering fuel to the manifold **26** at a rate in excess of the maximum fuel demand by the engine so that cyclic energization of the motor by the vibratory switch **45** will be adequate to meet all engine demands over the operating range.

The motor **24** is energized by a pair of leads **66** and **68** from a suitable E.M.F. source such as a battery and/or generator. Lead **66** is connected to one side of the motor **24** and lead **68** is connected to one side of the vibratory switch **45**, the second side of the vibratory switch being connected to the second side of the motor by a wire **70** to complete the motor circuit. Energization of the motor circuit is normally tied in with the ignition system of the internal combustion engine **28** so that the motor operates whenever the ignition circuit is closed.

Since the motor **24** is capable of delivering fuel at a rate in excess of the maximum demand by the internal combustion engine, energization of the motor under any operating condition results in a prompt rise in pressure in the switch chamber **48** to a magnitude to cause the movable contact **55** to retract from the fixed contact **52**. The resultant de-energization of the motor causes a prompt pressure drop in the switch chamber **48** because fuel is being continually consumed by the engine and bled through the by-pass of relief valve **35**. This pressure drop permits the spring **62** to move the contact **55** back to its circuit closing position. Thus, the described arrangement inherently causes the movable contact **55** to oscillate rapidly to open and close the motor circuit in the manner of a buzzer.

In the operation of such a vibratory switch, the frequency and/or the duration of the closed periods of the switch varies in accord with changes in the fuel demand and causes corresponding changes in the average rate

of current flow to the motor **24**. FIGURES 9 and 10 show, for example, how such a vibratory switch may operate at substantially constant frequency with the duration of the closed periods of the switch varied in response to changes in the fuel demand.

In FIGURE 9 the closed and open periods of the switch are substantially equal to result in an average flow of current at the level indicated by the broken line **72**, the motor current fluctuating between zero and a maximum value indicated by the line **74**. When the fuel demand of the engine **28** rises, the vibratory switch stays closed longer on each cycle to restore the fuel pressure to the critical magnitude with the result that the average current flow to the motor rises to the level of the broken line **75** in FIGURE 10. It is apparent that since the motor has substantial inertia the motor will run continuously as long as any fuel demand exists but will seek some equilibrium speed that will satisfy the engine demand. In FIGURES 9 and 10, it is assumed that the frequency of operation of the vibratory switch is constant, but there will probably be some variation in frequency in the operation of the switch in FIGURE 1 under maximum and minimum operating conditions.

The second embodiment of the invention illustrated by FIGURE 2 employs a fuel passage arrangement similar to the arrangement shown in FIGURE 1, as indicated by the use of corresponding numerals to indicate corresspondning parts. In this instance it is contemplated that a motor **76** will be used which is a D.C. two-pole permanent magnet type motor. The motor may be of any other type having similar operating characteristics, for example, a shunt wound motor. The desired characteristics of the motor are indicated in FIGURE 8 where it may be seen that with a constant output torque for the motor the applied armature current is also constant while the applied voltage to the motor is increased with the motor speed.

Since the motor **76** is directly connected to the positive displacement rotary pump **22**, the pressure maintained in the fuel line **32** immediately adjacent the discharge side of the pump is determined by the motor torque and, as indicated in FIGURE 8, the torque tends to be constant. With the torque at a magnitude to provide the desired pressure, say 20 p.s.i., at the manifold **26** at low fuel demands by the engine, any increase in the rate of fuel consumption results in corresponding increase in the motor speed without increase in the motor torque. Thus the motor inherently tends to maintain a given pressure at the pump end of the fuel line **32** at all rates of fuel demand by the engine. The pressure drop in the fuel line **32** varies with changes in the rate of flow, however, so that the pressure at the manifold **26** changes accordingly unless some provision is made for compensating changes in the motor torque. Since the pressure drop varies with the square of the velocity of flow, the maintenance of a constant motor torque will permit the pressure at the manifold to drop drastically at peak fuel demands. The present embodiment of the invention provides an automatic control unit represented by the rectangle **80** to compensate for this pressure drop by correspondingly increasing the torque of the motor in accord with increases in the rate of fuel consumption by the engine.

The functioning of the control unit **80** depends upon the fact that if the motor **76** is energized by a constant voltage source with resistance in series with the motor, the distribution of the voltage in the motor circuit, including the voltage drop across the motor, will vary with the speed of operation of the motor. Thus if the speed of the motor rises in response to an increase in the rate of fuel consumption by the engine, the voltage drop across the motor will rise in the manner indicated in FIGURE 8 and the voltage drop in the rest of the motor circuit will be reduced accordingly.

The purpose of the control unit **80** is to increase the torque to the motor in response to the progressive change in voltage distribution that occurs with progressive increase in the rate of operation of the motor. It is apparent that such a control unit may either respond directly to voltage changes across the motor or may respond directly to the inverse changes in voltage across resistance in the motor circuit. In this particular instance the control unit **80** responds directly to changes in the voltage drop across the motor **76**.

The portion of the motor circuit encompassed by the control unit **80** includes a vibratory switch of the buzzer type comprising a flexible magnetically responsive switch arm **82**. The switch arm **82** carries a contact **84** for cooperation with a fixed contact **85**, these two contacts being in series with the motor **76** and being shunted by a resistor **86**. The switch arm **82** is connected to one lead **88** from a constant voltage source for energization of the movable contact **84** and the fixed contact **85** is connected to one side of the motor by a wire **90**, the second side of the motor being connected to a second lead **92** from the voltage source through an electromagnet coil as will be explained later. It is apparent that when the vibratory motor switch is closed the motor is connected directly across the leads **88** and **92** for current flow to the motor at a maximum rate and that the opening of the vibratory switch reduces the current flow to the motor to some minimum value determined by the switch-shunting resistor **86**.

It is contemplated that the flexible switch arm **82** will vibrate at a relatively rapid rate with an essentially constant frequency and that the range of vibration of the switch will shift in response to the changes in voltage across the motor **76**. To cause the required continual vibration of the switch arm **82**, a contact **94** is mounted on the switch arm by a leaf spring **95** for cooperation with a fixed contact **96**. The switch arm **82** is resiliently biased to bring the movable contact **94** against the fixed contact **96** and an electromagnet **98** is arranged to attract the switch arm in the opposite direction to move the contact **94** away from the fixed contact **96**. One side of the electromagnet **98** is connected to the fixed contact **96** and the other side is connected by a wire **100** to the second lead **92**. It is apparent that the vibratory switch will operate in the manner of a buzzer since the electromagnet **98** will repeatedly attract the flexible switch arm to its open position with respect to current flow through the two contacts **94** and **96**. The flexible switch arm **82** has a shading coil **99** mounted thereon which has the function of maintaining the amplitude of the flexible arm essentially constant even though the voltage may vary and of causing the arm to vibrate at a non-resonant frequency. The shading coil **99** may be either a wire coil whose terminals are joined to form a closed loop or it may be a ring of conducting metal. Alternatively, the shading coil may be located on the core of the electromagnet **98**. Also, the flexible switch arm **82** may carry a small weight **102** which may be varied for adjustment of the frequency of vibration of the switch arm.

Control with respect to the average rate of current flow to the motor is exercised by a second regulating electromagnet having a fixed core **104** and two separate coils **105** and **106**. This regulating electromagnet is positioned to attract the flexible switch arm **82** in the direction to carry the movable contact **84** away from the fixed contact **85** but the magnetic attraction is merely strong enough to influence the behavior of the flexible switch arm without at any time causing the movable contact **84** to be held away from the fixed contact **85**. Thus the effect of the magnetic field exerted by the regulating electromagnet is to decrease the duration of the closed periods of the two contacts **84** and **85** thereby to decrease the average current flow which determines the motor torque. The strength of the regulating magnetic field is at maximum for minimum rates of fuel demand by the engine and is automatically progressively reduced with progressive increase in the rate of fuel demand.

The coil **105** of the regulating electromagnet is in series with the motor **76**, one end of the coil being connected to the wire **93** and the other end being connected to the lead **92**. Thus, the coil **105** is energized directly by the current flowing through the motor and therefore may be termed a current-sensing coil. The second coil **106** of the regulating electromagnet may be termed a voltage-sensing coil since it is connected across the motor **76** to respond directly to changes in the voltage across the motor. One side of the voltage-sensing coil **106** is connected to the previously mentioned wire **93** and the other side is connected by a wire **108** to an adjustable resistor **110**, the adjustable resistor in turn being connected to the wire **90** on the second side of the motor.

As the speed of operation of the motor **76** increases in response to increase in the fuel demand by the engine, the voltage across the motor increases with consequent increase in current flow through the voltage-sensing coil **106**. The polarity of the voltage-sensing coil **106** is reversed with respect to the polarity of the current-sensing coil **105** so that the magnetic field of the voltage-sensing coil bucks or opposes the magnetic field of the current-sensing coil. Consequently the increase in the current flow through the voltage-sensing coil reduces the strength of the regulating magnetic field that is coupled with the flexible switch arm **82**. With weakening of the regulating magnetic field the magnetic bias of the switch arm away from the fixed contact **85** is reduced and the duration of the closed periods of the two contacts **84** and **85** is increased for resulting increase in the average rate of current flow to the motor **76**. Thus the current flow to the motor is increased to increase the torque of the motor automatically as required to compensate for pressure drop in the fuel line **32** between the pump **22** and the engine manifold **26**.

The fuel system shown in FIGURE 3 is identical to the fuel system shown in FIGURE 2 except for a control unit **112** that is substituted for the control unit **80**.

The control unit **112** includes a variable resistor in the form of a carbon pile **114** and also includes regulating electromagnetic means in the form of a regulating solenoid having a movable core or armature **115** and two coils **116** and **118**. A suitable spring **120** under adjustable compression by a screw **122** presses against the armature **115** in a direction to increase the pressure on the carbon pile **114**.

One side of the motor **76** is connected directly to one lead **124** from a constant voltage source. One end of the coil **116** is connected to the second lead **125** and the second side of the coil **116** is connected by a wire **126** to one side of the carbon pile **114**. The same side of the coil **116** is also connected to one side of the coil **118** by a wire **128** and two resistors **130** and **132** in series, the resistor **132** being a trimming resistor. A fixed resistor **134** and a trimming resistor **135** shunt the coil **116** in parallel, the two resistors interconnecting lead **125** and wire **128**. The second side of the coil **118** and the second side of the carbon pile **114** are connected to the second side of the motor **76**.

It is apparent that the coil **116** is in series with the carbon pile **114** and the motor **76** and therefore functions as a current-sensing coil. The polarity of the coil **116** is such that the magnetic field created thereby acts on the movable armature **115** in the same direction as the spring **120** to exert pressure on the carbon pile. Since the electrical resistance of the carbon pile varies inversely with this pressure the tendency is for the spring **120** and the magnetic field of the current-sensing coil **116** to increase the flow of current to the motor. Coil **118**, which is a voltage-sensing coil, is in series with the two resistors **130** and **132** and shunts the carbon pile **114**.

When the voltage across the motor **76** rises in response to increased fuel consumption by the engine, the voltage in the rest of the motor circuit drops accordingly and the current flow through coil **118** drops correspondingly.

The coil **118** is of opposite polartiy to the coil **116** to buck or oppose the magnetic field of the coil **116** and therefore reduction of current flow through the coil **118** caused by reduced voltage across the coil with increasing motor speed results in increased pressure against the carbon pile **114** to step up the current flow to the motor. Since the carbon pile **114** is in parallel with the voltage-sensing coil **118**, the resuling reduction in resistance by the carbon pile results in diversion of current flow from the voltage-sensing coil **118** to the carbon pile. This diversion of current further weakens the magnetic field to amplify the current boosting effect. Thus, whenever the motor speeds up in response to increased fuel demand, the control unit **112** correspondingly boosts the motor torque to compensate for the increased pressure drop in the fuel line.

FIGURE 4 indicates the construction of a control unit **140** that may be substituted for either the control unit **112** of FIGURE 3 or the control unit **80** of FIGURE 2. The control unit **140** includes a vibratory switch comprising a resilient switch arm **142** carrying a contact **144** for cooperation with a contact **145**. The switch arm **142** is operated in the manner of a buzzer and for this purpose carries a contact **146** on a leaf spring **148** to cooperate with a fixed contact **150**, the switch arm being resiliently biased to bring the contact **146** against the contact **150**. An electromagnet **152** for attracting the switch arm **142** away from the fixed contact **150** is connected at one end to one lead **154** from the constant voltage source and is connected at the other end to the fixed contact **150**. The circuit for the electromaget **152** is completed by a wire **155** from the switch arm **142** to the second lead **156** from the constant voltage source. The switch arm **142** is provided with a weight **158** for adjusting its frequency of oscillation and preferably has a shading coil **159** for the purpose of maintaining an essentially constant amplitude of oscillation at a non-resonant frequency. An alternative location for the shading coil **159** is on the end of the core of the electromagnet **152** adjacent to the switch arm **142**.

The control unit **140** accomplishes its purpose by shifting the contact **145** relative to the range of oscillation of the switch arm **142** to vary the proportion of the oscillating movement of the switch arm at which the contact **145** abuts the contact **144**. Moving the contact **145** upward further into the range of oscillation of the switch arm **142** increases the duration of the periods during which the contacts **144** and **145** are closed and thus increases the average current flow through the motor **76**.

One side of the motor **76** is connected to the lead **154**. The other side of the motor is connected by a wire **160** to a resistor **162** and this resistor is connected in turn to a wire **163** and a resistor **164**. The wire **163** is connected to an angular lever **165** on which the contact **145** is mounted. Thus, the motor circuit is completed by wire **163**, angular lever **165**, contact **145**, contact **144**, switch arm **142** and wire **155** from the switch arm to the lead **156**. When the contacts **144** and **145** are open, reduced current is supplied to the motor through the shunting resistor **164**.

The angular lever **165** is mounted on a fixed pivot **166** and is provided with a suitable tension spring **168** which tends to rock the lever in a direction to move the contact **145** upward into the range of oscillation of the switch arm **142**. One end of the tension spring **168** is anchored to a fixed stud **170** and the other end is attached to the angular lever **165** by an eye screw **172** which extends through a smooth bore in the angular lever and is adjustably secured therein by a pair of lock nuts **174**.

A regulating electromagnet having a fixed core **175** is positioned to attract the lever **165** in opposition to the tension of the spring **168** thereby to cause the contact **145** to take an equilibrium position. The magnetic field of this electromagnet is weakened in response to voltage changes in the circuit to prolong the closed periods of the contacts **144** and **145** to increase the torque of the motor

76 automatically whenever the fuel demand by the engine increases. For this purpose the electromagnet has a current-sensing coil 176 and a voltage-sensing coil 178, both coils being of the same polarity whereby their magnetic fields are additive in attracting the angular lever 165 in opposition to the tension spring 168.

One end of the current-sensing coil 176 is connected by a wire 180 with one end of the resistor 162 and the other end of the coil is connected by a wire 182 to the second end of the resistor. Thus substantially the full current to the motor 76 passes through the current-sensing coil 176 to make the strength of its magnetic field substantially constant.

One end of the voltage-sensing coil 178 is connected to the wire 182 and the other end is connected by a wire 184 to the lead 156. Since the voltage-sensing coil 178 is in parallel with resistors 162 and 164, its voltage drop and consequently the strength of its magnetic field varies with the voltage drop across the two resistors.

When the motor 76 speeds up, the consequent increase in the voltage drop across the motor causes corresponding decrease in the voltage drop across the two resistors 162 and 164 with consequent weakening of the magnetic field of the voltage-sensing coil 178. The weakening of this magnetic field permits the tension spring 168 to shift the contact 145 further into the range of oscillation of the vibratory switch arm 142 to boost the average current to the motor and thereby increase the motor torque to compensate for the increase pressure drop in the fuel line.

As heretofore pointed out, when a fuel system of the present type is employed on an automotive vehicle with the fuel line extending generally longitudinally of the vehicle, the desired steady pressure in the fuel line at the engine may be defeated by the inertia of the fuel in the fuel line when the vehicle is accelerated or decelerated. One method of compensating for the inertia of the fuel in the fuel line is to orient the weighted vibratory switch arm 82 in FIGURE 2 so that the vibratory movement of the switch arm will be influenced by acceleration and deceleration of the vehicle, the direction of forward travel of the vehicle being indicated by the arrow F. Thus if the fuel is pumped forward through the fuel line 32 the vibratory switch arm 82 may be positioned forward of the fixed contact 85 whereby the inertia of the switch arm will tend to bias the switch arm towards the fixed contact 85 for momentary increase in the current to the motor to compensate for the inertia of the fuel in the fuel line. The same purpose may be accomplished in the use of the control unit 112 of FIGURE 3 where the direction of forward travel of the vehicle is indicated by the arrow F. The movable armature is positioned to extend forward from the carbon pile 114 whereby the inertia of the movable armature will increase the pressure on the carbon pile when the automotive vehicle is accelerated and vice versa.

FIGURE 4 shows how the control unit 140 may be provided with a pendulum 185 to compensate for the effect of inertia on the fuel in a forwardly extending fuel line. The arrow F in FIGURE 4 indicates the direction of forward travel of the vehicle and it is apparent that when the vehicle is accelerated or decelerated in its forward travel the inertia of the pendulum 185 will cause the pendulum to swing about its fixed pivot 188. The pendulum 185 is connected to the angular lever 165 in a yielding manner by a suitable push-pull spring 190, the spring acting in compression to resist forward movement of the pendulum relative to the angular lever and acting in tension to resist rearward movement of the pendulum. It is apparent that when the automotive vehicle is accelerated, for example, the rearward swing of the pendulum 185 will exert pull on the spring 190 to cause the contact 145 to be moved further into the range of oscillation of the switch arm 142 thereby to increase the current flow to the motor in compensation for the effect of inertia on the fuel in the fuel line.

FIGURE 5 shows a fuel system incorporating the same general arrangement as heretofore described, corresponding parts being indicated by corresponding numbers. In this instance control of the fuel line pressure is carried out in two stages. What may be termed a fine control is employed in the final stage near the fuel distribution manifold 26 and what may be termed a course control is employed for the first stage at the pump end of the fuel line. The fine control comprises a pressure-reducing valve generally designated 192 and the course control is a control unit 194 for the motor 76. The control unit 194 may be the control unit 80 of the system shown in FIGURE 2 or the control unit 112 of the system shown in FIGURE 3 or the control unit 140 shown in FIGURE 4.

The pressure-reducing valve 192 has an inlet port 195, an outlet port 196 and a valve member 198 to seat at the inlet port, the valve member being carried by a tubular stem 200 through which fluid flows from the inlet port to the outlet port. The upper end of the tubular stem 200 is slidingly confined by a cylindrical guide 202 and the lower end of the stem is slidingly guided by a surrounding cylindrical portion 204 of the valve body.

The tubular stem 200 extends through and is attached to a pair of spaced diaphragms 205 and 206 which divide the interior of the pressure-reducing valve into an upstream chamber 208 at the inlet port 195, a downstream chamber 210 and an intermediate diaphragm chamber 212. The upstream chamber 208 is in continuous communication with the interior of the tubular valve stem 200 by virtue of a plurality of elongated apertures 214 in the valve stem upstream from the diaphragm 205 and in like manner the downstream chamber 210 communicates with the interior of the tubular valve stem through a plurality of apertures 215 in the valve stem positioned downstream from the diaphragm 206. The intermediate diaphragm chamber 212 has a small vent passage 216 to a pressure reference which, in this example, is the atmosphere. The pressure reference may be any desirable source for such pressures as absolute pressure, inlet manifold pressure et cetera.

The tubular valve stem 200 together with the diaphragm 206 presents a relatively large area to the fluid in the downstream chamber 210 and the valve stem together with the diaphragm 205 presents a substantially smaller area to the fluid in the upstream chamber 208. With the pressure equalized between the upstream chamber 208 and the downstream chamber 210 the differential pressure on the tubular valve stem created by the chambers 208, 210 and 212 will urge the valve stem towards the inlet port 195 to close the valve member 198 against its seat.

This differential pressure is opposed by a coil spring 218 that seats on an annular shoulder 220. The spring presses upward against the flange 222 of a flared skirt member 224 that is anchored to the tubular valve stem 200 by a nut 225. The purpose of the spring 218 is to determine and control the final fuel pressure at the end of a fuel line in the region of the distribution manifold 26. The valve member 198 under control of the two diaphragms will open and close automatically to seek an intermediate open position that will maintain a given equilibrium pressure in the two chambers 208 and 210, the magnitude of the given pressure being determined by the spring 218. This equilibrium pressure is the pressure desired at the distribution manifold 26 and in this instance is 20 p.s.i. The described pressure-reducing valve 192 will act automatically to prevent a departure of more than ½ p.s.i from this desired pressure.

The course control afforded by the control unit 194 cooperates with the motor 76 to maintain a somewhat higher pressure at the upstream pump end of the fuel line 32, say a pressure of 25 p.s.i. so that the pressure at the inlet port 195 of the pressure-reducing valve is always at least slightly more than the desired ultimate pressure

of 20 p.s.i. When the fuel demand by the engine increases and the motor and pump speed up to meet this increase, the course control unit **194** automatically increases the current flow to the motor to raise the motor torque in compensation for the increased pressure drop in the fuel line **32** between the pump **22** and the pressure-reducing valve **192**. Thus the course control unit **194** tends to maintain a constant pressure at the inlet port **195** of the pressure-reducing valve **192**, this constant pressure being above the selected pressure of 20 p.s.i.

The fuel system shown in FIGURE 6 is largely identical with the previously described fuel system shown in FIGURE 1 as indicated by the use of corresponding numerals to indicate corresponding parts. The system shown in FIGURE 6 differs only in the employment of the previously described pressure-reducing valve **192** at the end of the fuel line **32** between the vibratory pressure-responsive switch **45** and the fuel distribution manifold **26**. Here again, the pressure-reducing valve **192** is used as the fine control for the desired ultimate pressure of 20 p.s.i. and the pressure-sensitive vibratory switch **45** functions as a course upstream control to maintain a pressure on the upstream side of the pressure-reducing valve that is at least slightly greater than the selected pressure of 20 p.s.i. When an increase in the fuel demand by the engine tends to cause reduction of pressure at the inlet of the pressure-reducing valve in consequence of the pressure drop between the pump **22** and the pressure-reducing valve, the vibratory switch **45** automatically functions in the manner heretofore described to increase the average current to the motor for raising the motor torque thereby to raise the pressure in the fuel line at the pump to compensate for the increased pressure drop in the fuel line.

FIGURE 6*a* is a diagram of a control unit for the motor similar to that of FIGURE 4 which is employed in another embodiment of the invention. A vibratory control switch in the motor circuit is responsive to changes in the voltage distribution in the motor circuit and to inertia forces that tend to vary the pressure in the fuel line at the engine.

FIGURE 6*a* indicates the construction of a control unit **250** which may be substituted for the control unit **140** of FIGURE 4, or the control unit **112** of FIGURE 3, or the control unit **80** of FIGURE 2. The control unit **250** includes a vibratory switch comprising a resilient switch arm **254** carrying a contact **255** for cooperation with a contact **256**. The switch arm **254** is operated in the manner of a buzzer and for this purpose carries a contact **257** on a leaf spring **258** to cooperate with a fixed contact **260**, the switch arm being resiliently biased to bring the contact **257** against the contact **260**. An electromagnet **261** for attracting the switch arm **254** away from the fixed contact **260** is connected at one end to one lead **253** from the constant voltage source and is connected at the other end to the fixed contact **260**. The circuit for the electromagnet **261** is completed by a wire **262** from the switch arm **254** to the second lead **252** from the constant voltage source. The switch arm **254** is provided with a weight **263** for adjusting its frequency of oscillation and a shading coil **259** for the purpose of maintaining an essentially constant amplitude of oscillation at a nonresonant frequency. The shading coil **259** is preferably mounted on the switch arm **254** as shown but may be mounted at or near the end of the core of the electromagnet **261** adjacent the switch arm **254**.

The control unit **250** accomplishes its purpose by shifting the contact **256** relative to the range of oscillation of the switch arm **254** to vary the proportion of the oscillating movement of the switch arm during which the contact **256** abuts the contact **255**. Moving the contact **256** further upward into the range of oscillation of the switch arm **254** increases the duration of the periods during which the contacts **255** and **256** are closed and thus increases the average current flow through the motor **76**.

One side of the motor **76** is connected to the lead **253**. The other side of the motor is connected by a wire **264** to a current sensing coil **265** of a multiple coil regulating electromagnet and this current sensing coil is connected in turn to an angular lever **266** on which the contact **256** is mounted. Thus the motor circuit is completed by coil **265**, angular lever **266**, contact **256**, contact **255**, switch arm **254**, and wire **262** from the switch arm to the lead **252**. When the contacts **255** and **256** are open, reduced current is supplied to the motor through the shunting resistor **267**.

The angular lever **266** is mounted on a fixed pivot **270** and is provided with a suitable tension spring **271** which tends to rock the lever in a direction to move the contact **256** upward into the range of oscillation of the switch arm **254**. One end of the tension spring **271** is anchored to a fixed support, and the other end is attached to the angular lever **266** by an eye screw **273** which extends through a smooth bore in the angular lever and is adjustably secured therein by a pair of lock nuts **274**.

The multiple coil regulating electromagnet has a fixed core **275** and is positioned to attract the lever **266** in opposition to the tension of the spring **271** thereby to cause the contact **256** to take an equilibrium position. It is contemplated that the magnetic field of this regulating electromagnet will be weakened in response to voltage changes in the circuit to prolong the closed periods of the contacts **255** and **256** thereby to increase the torque and speed of the motor **76** automatically whenever the fuel demand by the engine increases. For this purpose the regulating electromagnet has the previously mentioned current-sensing coil **265**, a voltage-sensing coil **276**, and preferably a shading coil **277**. The sensing coils **265** and **276** are of the same polarity, whereby their magnetic fields are additive in attracting the angular lever **266** in opposition to the tension spring **271**.

The current sensing coil **265** is connected in series with the contacts **255** and **256** and, therefore, has a pulsating current therein. To dampen the pulsing effect of the current sensing coil **265** and allow the lever **266** to maintain an equilibrium position, the shading coil **277** is mounted at or near the tip of the fixed core **275**. The induced current in the shading coil **277** resists and slows the pulsing effect of the current sensing coil **265** on the magnetic force in the core **275** and thereby tends to maintain the magnetic force of the core at a constant level, so that the lever **266** will maintain an equilibrium position rather than continuously moving or "hunting." Although the shading coil damps the pulsing effect of the current coil **265**, it does not materially alter the action of the electromagnet in shifting the lever **266** in response to a change in the state of the fuel system, such as an increase or decrease in engine demand level. Although it is preferable to utilize the shading coil **277** in this form of the invention, it may be omitted under certain conditions.

The voltage-sensing coil **276** is connected in parallel with the resistor **267** and, therefore, its voltage drop, and consequently the strength of its magnetic field, varies with the voltage drop across the resistor.

When the motor **76** speeds up, the consequent increase in the voltage drop across the motor causes corresponding decrease in the voltage drop across the resistor **267** with consequent weakening of the magnetic field of the voltage-sensing coil **276**. The weakening of this magnetic field permits the tension spring **271** to shift the contact **256** further into the range of oscillation of the vibratory switch arm **254** to boost the average current to the motor and thereby increase the motor torque to compensate for the increased pressure drop in the fuel line.

As previously discussed, in an automotive vehicular application, the desired steady fuel pressure in the distribution system may be upset during acceleration and deceleration by the inertia of the fuel in the fuel line. The

control unit **250** is provided with a pendulum **280** to compensate for the inertia effect on the fuel in the fuel line. The arrow F indicates the direction of forward travel of the vehicle, and it is apparent that, when the vehicle is accelerated or decelerated in its forward travel, the inertia of the pendulum **280** will cause the pendulum to swing about its fixed pivot **282**. The pendulum **280** is connected to the angular lever **266** in a yielding manner by a suitable push-pull spring **285**, the spring acting in compression to resist forward movement of the pendulum relative to the angular lever and acting in tension to resist rearward movement of the pendulum. It is apparent that when the automotive vehicle is accelerated, for example, the rearward swing of the pendulum **280** will exert pull on the spring **285** to cause the contact **256** to be moved further into the range of oscillation of the switch arm **254** thereby to increase the current flow to the motor in compensation for the effect of inertia on the fuel in the fuel line.

Our description in specific detail of selected practices of the invention will suggest various changes, substitutions and other departures from our disclosure within the spirit and scope of the appended claims.

We claim:

1. In a fuel system wherein fuel is forced through a fuel line from a fuel source to an engine or the like, means to maintain pressure in the fuel line at the engine, comprising: a pump to force fuel through said fuel line, said pump being of the type in which increase in pump speed increases the rate of fluid flow; a motor to operate said pump; a circuit to energize said motor to maintain said line under pressure whereby the speed of operation of the motor varies with the rate of fuel consumption by said engine; and means directly responsive to electrical energy changes in said circuit to vary said circuit for increasing the torque of the motor when the motor speed increases thereby to compensate for pressure drop in the fuel line.

2. A combination as set forth in claim 1 in which said circuit includes resistance whereby the distribution of the voltage in the circuit including the voltage drop across the motor varies with the speed of operation of the motor; and in which said means to increase the torque of the motor when the motor speed increases is directly responsive to changes in the distribution of the voltage in the circuit.

3. A combination as set forth in claim 1 in which said engine or the like is carried by an automotive vehicle with the fuel line extending generally longitudinally of the vehicle; and in which said responsive means is also responsive to inertia to compensate for the inertia of the fuel in said fuel line when said vehicle is accelerated and decelerated.

4. A combination as set forth in claim 3 which includes pendulum means operatively connected with said responsive means to sense acceleration and deceleration of the vehicle.

5. A combination as set forth in claim 1 which includes a switch controlling at least a portion of the current in said circuit whereby closing the switch increases the motor current and opening the switch decreases the motor current; which further includes means to open and close said switch in a vibratory manner whereby the average current delivered to the motor depends on the frequency and duration of the closed periods of the switch; and in which said means that is directly responsive to electrical energy changes in the circuit varies the vibratory operation of the switch.

6. A combination as set forth in claim 5 in which said circuit includes resistance whereby the distribution of the voltage in the circuit including the voltage drop across the motor varies with the speed of operation of the motor; and in which said responsive means responds to changes in said distribution of the voltage drop to increase the average current through the motor when the speed of operation of the motor increases.

7. A combination as set forth in claim 5 in which said circuit includes resistance in series with the motor whereby the voltage drop across said resistance is reduced by increase in the motor speed; and in which said responsive means varies the vibratory operation of said switch to increase the average current through the motor in response to reduction in the voltage drop across at least a portion of said resistance.

8. A combination as set forth in claim 5 in which said switch is responsive to magnetism; and in which said responsive means comprises a variable electro-magnet magnetically coupled with said switch, said electromagnet being responsive to changes in current flow in said circuit with changes in the speed of operation of said motor.

9. A combination as set forth in claim 5 in which said vibratory switch is oriented to respond to inertia forces generally longitudinally of the vehicle.

10. A combination as set forth in claim 5 which includes: a resistance in said circuit whereby distribution of the voltage in the circuit including the voltage drop across the motor varies with the speed of operation of the motor; means to open and close said switch in a vibratory manner whereby the average current delivered to the motor depends on the frequency and duration of the closed periods of the switch; and a variable electro-magnet coupled with said switch to vary the vibratory operation of the switch thereby to vary the average current delivered to the motor, said electromagnet having two energizing coils, one of said coils being responsive to current flow in said circuit, the other of said coils being responsive to changes in the voltage distribution in the circuit to increase the average current through the motor when the motor speed increases and vice versa.

11. A combination as set forth in claim 10 in which said two coils are bucking coils and in which said voltage-responsive coil responds directly to changes in the voltage drop across the motor.

12. A combination as set forth in claim 10 in which said voltage-responsive coil is of the same polarity as the current-responsive coil, the magnetic fields of both coils biasing the vibrating switch towards its open position; and in which said voltage-responsive coil responds to the voltage drop across at least a portion of said resistance whereby the magnetic field of the voltage-responsive coil is reduced in response to increase in the motor speed thereby to reduce the magnetic biasing of said switch towards its closed position for increasing the average current to the motor.

13. A combination as set forth in claim 5 in which said circuit includes resistance whereby the distribution of the voltage in the circuit including the voltage drop across the motor varies with the speed of operation of the motor; in which said switch includes a switch member, a first switch contact carried by the switch member, and a second switch contact adjacent the switch member to cooperate with said first contact to open at least a portion of the circuit for at least lowering the current flow through the motor in a periodic manner with the ratio of the duration of the closed contact periods relative to the duration of the open contact periods determined by the position of said second contact relative to the range of vibratory reciprocation of the switch member; and which includes an electro-magnet to change the position of said second switch contact relative to said range in response to changes in the voltage distribution in said circuit to increase the average current to the motor when the motor speed increases and vice versa.

14. A combination as set forth in claim 13 in which said engine is carried by an automotive vehicle with said fuel line extending generally longitudinally of the vehicle; and which includes inertia-responsive means to shift said second switch contact to compensate for the effect of inertia on the fuel in said fuel line when said vehicle is accelerated and decelerated.

15. A combination as set forth in claim 14 in which

said inertia-responsive means comprises a pendulum; and which includes spring means to resist attraction of said second switch contact by said electromagnet.

16. In a fuel system wherein fuel is forced through a fuel line from a fuel source to an engine or the like, means to maintain pressure in the fuel line at the engine comprising: a pump to force fuel through said fuel line, said pump being of the type in which increase in pump speed increases the rate of fluid flow; a motor to operate said pump; a circuit to energize said motor with the voltage across the motor varying with the speed of the motor; and means directly responsive to increase in the voltage across the motor to increase the torque of the motor to compensate for changes in pressure drop in the fuel line with changes in the velocity of flow through the fuel line.

17. In a fuel system for an engine or the like wherein fluid fuel is maintained under pressure in a fuel line for release to the engine, means to introduce fluid fuel from a supply source into the fuel line at a point spaced from the engine with automatic compensation for changes in pressure drop between said point and the engine at different rates of fuel demand by the engine, said means comprising: a pump to force the fuel from said source into the fuel line, said pump being of the type in which increase in pump speed increases the rate of fluid flow; an electric motor to drive said pump whereby the speed of the motor increases with dropping pressure on the discharge side of the pump; a circuit to energize said motor including resistance in series with the motor whereby the distribution of the voltage in the circuit including the voltage drop across the motor varies with the speed of operation of the motor; a variable resistor in said circuit to vary the current flow therethrough thereby to vary the torque of the motor; and electromagnetic means to control said resistor, said electromagnetic means being responsive to the changes of said distribution of voltage to boost the current flow to the motor when the motor speed increases and vice versa.

18. A combination as set forth in claim 17 in which said variable resistor is a carbon pile; and in which said electromagnet varies the pressure on said carbon pile.

19. A combination as set forth in claim 18 in which said electromagnet has a first coil responsive to current flow through said circuit and a second bucking coil responsive to the voltage drop across at least a portion of said resistance, the magnetic field of said second coil tending to decrease the pressure on said carbon pile, said second coil being in parallel with said carbon pile.

20. In a fuel system for an engine or the like wherein fluid fuel is maintained under pressure in a fuel line for release to the engine, means to introduce fluid fuel from a supply course into the fuel line at a point spaced from the engine with automatic compensation for changes in pressure drop between said point and the engine at different rates of fuel demand by the engine, said means comprising: a pump to force the fuel from said source into the fuel line, said pump being of the type in which increase in pump speed increases the rate of fluid flow; a motor operatively connected to said pump whereby the speed of the motor increases with dropping pressure on the discharge side of the pump, said motor having an output torque to maintain the pressure in the fuel line above the pressure required at said engine; a circuit to energize said motor, said circuit including a resistance in series with said motor whereby the distribution of the voltage in the circuit including the voltage drop across the motor varies with the speed of operation of the motor; a pressure-reducing valve in the fuel line near the engine to reduce said pressure in the fuel line to the desired pressure; and means directly responsive to change in the distribution of the voltage in said circuit to increase the motor torque to compensate for increase in pressure drop between the motor and the pressure-reducing valve when the speed of the motor increases.

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