Oct. 22, 1968 E. W. HINES 3,406,670

MAGNETOSTRICTIVELY ACTUATED FUEL SYSTEM FOR ENGINES

Filed March 10, 1966 2 Sheets-Sheet 1

FIG. 1

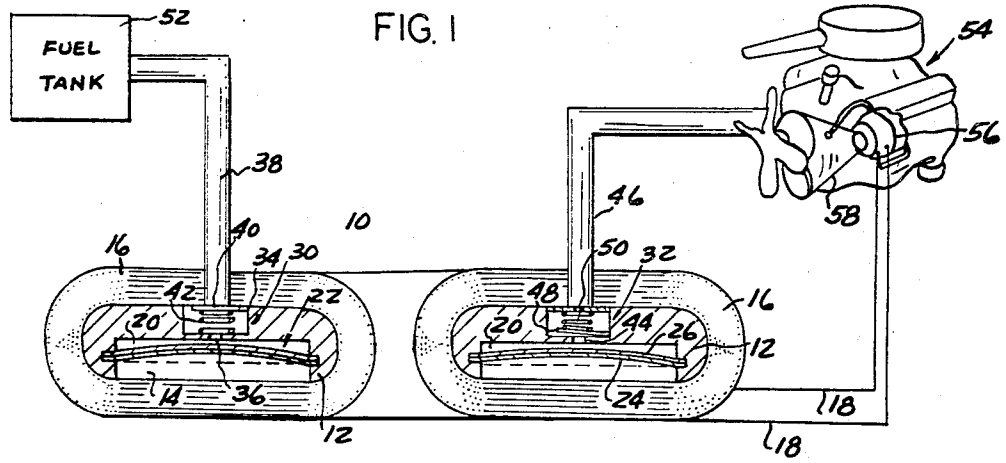


FIG. 2

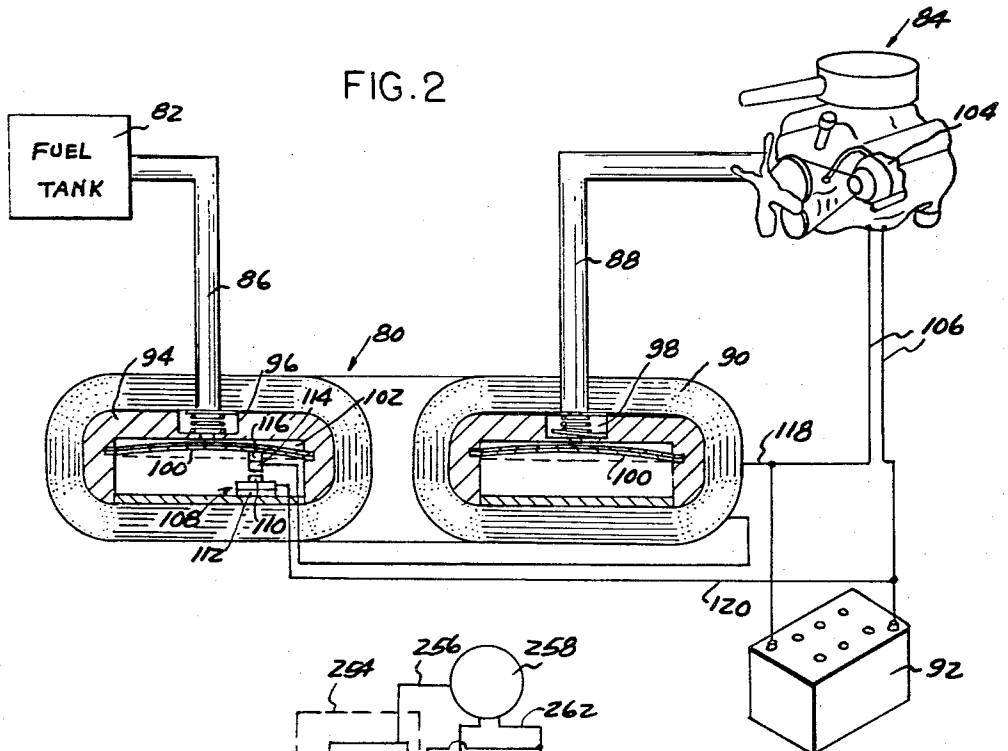
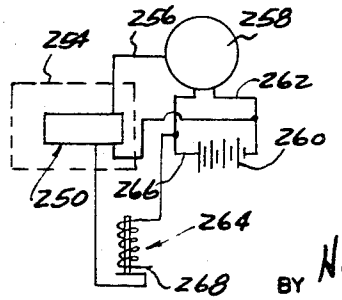


FIG. 5



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MAGNETOSTRICTIVELY ACTUATED FUEL SYSTEM FOR ENGINES

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FIG. 3

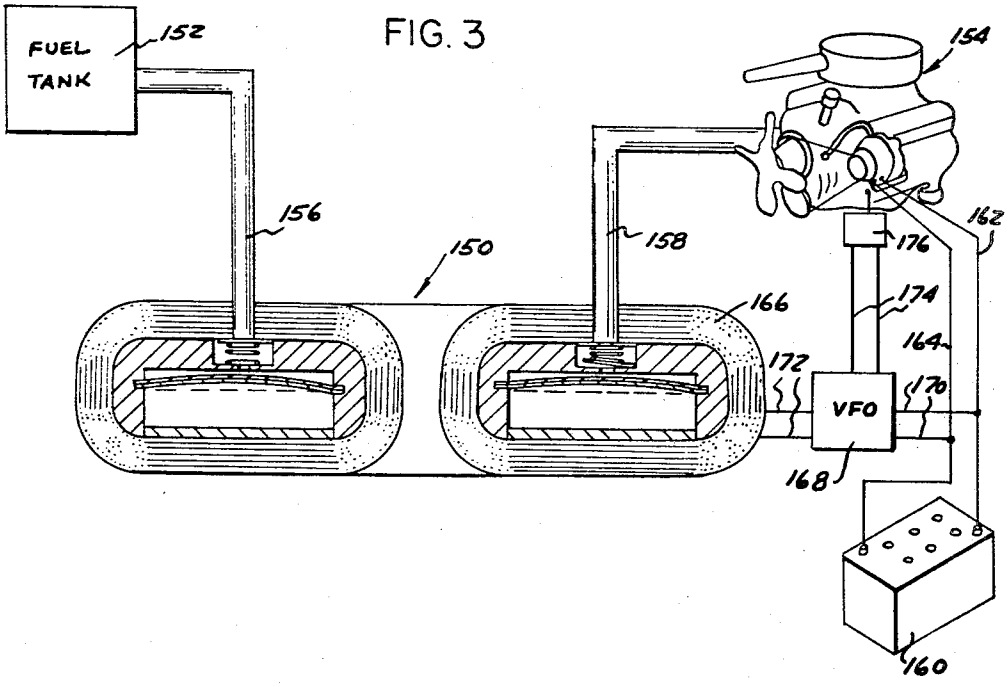
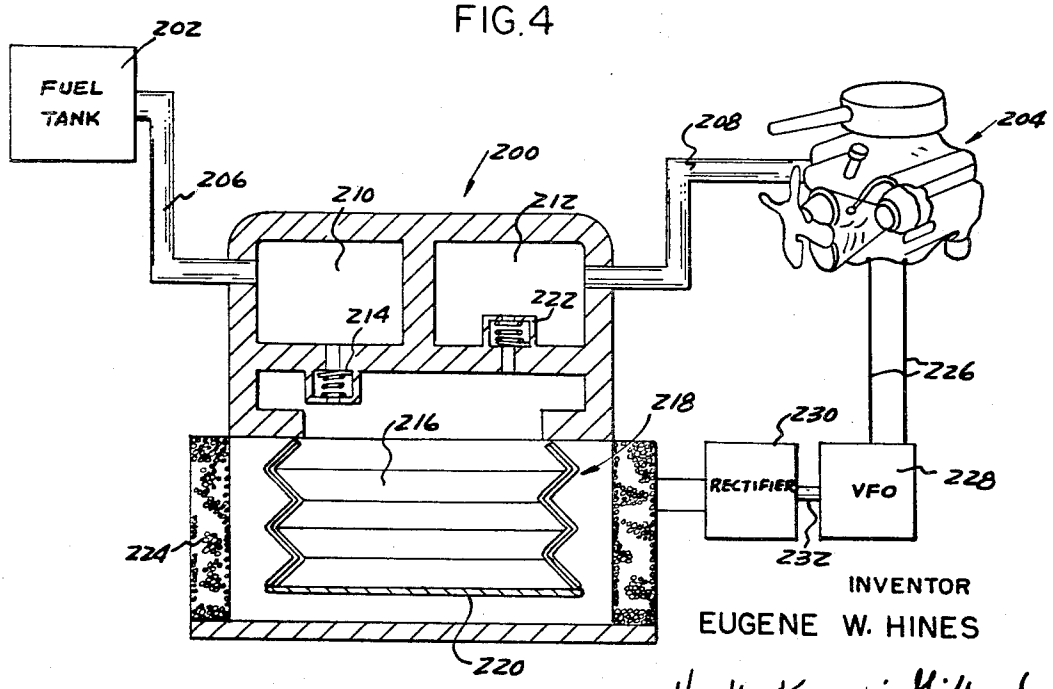


FIG. 4



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MAGNETOSTRICTIVELY ACTUATED FUEL SYSTEM FOR ENGINES

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12 Claims. (Cl. 123—139)

ABSTRACT OF THE DISCLOSURE

A fuel system for an internal combustion engine employing a laminated magnetostrictive diaphragm as the pumping member in the fuel pump for delivering fuel to the engine. Various means are disclosed for creating a magnetic field for the diaphragm which varies as a function of an operating parameter of the engine.

This invention relates to a system for providing fuel to the combustion chamber of an internal combustion system, employing a fuel pump which uses the dimensional changes exhibited by a magnetostrictive element under a varying magnetic field as a source of pumping power and more particularly to such a system which controls the amount of fluid provided to the engine in accordance with varying operating conditions thereof.

In my previously filed patent application entitled, "Fluid Pumps Energized by Magnetostrictive Action," executed Feb. 7, 1966, I have disclosed a class of pumps which utilize actuating members formed of two metallic parts having different coefficients of magnetostrictive expansion, laminated together in such a manner so as to provide a relatively large motion of the member in response to variations in applied magnetic fields. These members utilize the extremely small dimensional changes which occur in ferromagnetic materials when magnetic fields are applied to them to provide magnified output motions through appreciable distances which are suitable for use as actuating members in pumps. For example, a nickel rod one foot long will only change its length by about 3.6 ten thousandths of an inch when a magnetic field of optimum intensity is applied to it. However, a much shorter laminated magnetostrictive device, formed in accordance with my previous invention may move through as much as one half to one inch when suitably formed and energized.

My previous application disclosed one form of fuel pump wherein a compartment having inlet and outlet valves was bounded on one side by a diaphragm formed of laminated magnetostrictive material. The laminations were formed of materials having different coefficients of magnetostrictive dimensional variation so that when a magnetic field was applied to the diaphragm one of the laminations would tend to enlarge more than the other, and resultant forces would be created at the boundary between the two which would cause the diaphragm to bend. This bending would vary the dimensions of the fluid compartment, and upon the removal of the field, the diaphragm would flex back to its original position. The resulting variations in the dimension of the fluid compartment would draw fluid through the intake valve as the compartment decreased in volume. Other variations of my invention disclosed in the previous application employed magnetostrictive flexing members to move normal diaphragms, and a magnetostrictive bellows member which formed a wall of a chamber.

The present invention contemplates use of these pumps as elements in fuel systems for engines, wherein control is exerted over the flow of volume in accordance with the operating parameters of the engine. For example, in one of the embodiments which will be subsequently disclosed in detail, an engine employing an alternator as the source of electric power utilizes a magnetostrictive pump of the type employing a diaphragm formed of the laminated material to pump gasoline or other fuel from the fuel tank to the engine carburetor or combustion chamber. The current creating the magnetic field which causes the diaphragm to flex is provided from the alternator, either directly or through pulse-shaping circuitry. The diaphragm of the pump undergoes one flexure for each half cycle of alternating current which is applied to it from the alternator. Since the output frequency of the current from the alternator is a function of the engine speed, the pump provides a fuel flow to the engine which is also proportional to engine speed. This condition is highly desirable since the engine consumes fuel at a rate which is a function of its speed, among other variables, and the provision of excess fuel to the engine causes unsatisfactory combustion conditions. Thus, the system is a closed, generally self-regulating one, with the quantity of fuel provided to the engine being controlled by the speed of the engine through use of the alternator.

In another embodiment to the invention which is also subsequently disclosed in detail, the pump magnetic coil is powered from the battery. However, in order for the pump to respectively flex, it must be supplied with an interrupted direct current, and the battery current is passed through a set of breaker contact points which utilize the motion of the diaphragm itself to provide their mechanical actuation.

These and other embodiments which are subsequently disclosed may employ control systems which measure various of the engine parameters in order to modify the shape and frequency of the currents applied to the coils which generate the magnetic fields for the magnetostrictive elements. One manner in which I have found that the alternating current applied to the pump coil may be advantageously modified is by rectifying it to only provide a half wave signal to the coil. This provides a more adequate time for the diaphragm to relax and prevents undesirable flutter effects which might otherwise occur at relatively high frequencies at rapid engine speeds. Another manner in which the alternating currents signal may be modified is by shaping it into the square waves, having relatively sharp rise and decay times with definite spaces between them. Such shapes provide a more definite actuation to the diaphragm.

The control may take the form of altering the frequency of current provided to the coil or of deleting selected half waves of power. The control is derived from the operating parameters of the engine itself, such as the manifold vacuum, the engine speed or possibly the engine exhaust content. These conditions may be sensed by transducers to provide electrical signals which modify the power applied to the magnetic coil or mechanical devices may be used to modify the control signal in accordance with the engine parameters.

It is therefore seen to be a primary object of the present invention to provide a fuel system for an internal combustion engine employing a pump actuated by the variation in dimensional changes of pump elements as the result of applied magnetic fields wherein the magnetic fields are produced and controlled by normal engine components.

Another object is to provide such a system where the power for the pump is provided by an alternator so that the pumping volume is a function of the engine speed.

Still another object is to provide such a system wherein the pump is powered by a direct current which is interrupted by breakers controlled by the pump elements motion.

A still further object is to provide a system wherein the power applied to the pump coil is modified in accordance

with various engine parameters to control the fuel flow in such a manner as to optimize the engine performance.

Other objects, advantages and applications of the present invention will be made apparent by the following detailed descriptions of several embodiments of the invention. The descriptions make reference to the accompanying drawings in which:

FIGURE 1 is a generally schematic view of a first embodiment of the invention employing a toroidal pump having an annular magnetostrictive diaphragm, the diaphragm being actuated by a coil which is energized from the alternator of the engine;

FIGURE 2 is a schematic view of a second embodiment of the invention wherein the pump is powered by a battery through a set of breakers actuated by the diaphragm motion;

FIGURE 3 is a schematic diagram of a third embodiment of the invention wherein the current applied to the pump coil is derived from the battery through a variable frequency oscillator which has a frequency controlled in accordance with engine parameters;

FIGURE 4 is a schematic view of a fourth embodiment of the invention employing a bellows type pump formed of magnetostrictive elements wherein the controlled signal to the magnetic coil of the pump is derived from the alternator through a variable frequency oscillator and a pulse shaping circuit; and

FIGURE 5 is a schematic view of a fifth embodiment of my invention wherein the pump is located within the fuel tank and external breaker points convert the output of a storage battery into a suitable condition for application to the pump coil.

Referring to the drawings, in FIGURE 1, a pump formed in accordance with my previous invention is generally indicated at **10**. The pump is shown in schematic cross-section through the center of its toroidal housing **12**. The housing may be formed of plastic with an open bottom **14**. A toroidal coil magnet wire **16** is wound about the housing. The ends of the coil **16** are brought out in two leads **18**. The housing has a central downward directed cavity **20** with rectangular walls, which opens on the section **14**. An annular diaphragm, generally indicated at **22** extends across the opening **14** with its inner and outer edge imbedded in the opposed sidewalls of the housing **12**.

The diaphragm **22** is formed of two annular metal sheets **24** and **26** laminated together by any of the methods which are employed to form bimetallic laminations for thermostats and the like. At least one of the materials **24** and **26** is a ferromagnetic metal alloy. Preferably both of the layers are ferromagnetic, but it is essential that they be different alloys so as to exhibit different rates of magnetostrictive dimensional changes when subjected to a magnetic field.

For example, the layer **24** may be formed of an alloy containing 12% aluminum and 88% iron; while the layer **26** is formed of an alloy of 90% cobalt and 10% iron. Alternatively, the layer **24** might be formed of pure nickel, with the layer **26** formed of 20% nickel, 6% magnesium and 74% iron. Each of these alloys exhibits different dimensional changes upon being subjected to a magnetic field. The resultant boundary layer forces created when a laminated unit formed of two of the materials is subjected to a magnetic field produces a bowing of the diaphragm **22** in a manner which will be subsequently described.

It should be understood that this laminated magnetostrictive structure, as well as the equivalent structures contained in the following embodiments might be replaced with three layer laminated structures of a type manufactured by the W. M. Chase Co. of Detroit, Mich. Such three layer structures exhibit no thermostatic dimensional changes and are therefore suitable for use in high temperature locations, such as under an automotive engine hood.

The diaphragm **22** closes off the upper section of the annular cavity **20** so as to form a compartment which is fluid tight except for an inlet valve, generally indicated at **30** and an outlet valve, generally indicated at **32**. Each of these valves are located in the top wall of the housing **12**. The inlet valve includes a cylindrical cavity **34** in the wall **16**, communicating with the volume of the chamber **20**, above the diaphragm **22** by means of an opening **36**. An inlet tube **38** communicates with the top of the valve **30** and its passage to the chamber **34** is normally closed off by a hinged leaf valve **40**, which is biased by a spring **42**. The valve allows flow from the line **38** into the volume **20**, but prevents flow in a reverse direction. The outlet valve **32** communicates with the volume **20** through a passage **44** and provides output through a tube **46**. A hinged leaf valve **48** under the bias of a spring **50**, allows flow from the volume **20** through the outlet line **46**, but prevents flow in a reverse direction.

The inlet line **38** connects to a fuel tank **52** containing gasoline or other suitable fuel for an automotive engine generally indicated at **54**. The outlet line **56** is shown schematically connected to the engine **54** so as to provide fuel to its carburetor. It should be recognized that in other varieties of engine fuel might be directed into a combustion chamber of the engine. Also, in a multicylinder engine, a plurality of pumps of the general nature of **10** might be associated with each of the chambers so as to provide a fuel injection type of action.

The engine **54** includes an alternator **56** driven by a belt **58** from the output shaft of the engine. This alternator may be of the type commonly employed with present automotive engines in connection with rectifying diodes, to provide power for the engine electrical system. The alternator **56** is connected to the coil **16** of the pump **10** by means of the coil end leads **18**.

Each time the alternator **56** provides a half cycle of alternating current power, a current flows through the coil **16**, creating a magnetic field which has substantial components transversely through the diaphragm **22**. This magnetic field causes a magnetostrictive dimensional change in both of the layers of the diaphragm. The dimensional changes create forces at the inner face which cause the diaphragm to bow in the manner illustrated between its visible and phantom positions as shown in FIGURE 1. When the alternating current half cycle goes back to zero, the magnetic field collapses and the diaphragm **22** resumes its initial position.

The magnetostrictive changes are independent of the direction of the magnetic field so that two effective power pulses will be provided to the pump for each full cycle of generation of the alternator **56**.

On each pump stroke, as the diaphragm flexed from the position shown in full lines in FIGURE 1, to its phantom position, wherein it is relaxed, the volume of the chamber **20** will expand and fuel will be drawn in through the intake valve **40** from the fuel tank **52**. As the magnetic field is again imposed, causing the diaphragm to bow into the position shown in full lines in FIGURE 1, the volume of the fluid chamber **22** will contract, expelling fuel through the outlet valve **32** in the line **46** to the engine.

Since the frequency of the alternating current provided by the alternator **56** is a function of engine speed, the number of power strokes provided by the pump and the fluid flow to the engine will also be a function of engine speed. This is a highly desirable condition since the engine's fuel consumption is a function of its speed. In the manner which will be disclosed by the subsequent embodiments, the fuel flow to the engine might be modified in accordance with other performance factors.

The embodiment of the invention disclosed in FIGURE 2, employs a magnetostrictive fuel pump, generally indicated at **80**, which is essentially the same variety as the pump **10** in FIGURE 1. The pump **88** is connected between a fuel tank **82** and an engine generally indicated at **84** by means of an inlet line **86** and an outlet line **88**

respectively. In this embodiment, the pump coil **90** is powered by a storage battery **92** of the vehicle electric system rather than the alternator of the first embodiment. The pump again has a toroidal plastic housing **94**, an inlet valve **96**, an outlet valve **98** and a laminated bimetal magnetostrictive diaphragm **100** of annular shape closing off the upper portion of a volume **102** of the chamber.

The electrical system of the engine **84** may employ a generator **104** rather than an alternator. The generator and the engine **84** generally are shown schematically connected to the storage battery **92** by means of lines **106**. Since the pump **80** cannot operate from straight direct current, but must rather have an alternating current or pulsed direct current input, a pair of breaker points generally indicated at **108** are connected in series between the battery **92** and the two leads **118** and **120** of the coil ends.

The breaker **108** includes one contact member **110** which is fixedly supported on an insulated base **112** on the bottom of the housing **94**, which makes electrical contact with the lead **120**. The other contact **114** is fitted on an insulated base **116** disposed on the bottom of the diaphragm **100**. The position of the contact **114** with respect to the contact **110**, is such that when a magnetic field is imposed on the field **90**, and the diaphragm **100** is flexed into the position shown in full lines in FIGURE 2, the contacts **110** and **114** are separated; however, when the magnetic field is removed and the diaphragm **100** returns to the unflexed position shown in phantom lines in FIGURE 2, contact is made between the breaker points **110** and **114**. When contact is made between the breaker points, current flows through the coil **90**, from the battery **92**, creating a magnetic field which again flexes the diaphragm into its bowed position, and opens the breaker points. This results in a self-energizing type of action which provides repeated direct current pulses to the coil **90** and produces a fuel flow from the tank through the pump into the engine **84**.

It should be recognized that various mechanical or electrical control means might be imposed for varying the position of the contact members relative to one another so as to vary the flexure of the diaphragm required to open them, and accordingly modify the frequency of operation of the pump. This might be done in accordance with variations in the operating parameters of the engine as will subsequently be described.

In the embodiment of the invention disclosed in FIGURE 3, a toroidal laminated magnetostrictive pump, generally indicated at **150**, of the same nature as that employed in FIGURE 1, is connected between a fuel tank **152** and an engine, generally indicated at **154**, by means of an inlet line **156** and an outlet line **158**, respectively. The engine has a storage battery **160** providing power for its electrical system. The battery **160** is connected to the engine by a pair of leads **162** and **164**.

Rather than employing breaker points to convert the direct current of the battery into a pulsating direct current suitable for energizing coil **166** of the pump, a variable frequency oscillator **168** is employed for that purpose. The oscillator receives direct current power from the battery on lines **170** and provides a pulsed output to the coil **166** through lines **172**. While the oscillator **168** might have a fixed output frequency, it is preferably a variable frequency oscillator of the type wherein the frequency is controlled by an electrical signal provided on lines **174**. These lines are connected to a transducer **176** which is associated with the engine **154**. This transducer measures some parameter of operation of the engine, such as the manifold vacuum, the various constituents of the crank case of exhaust gases, or other factors which are influenced by the volume of fuel provided to the engine by the pump **150**. The transducer **176** provides a control signal to the variable frequency oscillator which varies the frequency of its pulses outlet provided on the lines **172** to the coil **166** and thereby varies the fuel flow provided on the line **158** to the engine.

The exact construction of variable frequency oscillator is considered to be well within the skill of electrical engineers and its circuitry is therefore not disclosed in detail. The oscillator might be of the general variety illustrated in FIGURE 4 of United States Patent No. 3,122,691 with suitable auxiliary circuitry. The pump **200** shown in schematic cross-section, has an upper head divided into two separated fluid chambers **210** and **212**. The input line **206** connects to the chamber **210** which acts as an inlet storage chamber while the chamber **212** connects to the outlet line **208**. The chamber **210** connects through a unidirectional inlet valve **214** to a pumping chamber **216** which has its lower section formed by a closed bellows arrangement, generally indicated at **218**.

The bellows **218** has side walls formed of the laminated magnetostrictive sheet of the same type employed in the previous embodiments. The sheet is wound into a cylindrical configuration and is bent and rebent into a bellows shape. The points of bend are relatively flexible with respect to the balance of the sheet. The lower end of the bellows is closed off by a solid disc **220**. The volume **216** enclosed by the bellows **218** provides output through a valve **222** to the outlet storage chamber **212**. The bellows **218** is surrounded by a coil of magnet wire **224** which imposes a magnetic field on the magnetostrictive material of the bellows at such time as current passes through the coil. The resulting magnetostrictive action causes the material of the bellows lamination to dimensionally change, causing stresses at the boundary areas. These stresses result in a bowing of each of the individual cylindrical segments of the bellows, and cause the bellows to contract, raising the base member **220** and diminishing the volume of the fluid chamber **216**. When the current is terminated through the coil **224**, the magnetic field collapses and the materials of the magnetostrictive laminations return to their original dimensions causing the bellows to relax, lowering the bottom disc **220** and enlarging the volume of the chamber.

As the volume of the chamber **216** contracts as a result of imposition of the magnetic field via the coil **224**, fluid is expelled from the chamber **216** through the outlet valve **222** to the storage chamber **212** and through the line **208** to the engine. When the magnetic field decays as the result of removal of the current from the coil **224**, the expansion of the bellows draws fluid in through the valve **214** from the inlet storage chamber **210** and from the fuel tank **202** through the line **206**.

Power for energizing the coil **224** is derived from the engine electrical system as shown schematically through lines **226** which connect the electrical system to an oscillator **228**. This may be a constant frequency oscillator or its frequency may be controlled in accordance with other operating parameters in the same manner as the embodiment to FIGURE 3.

The output of the variable frequency oscillator **228** is applied to a half wave rectifier **230** by leads **232**. It has been found that at high frequencies of operation of the pump, if a full wave alternating current cycle is applied to the pump, the bellows type diaphragm will not have sufficient time to return to its original length in the short period of current decay between half cycles. Accordingly, half wave rectifier acts to impose half wave current on the coil, and therefore the coil vibrates at the oscillator frequency rather than at twice the oscillator frequency. The rectifier **230** might also be selectively controlled from various engine parameters, including the quantity of fuel in the carburetor flow chamber, to modify the alternating current signal applied from the units **228** to the coil **224**.

In the embodiment of FIGURE 5, a pump of the previous type described, schematically illustrated at **250**, is itself disposed within the confines of a fuel tank **252**. Such an arrangement is being employed in certain automobiles today and provides important advantages in terms of the

length of the connection between the fuel tank **254** and the pump. The output of the pump is provided through a line **256** to an engine **258**. The engine electrical supply includes a storage battery **260** connected to the engine through lines **262**. The storage battery also connects to the coil of the pump **250** through a breaker point arrangement generally indicated at **264**. This includes a coil **266**, wound about an iron core, and a pair of breaker points **268** which automatically vibrate to open and close the circuit as power is applied to the coil in a well known manner. The breaker points provide the interrupted direct current necessary for actuation of the pump.

Having thus described my invention, I claim:

1. An engine fuel system of the type described, comprising, in combination: a fuel tank, an internal combustion engine capable of being powered by fuel contained in the tank; an electrical system powered by said engine; a fuel pump having a pumping chamber formed in part by a magnetostrictive driving element formed of at least two sheets of material laminated together, at least one of which is ferromagnetic so that said element is capable of flexing under the influence of a magnetic field, and a coil associated with said driving element operative to impose a magnetic field on the element at such time as current flows through the coil; and connections between the electrical system and the coil operative to cause currents to flow through the coil so as to energize the driving element; and fluid circuitry connecting the fluid tank to the pump and the pump to the engine, whereby the pump provides fuel to the engine from the fuel tank at such time as it is energized by the electrical system of the engine.

2. The system of claim **1** wherein the electrical system for the engine includes an alternator, rotated by the engine, and providing an alternating current output and the alternating current output is applied to the pump coil, whereby the pump volume varies with the speed of the engine.

3. The system of claim **1** wherein the electrical system for the engine includes a storage battery and the power for the pump coil is derived from the storage battery through suitable means for varying the current magnitude over a period of time.

4. The system of claim **3** wherein the means for varying the current magnitude constitutes a set of breaker points, disposed in series between the storage battery and the coil, the opening and closing of the breaker points being energized by the motion of the pump driving element.

5. The system of claim **3** wherein the pump is disposed within the fuel tank and the means for varying the current magnitude over a period of time comprises a set of breaker points, connected between the pump coil and the storage battery and operative to repetitively interrupt the current applied from the storage battery to the coil.

6. The system of claim **3** wherein the means for varying the current magnitude over a period of time constitutes a variable frequency oscillator powered by the storage battery.

7. The system of claim **1**, wherein means are provided for varying the electrical power applied from the engine electrical system to the coil in accordance with an operating parameter of the enigne.

8. A system of the type described, comprising, in combination: a fuel tank, an engine; a pump connected between the fuel tank and the engine, said pump including an enclosed volume partially bounded by a magnetostrictive member consisting of a laminated diaphragm including at least one sheet of ferromagnetic material, a coil operative to pass a magnetic field through at least sections of said magnetostrictive member when a current passes through the coil, and an inlet valve and an outlet valve communicating with said volume, whereby the magnetostrictive member undergoes dimensional charges as a result of variations of the magnetic field applied by the coil, causing the enclosed volume to vary so as to provide a pumping action between the fuel tank and the engine, an electrical system for said engine; and means for providing power to said coil from said electrical system.

9. The system of claim **8** wherein the electrical system includes an alternator, driven by the shaft of the engine, the alternator providing an alternating current power which energizes the pump coil whereby the pump provides a fluid volume to the engine which is proportional to the engine speed.

10. The system of claim **1** wherein means are provided for varying the nature of the current applied to the pump coil from the electrical system in accordance with an operating parameter of the engine.

11. The system of claim **9** wherein rectifying means are provided for rectifying the alternating current power applied from the alternator to the pump coil, so as to provide half wave power to the pump coil.

12. A system of the type described, comprising, in combination:

(a) a fuel tank;

(b) an engine capable of being operated by fuel from said tank;

(c) a fuel pump comprising:

(1) means defining a pumping chamber having inlet means for receiving fuel from said tank, an outlet means for discharging said fuel to said engine;

(2) valve means disposed in relation to said inlet means and said outlet means to allow fuel flow into said pumping chamber only through said inlet means and out of said pumping chamber only through said outlet means;

(3) a magnetostrictive actuating member consisting of a diaphragm formed of a pair of laminated sheets having differing magnetostrictive properties and forming one of the boundaries of said pumping chamber so that changes in the position of said actuating member varies the volume of said chamber so as to provide a pumping action between said fuel tank and said engine;

(4) a wire coil magnetically coupled to at least a portion of said actuating mmeber, and

(d) means for passing a variable electric current through said coil so as to create a variable magnetic field comprising:

(1) an electrical system powered by said engine, including a storage battery;

(2) a variable frequency oscillator for providing a pulsating electrical current to said coil under the influence of a control signal; and

(3) a transducer on said engine for measuring an operational parameter of said engine and coupled with said variable frequency oscillator for the transmission of a control signal reflecting said operational parameter so that the volume of fuel delivered to said engine varies with said operational parameter.

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