Fel. 24, 1959 H. H. VICKERS 2,874,640

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Filed March 11, 1954 2 Sheets-Sheet 1

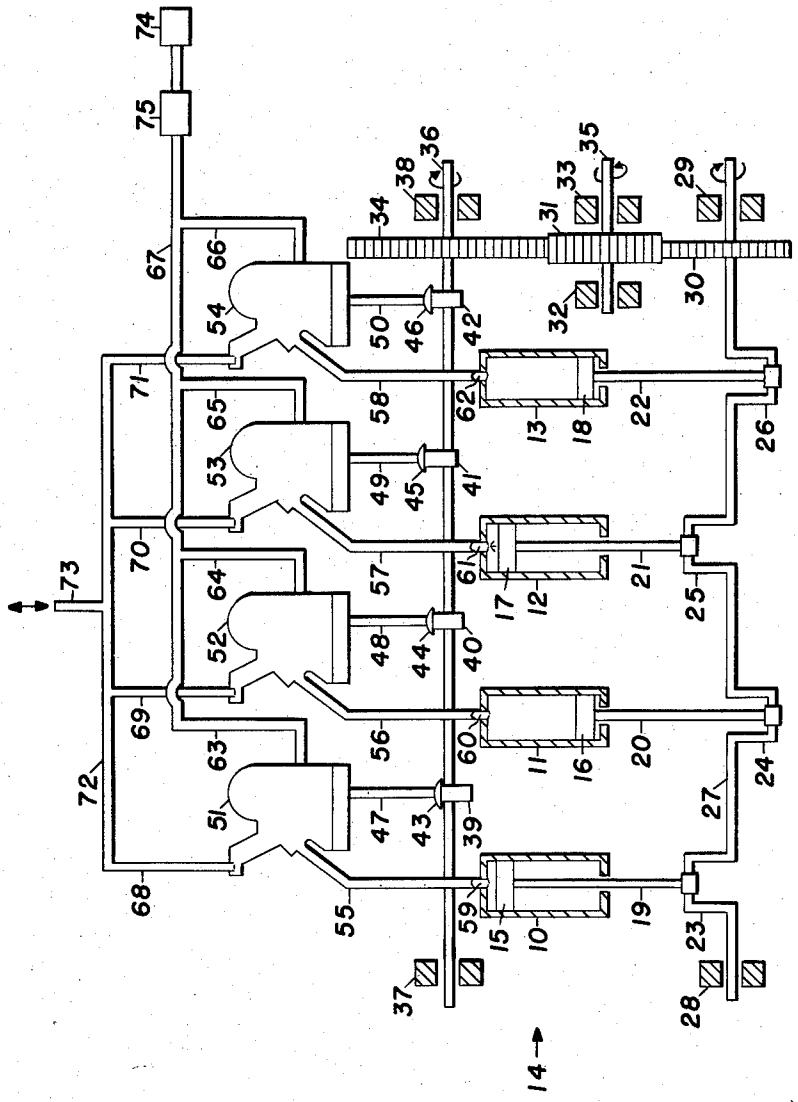


FIG. - 1

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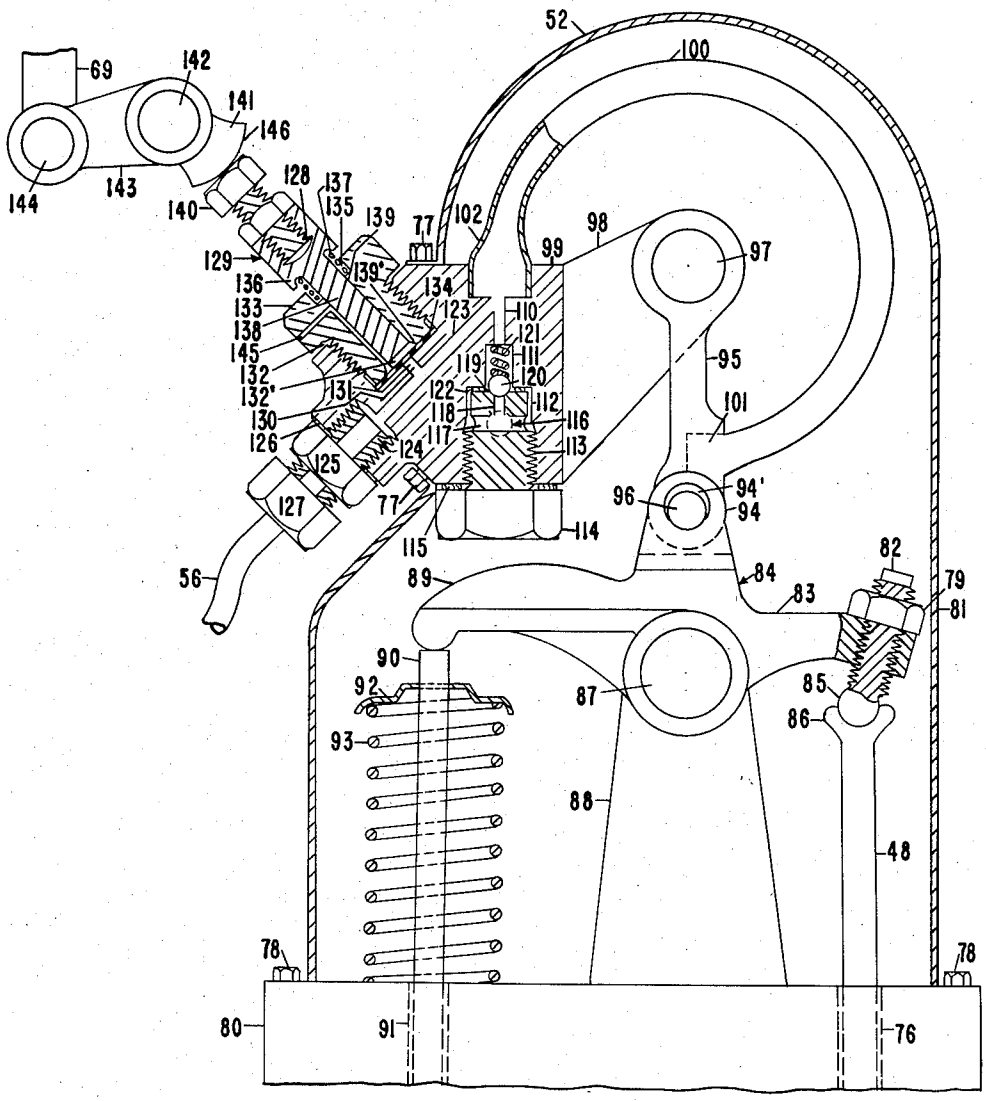


FIG. - 2

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PUMP

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3 Claims. (Cl. 103—37)

This invention relates to pumping apparatus and more particularly relates to apparatus adapted to charge fuel to an internal combustion engine. Still more particularly this invention relates to apparatus adapted to separately charge predetermined amounts of fuel to individual cylinders of a multiple-cylinder internal combustion engine.

It is well known that the distribution of fuel to individual cylinders of a multiple-cylinder internal combustion engine has a substantial effect on the operation of such an engine, especially in regard to engine power and fuel economy. In the case of a multiple-cylinder internal combustion engine which employs a carburetor and an intake manifold which are common to all cylinders, it is not unusual to have a wide variation in the amounts of fuel distributed to the different cylinders. Thus some of the cylinders will operate on the lean side and others on the rich side of that required for maximum power or maximum fuel economy, as the case may be. For a particular engine, improvement of fuel distribution is one of the principal ways in which power can be gained. Normally, however, for a particular engine the advantage to be gained directly as a reduction in fuel consumption due to the better distribution is small. However, the resultant improved performance of the engine that is gained due to the better fuel distribution will permit readjustment of the air-fuel mixture by reducing the amount of fuel required so as to afford increased economy in this manner. There are also a number of other advantages to be gained from improved fuel distribution, such as easier engine starting, especially under conditions of extremely low temperature, elimination of carburetor icing, better acceleration characteristics under heavy load conditions, and elimination of vapor lock when operating under conditions of exteme heat.

Although, of couse, the engine performance depends upon the particular mixture of air and fuel reaching the cylinders, the distribution problem is mainly attributable to the fuel portion of the mixture due to the peculiar volatility properties of a liquid fuel. More specifically, when employing a conventional carburetor the fuel may reach the cylinder as a combination of a vaporized fraction, an atomized fraction, and a liquid heavy ends fraction, so that under these conditions optimum distribution of the fuel is extremely difficult to obtain. Manufacturers of fuels are constantly striving to improve the volatility characteristics of their fuels in order to improve this distribution of fuel to the various cylinders of an engine. However, there is a limit as to the improvement which can be gained in this manner, as liquid fuels, such as gasolines, are a mixture of hydrocarbons having different volatility characteristics so that perfect distribution with conventional carburetion devices is therefore inherently limited.

In regard to the air-fuel mixture, it is, of course, essential that combustible proportions be employed. If this is the case, then the rate at which the flame is propagated throughout the combustible mixture in the cylinder, and

consequently the time required in an engine to develop maximum pressure, is dependent in a very large measure on the proportions of air and fuel being used. If the mixture is either too lean or too rich, the rate of combustion will be decreased and consequently the power of the engine will be reduced. For any given cylinder there is an optimum ratio of air to fuel required to develop maximum power at any given speed and load. The limits of flammability for mixtures of air and normal gasolines are approximately 7:1 by weight at the low or rich end of the mixture scale and about 20:1 at the high or lean end. Complete combustion of the air-fuel mixture for commercial gasolines occurs at approximately 15:1. For conventional automotive engines maximum engine horsepower is developed at a mixture strength of about 12.5:1 and maximum fuel economy usually is obtained at, or slightly above, the 15:1 ratio required for complete combustion. It is readily apparent, then, that the full power and maximum economy requirements differ. This is in large measure overcome in automotive engines by suitable carburetion devices that furnish a fairly rich mixture to provide maximum power for acceleration and a reasonably lean mixture to provide good fuel economy at substantially constant speed. However, even at substantially constant speed there is a compromise made between power and fuel economy so that the air-fuel ratio is usually set someplace between 12.5:1 and 15:1. Normally when operating at substantially constant speed and load conditions, for a rather small sacrifice in maximum power, the air-fuel ratio may be increased considerably to give an appreciable increase in the economy of the engine. Thus it will be seen that the power and economy of an engine are to some degree interchangeable within certain limits. Therefore, any improvement in fuel distribution may be realized as either an increase in power output or as a saving in fuel, or a combination of the two.

A number of different steps have been taken to improve the distribution of fuel to individual cylinders of an internal combustion engine. For example, as previously mentioned, the volatility of the fuel itself has been improved. Also heating devices have been installed in conjunction with the intake manifolds to improve the vaporization of the fuel. However, one of the most significant steps taken to improve fuel distribution has been the development of separate fuel injection devices for each individual cylinder. Such fuel distribution devices have to date been employed extensively in the aircraft engine and the diesel engine fields. However, heretofore no successful economical fuel injection device of this type has been conceived for utilization with automotive engines such as those used in passenger cars, trucks, etc. Unfortunately, the cost of using individual injection devices similar to those employed in aircraft and diesel engines has been prohibitive.

The present invention is designed to fulfill this long-felt need for a practical feed distribution apparatus which is adapted to charge a separate predetermined amount of fuel to each cylinder of a multiple cylinder internal combustion engine. Briefly, the present invention comprises an individual injection device for each individual cylinder of an internal combustion engine. Each injection device of this invention includes a Bourdon tube which is provided with a pressure responsive inlet means for receiving a liquid fuel from a fuel source common to all of the feed means and a pressure responsive outlet means for discharging a predetermined amount of liquid fuel therefrom to the cylinder associated with it. In combination with the Bourdon tube is a variable control device for adjusting the amount of fuel discharged from the Bourdon tube. The variable control device includes a chamber which is divided into two fluid tight compart-

ments by a fluid tight flexible diaphragm with one of the compartments of the chamber being in fluid communication with the interior of the Bourdon tube. Arranged in the other compartment of the chamber is an adjustable piston member.

One end of the Bourdon tube is maintained in a fixed position while the other end is connected to operating means associated with its particular cylinder. The operating means flexes the Bourdon tube in one direction so as to thereby increase the effective volume of the Bourdon tube in order to permit fuel to be taken into the interior of the Bourdon tube through the inlet means. At the appropriate time during the cycle of the associated cylinder the operating means flexes the Bourdon tube in the other direction so as to thereby decrease the effective volume of the Bourdon tube in order to discharge fuel therefrom into the cylinder associated therewith. During the discharge movement of the Bourdon tube the flexible diaphragm of the variable control device is also flexed due to the pressure created by the flexure of the Bourdon tube. This displacement of the diaphragm, therefore, in effect increases the effective volume of the Bourdon tube and the limit of this expansion of the diaphragm is controlled by the position of the piston member. Thus the greater the movement of the diaphragm, the less fuel is pumped to the cylinder. The position of the piston member is controlled by the accelerator of the engine which is common to all injection devices. Provision is made for minor changes in the position of the piston member to permit manual adjustment of each injection device. In the above described manner a predetermined and definite amount of liquid fuel may be discharged separately into each cylinder of a multiple cylinder internal combustion engine.

It is an object of this invention to provide apparatus for improving the performance and economy of operation of internal combustion engines.

It is a further object of this invention to provide a simple, inexpensive, and dependable apparatus for separately charging a predetermined and definite amount of fuel to each cylinder of a multiple cylinder internal combustion engine.

These and other objects of this invention will be apparent from a reading of this specification, which will best be understood when read in conjunction with the drawings, in which:

Fig. 1 is a diagrammatic showing of a four cylinder engine in combination with the fuel distribution apparatus of this invention, in which portions are shown in cross section so as to facilitate the disclosure, and

Fig. 2 is a detailed diagrammatic showing of one of the fuel injection devices made in accordance with this invention, in which portions are shown in cross section in order to facilitate the disclosure.

Referring now to Fig. 1, reference characters **10, 11, 12,** and **13** indicate the individual cylinders of a four cylinder four stroke internal combustion engine **14**. The drawing of engine **14** shown in Fig. 1 is purely schematic and shows only those parts of engine **14** which are necessary for an understanding of this invention. The parts not shown are conventional to internal combustion engines, and their operation and arrangement will be readily understood by those skilled in the art. Cylinders **10, 11, 12,** and **13** are each provided with a piston axially movable therein. Thus pistons **15, 16, 17** and **18** are arranged respectively within cylinders **10, 11, 12** and **13**. Each piston is preferably provided with piston rings. Connecting rods **19, 20, 21,** and **22** are respectively connected to pistons **15, 16, 17** and **18** at their lower ends and are respectively connected to cranks **23, 24, 25** and **26** of crankshaft **27** at their other ends. Crankshaft **27** is supported by bearings **28** and **29** which are arranged at the two ends of crankshaft **27** such that crankshaft **27** is axially rotatable therein.

Engine **14** delivers two power strokes for each revolution of crankshaft **27**. Thus in Fig. 1 cylinder **10** is about to begin the power or working stroke, cylinder **11** is about to begin the exhaust stroke, cylinder **12** is about to begin the suction or intake stroke, and cylinder **13** is about to begin the compression stroke. Each of the cylinders will fire once for every two revolutions of crankshaft **27** with the order of firing being cylinders **10, 11, 12** and **13**. However, it is to be understood that the present invention is not limited to this particular arrangement or number of cylinders. On the power stroke the ignited combustible mixture of air and fuel expands to move the piston downwards in Fig. 1; on the exhaust stroke the piston moves upward in Fig. 1 to discharge the exhaust gases from the cylinder which were formed by the combustion occurring in the power stroke; on the intake or suction stroke the piston moves downward again to draw in a combustible air-fuel mixture; and on the compression stroke the combustible air-fuel mixture is compressed as the piston again moves upward. It is to be understood that cylinders **10, 11, 12,** and **13** are provided with conventional air inlets, exhaust ports, and spark plugs (not shown) so that engine **14** may perform the above cycle. In addition to these conventional parts, engine **14** is provided with a fuel distribution apparatus made in accordance with the present invention which will be hereinafter described in detail.

Arranged on one end of crankshaft **27** is gear **30** which is rotated by crankshaft **27**. Meshing with gear **30** is gear **31** which is provided in this system to mesh with gears **30** and **34** to drive gear **34** in the same direction as gear **30**. It will be noted that gear **31** rotates at the same speed as gear **30** and crankshaft **27**. Gear **31** is arranged on shaft **35**, which is supported in bearings **32** and **33**. Gear **34** is designed to rotate at one-half of the speed of gears **30** and **31** and crankshaft **27** and it is arranged on one end of camshaft **36**, which is supported at its ends by bearings **37** and **38** wherein it is adapted to rotate. Arranged along camshaft **36** in spaced relation to each other are cams **39, 40, 41,** and **42**. These cams are arranged consecutively ninety degrees apart from each other in respect to their angular positions.

Cooperating with cams **39, 40, 41,** and **42** are their respective cam followers **43, 44, 45,** and **46**, which are attached to the ends of push rods **47, 48, 49,** and **50** respectively. The respective push rods extend at their other ends into fuel injection devices **51, 52, 53,** and **54**. These push rods are the operating means by which the fuel injection devices of this invention are actuated so that a separate predetermined amount of fuel will be discharged into each of cylinders **10, 11, 12,** and **13**. The rotation of camshaft **36** causes the cams thereon to rotate so that a reciprocating motion is imparted to the push rods due to the cooperation of the cams and cam followers. The separate amounts of fuel discharged from feed injection devices **51, 52, 53,** and **54** are respectively conducted to cylinders **10, 11, 12,** and **13** by means of conduits **55, 56, 57** and **58**. Arranged at the end of each conduit at the fuel inlet to each cylinder is a spring loaded injector nozzle which is designed to open at a given predetermined pressure to permit fuel to flow through the conduits. The nozzle in the open position sprays a definite amount of fuel into the cylinder and immediately thereafter closes to effect a seal against any pressure existing in the cylinders. In effect the spring loaded injector nozzles function as flow check means, holding against pressure in an upstream direction through the conduits **55, 56, 57** and **58**. Thus spring loaded injector nozzles **59, 60, 61,** and **62** are arranged respectively in conduits **55, 56, 57,** and **58** immediately prior to their respective cylinders. Any suitable conventional pressure responsive nozzle which will perform the function contemplated may be employed. A typical spring loaded injector nozzle of the character contemplated is one such as illustrated in the publication "Diesel

Engines" by B. J. Von Bongart, D. Van Nostrand Company, Inc., New York, 1938, by Fig. 92 on page 109 thereof.

Liquid fuel is fed to fuel injection devices **51**, **52**, **53**, and **54** through inlet conduits **63**, **64**, **65**, and **66** respectively, which all communicate with common conduit **67**, which in turn communicates with the source of fuel such as fuel tank **74**. A fuel pump **75** may be installed in conduit **67**, if necessary, to provide any pressure which may be required to assure passage of fuel from fuel tank **74** to the fuel injection devices of this invention. Mechanically connected to fuel injection devices **51**, **52**, **53**, and **54** are push rods **68**, **69**, **70**, and **71** respectively, which are connected at their other ends to bar **72**. Connecting rod **73**, which is connected to bar **72**, is adapted to be actuated by the accelerator (not shown) of engine **14**. Operation of the accelerator depresses or raises push rods **68**, **69**, **70**, and **71** to thereby regulate the amount of fuel injected into engine **14** as will be hereinafter described in greater detail.

Referring now to Fig. 2, fuel injection device **52** is shown in detail. It is to be understood that fuel injection devices **51**, **53** and **54** are identical in design to fuel injection device **52**. Reference character **80** designates a mounting block which may be the cylinder head of engine **14** upon which the other parts of fuel injection device **52** are mounted. Supported upon mounting block **80** is housing **81**, which is secured to mounting block **80** by bolts **78** and which encloses some of the working parts of fuel injection device **52**. Push rod **48** extends up into housing **81** through opening **76** in mounting block **80**, and it is longitudinally movable therein. The end of push rod **48** within housing **81** is adapted to cooperate with ball **85** of bolt **82**, which is threaded into arm **83** of rocker arm **84** and locked in place by means of nut **79**. Ball **85** of bolt **82** is adaped to engage socket **86** arranged at the end of push rod **48**.

Rocker arm **84** is pivotally mounted on pivot **87** arranged on the upper end of support **88** which in turn is secured at its lower end to mounting block **80**. Arm **89** of rocker arm **84** is adapted to cooperate with one end of valve stem **90**, which is guided by slot **91** in mounting block **80**. In this specific embodiment of the present invention the lower end of valve stem **90** is connected to the air inlet valve (not shown) associated with cylinder **11** so that the pivotal movement of rocker arm **84** will operate the air inlet valve through valve stem **90** so that the air inlet valve will be opened and closed at the appropriate times in the cycle of cylinder **11**. In moving downward valve stem **90** opens the air inlet valve. Valve stem **90** is provided at its upper end with an annular flanged member **92** which is rigidly secured thereto and which engages spring **93** which is disposed between annular flanged member **92** and mounting block **80**. Thus when connecting rod **48** is raised, rocker arm **84** is turned in a counterclockwise direction so that arm **89** depresses valve stem **90**, which compresses spring **93**; and when connecting rod **48** is lowered, rocker arm **84** is turned in a clockwise direction due to the force exerted on arm **89** by spring **93** acting through valve stem **90**.

Arm **94** of rocker arm **84** is integral therewith and extends upward from pivot **87** substantially perpendicular to arms **83** and **89**. Arm **94** is provided in its upper end with slot **94'** which cooperates with pivot **96** of arm **95** to provide a pivotal connection between the lower end of arm **95** and the upper end of arm **94**. Pivot **96** is positioned at the lower end of arm **95**, is integral therewith and extends through slot **94'** which is elongated in the vertical direction. This connection is such as to permit limited transverse movement of arms **94** and **95** at their point of juncture. The upper end of arm **95** is connected to pivot **97**, which is supported by means of fixed arm **98** to mounting block **99**, which in turn is secured to housing **81** by means of one or more bolts **77**. Mounting block **99** is thus rigidly fixed to mounting block **80** by means of housing **81**.

Pivot **97** is mounted on arm **98** at a position substantially coinciding with the center of the arc of an arcuate tube **100**. End **101** of tube **100** is secured to the end of arm **95** which is adjacent to pivot **96** by any conventional means such as by welding. Tube **100** is a slender, thin-walled tube with its one end **101** being closed and its other end **102** being open. Tube **100** is of the type used in Bourdon pressure gauges but is not restricted thereto. It will be hereinafter termed Bourdon tube **100** to imply that there is a definite relationship between the shape of the tube and the volume and pressure of fluid contained therein. Bourdon tube **100** is preferably formed in an arc of at least about 90° and preferably has a generally elliptical shape in transverse cross section. If desired, Bourdon tube **100** may be coiled in an arc exceeding 360°. Bourdon tube **100** is constructed of a material such as stainless steel, carbon steel or Monel metal which is capable of withstanding a maximum bursting pressure of at least about 2000 p. s. i. End **102** of Bourdon tube **100** is rigidly fixed to block **99**. Thus any longitudinal movement of push rod **48** turns rocker arm **84** so that arm **94** causes arm **95** to pivot, which in turn causes a movement of end **101** of Bourdon tube **100**. The resultant flexure of Bourdon tube **100** causes a change in shape thereof which results in a change in the volume or capacity of the interior of Bourdon tube **100**. Thus when a fluid is sealed in the interior of Bourdon tube **100**, any flexure of the tube will result in a change in pressure on the particular fluid.

In the particular arrangement shown in Fig. 2 when end **101** of Bourdon tube **100** is moved slightly to the left in the drawing, the volume of Bourdon tube **100** is decreased, which causes an increase in pressure of any fluid contained therein. Because Bourdon tube **100** is generally elliptical in transverse cross section, the movement of end **101** of Bourdon tube **100** to the left in Fig. 2 will increase the major axis of this ellipse and will decrease the minor axis so that the resultant transverse cross sectional area of Bourdon tube **100** is decreased. It is to be understood that the length of Bourdon tube **100** remains substantially constant at all times. On the other hand, when end **101** of Bourdon tube **100** is moved slightly to the right in the drawing, the volume of Bourdon tube **100** is increased, which causes a decrease in pressure of any fluid contained therein. Thus the movement of end **101** of Bourdon tube **100** to the right in Fig. 2 decreases the major axis of the ellipse and increases the minor axis so that the resultant transverse cross sectional area of Bourdon tube **100** is increased. Thus when push rod **48** moves upward to its uppermost position, end **101** of Bourdon tube **100** is moved to the left in Fig. 2 so that the volume of Bourdon tube **100** is at its smallest value in this particular arrangement. On the other hand, when push rod **48** moves downward to its lowest position, end **101** of Bourdon tube **100** is moved to the right in Fig. 2 so that the volume of Bourdon tube **100** is at its largest in this particular arrangement. The particular position of push rod **48** at any one moment will be dependent, of course, upon the position of cam **40** on camshaft **36**. Push rod **48** and Bourdon tube **100** are shown at their intermediate positions in Fig. 2. When in this intermediate position, Bourdon tube **100** is preferably in its preformed natural and unstressed shape such that it is neither flexed in one direction nor the other. In this way the strain on Bourdon tube **100** is minimized.

Communicating with end **102** of Bourdon tube **100** is one end of fuel inlet passageway **110**, which is bored from block **99**. The other end of fuel inlet passageway **110** communicates with chamber **111**, which is bored out of block **99** and which in turn communicates at its other end with enlarged chamber **112**. Plug **113**, which is partially threaded, is arranged in chamber **112** engaging

the internal threads of block 99, which partially define chamber 112. In its intermediate portion plug 113 is necked down so that in this portion plug 113 is spaced from the wall forming chamber 112. Head 114 of plug 113 is maintained in a fluid tight relationship with block 99 by means of annular gasket 115, which is disposed therebetween. Communicating with chamber 112 at a point facing the necked down portion of plug 113 is inlet 116 of conduit 64, through which liquid fuel enters fuel injection device 52. Inlet 116 is indicated by the dotted circle shown in chamber 112 in Fig. 2. Plug 113 is provided in its necked down intermediate portion with a horizontal bored opening 117 which communicates with the interior of chamber 112. Plug 113 is also provided at its end adjacent to chamber 111 with a vertical bored opening 118 which communicates at one end with opening 117 and at the other end with chamber 111. Opening 118 in plug 113 forms seat 119, which is circular in form. Cooperating with seat 119, is ball 120, which is generally maintained in fluid tight contact with seat 119 by means of spring 121 arranged in chamber 111. Seat 119, ball 120 and spring 121 are designed to provide a check valve arrangement for fuel inlet passageway 110. The strength of spring 121 is selected to be substantially less than the force exerted on ball 120 by the fuel in opening 118 so that ball 120 will be displaced from seat 119 when the pressure of the fuel in the interior of Bourdon tube 100 is slightly less than the pressure of the fuel in opening 118. Gasket 122 is arranged around seat 119 between block 99 and the end of plug 113 adjacent seat 119 to prevent the passage of fuel from chamber 112 to chamber 111 other than through opening 118.

The manner in which fuel is drawn in Bourdon tube 100 on the intake or suction strokes is as follows. When push rod 48 is moved downwards, rocker arm 84 is turned such that arm 94 is turned to the right in Fig. 2. The movement of arm 94 causes arm 95 to also move to the right and in so doing causes end 101 of Bourdon tube 100 to move to the right also. This movement or flexure of Bourdon tube 100 enlarges the volume of Bourdon tube 100 as previously described, which causes a decrease in pressure of the fuel therein. When the pressure of the fuel in Bourdon tube 100 becomes slightly less than the pressure of the fuel in conduit 64, which occurs almost immediately after the suction stroke in the Bourdon tube is begun, fuel will flow from conduit 64 through inlet 116 into chamber 112 around the necked down portion of plug 113 and then through openings 117 and 118 of plug 113 into chamber 111 by forcing ball 120 away from seat 119. The fuel then passes through chamber 111 through fuel inlet passageway 110 into the interior of Bourdon tube 100. Chambers 111 and 112, openings 117 and 118, and passageway 110 are in effect a continuation of inlet conduit 64. In this manner fuel is drawn into Bourdon tube 100. This in effect then is the intake stroke of the pumping apparatus of this invention. On the other hand, when the pressure in Bourdon tube 100 exceeds the pressure in conduit 64, such as occurs when push rod 48 is moving upward so that Bourdon tube 100 is flexed in the opposite direction, ball 120 is forced by spring 121 back against seat 119 to thereby prevent passage of fuel from Bourdon tube 100 back into conduit 64. In the continuous operation of the apparatus of this invention all of the aforementioned chambers and passageways will be filled with fuel at all times. Of course, it is to be understood that the differential pressure between the interior of Bourdon tube 100 and conduit 64 must be sufficient to overcome the slight force exerted on ball 120 by spring 121 before fuel will flow into Bourdon tube 100.

Also communicating with end 102 of Bourdon tube 100 is fuel discharge passageway 123, which is bored out of block 99. Bourdon tube 100, fuel inlet passageway 110 and fuel discharge passageway 123 form a somewhat Y-shaped opening in block 99. Fuel discharge passageway 123 is enlarged at its discharge end. Coupling 124 is arranged in this enlarged end of fuel discharge passageway 123 and the threads of coupling 124 engage the internal threading of block 99, which partially defines the enlarged end of passageway 123, to thereby secure coupling 124 thereto. Coupling 124 is provided with nut 125 which is turned down against annular gasket 126 to provide a fluid tight external seal between coupling 124 and block 99. Communicating with fuel discharge passageway 123 through coupling 124 is conduit 56, which is secured to coupling 124 by fastening means 127. Fuel is thus discharged from Bourdon tube 100 through fuel discharge passageway 123 and coupling 124, which are in effect an extension of conduit 56. The fuel then passes through conduit 56 to cylinder 11 through spring loaded injection nozzle 60. In this specific embodiment of the present invention the fuel is discharged into cylinder 11 during the suction stroke together with an appropriate amount of air which is introduced through the air inlet valve operated by valve stem 90. However, it is to be understood that, if desired, the time of injection could be changed so that the fuel would be injected at the end of the compression stroke and during the power stroke. This change would merely involve a change in timing of the particular elements involved and will be apparent to those skilled in the art. As previously mentioned, spring loaded injection nozzle 60 is arranged at the end of conduit 56 to regulate the flow of fuel into cylinder 11 as well as to spray the fuel into cylinder 11. Spring loaded injection nozzle 60 is designed to open in response to a predetermined pressure developed in Bourdon tube 100 when the tube is flexed for discharge. Normally a setting responsive to a pressure of about 100 p. s. i. in conduit 56 will be sufficient when the fuel is discharged during the suction stroke of cylinder 11. If it should be desired to discharge fuel into cylinder 11 at the end of the compression stroke and during the power stroke then a setting responsive to about 1000 p. s. i. will be required due to the pressure existing in cylinder 11 at that part of the cycle. After discharge of the fuel charge into cylinder 11, spring loaded injection nozzle 60 is closed by the force of its spring so that no material can move backwards from cylinder 11 into the interior of Bourdon tube 100. The function and operation of nozzle 60 is similar to an injection nozzle employed in Diesel engines and will be apparent to a person skilled in the art.

Communicating with fuel discharge passageway 123 is chamber 130, which comprises passageway 131 and compartment 132 which are cored out of block 99. Compartment 132 is an enlarged opening in block 99, and plug 133, which is threaded, is arranged therein and is secured to internal threading of block 99, which partially defines compartment 132. Arranged between the lower end of plug 133 and the annular wall of block 99 defining the adjacent side of compartment 132 is diaphragm 134. Plug 133 is turned down into compartment 132 so that diaphragm 134 is held securely in place by the resultant compressive force. Diaphragm 134 is made of a flexible material which is capable of withstanding many flexures without losing its elastic properties such as an oil-resistant rubber or metal such as brass, steel or Monel. In effect then, only passageway 131 of chamber 130 communicates in fluid relationship with fuel discharge passageway 123, as diaphragm 134 provides a fluid tight seal between passageway 123 and compartment 132.

Plug 133 is provided with an axially arranged, preferably cylindrical, opening 139 which extends the entire length thereof. Cooperating with opening 139 is plunger 129, which comprises head 136 and piston 138. Arranged within opening 139 is piston 138, which is axially movable therein. Plug 133 is provided at its outer end with an annular recess 135, which is larger in diameter than opening 139. Spring 137 is arranged around piston 138 of plunger 129 and is partially compressed between

recess 135 of plug 133 and head 136 of plunger 129. The bottom of piston 138 of plunger 129 is normally spaced from diaphragm 134 so that expansion chamber 132' is formed therebetween. Expansion chamber 132' is provided in this invention to permit expansion of diaphragm 134 in response to pressure exerted thereon by the liquid fuel is passageway 131. The degree of expansion of diaphragm 134 is thus governed by the position of piston 138 of plunger 129, and as a result, therefore, determines the amount of fuel which is discharged from Bourdon tube 100 into cylinder 11. While passageway 131 is shown in Fig. 2 as communicating directly with fuel discharge passageway 123, it is to be understood that this particular arrangement is not essential, as it is only essential that passageway 131 be in fluid communication with the interior of Bourdon tube 100.

Head 136 of plunger 129 is provided with a threaded opening 128 with the threads engaging bolt 140. Cam 141, which has an eccentric bearing surface 146, is adapted to cooperate with the head of bolt 140 so that as arm 141 is turned about pivot 142, plunger 129 is raised or depressed in opening 139 in plug 133 to thereby vary the size of expansion chamber 132'. Arm 141 is rigidly fixed to arm 143, which is actuated by push rod 69 associated with the accelerator of engine 14. Thus, when push rod 69 is depressed, arm 141 is rotated in a counterclockwise direction in Fig. 2 so that the smaller radius portion of arm 141 is brought into contact with bolt 140. Spring 137 then forces plunger 129 out of opening 139 in plug 133 so that expansion chamber 132' is thereby enlarged. Expansion chamber 132' is provided with vent line 145 so as to permit free movement of diaphragm 134 and plunger 129.

During the discharge stroke of Bourdon tube 100 diaphragm 134 is expanded outwards due to the pressure buildup in Bourdon tube 100 and passageway 131 until it contacts the bottom of piston 138 of plunger 129. The particular position of piston 138 will govern how much diaphragm 134 is expanded. By regulating the displacement of diaphragm 134 in this manner it is possible to thereby vary the amount of fuel pumped from Bourdon tube 100 to cylinder 11. Without the variable control device comprising piston 138, diaphragm 134, and chamber 132', Bourdon tube 100 would pump the same amount of fuel on each discharge stroke. In general, the position of piston 138 will be regulated by the accelerating mechanism of the engine through push rod 69, although provision is made for a minor manual adjustment by means of bolt 140 which may be turned to thereby adjust the position of piston 138 by varying the combined length of bolt 140 and plunger 129.

In the operation of this invention, during the intake stroke of Bourdon tube 100, diaphragm 134 remains in the flat position shown in Fig. 2. At the end of the intake stroke the Bourdon tube, together with the passageways communicating with it, are filled with fuel and diaphragm 134 is still in the flat position. The intake stroke of Bourdon tube 100 extends from the time that end 101 is at the extreme left in Fig. 2 until end 101 has moved to the extreme right in the drawing. Thereafter the Bourdon tube 100 begins its discharge stroke by moving from right to left in Fig. 2. Immediately after the discharge stroke has begun, the pressure on the fuel in the interior of Bourdon tube 100 is increased so that ball 120 seats upon seat 119 to prevent the flow of fuel back into conduit 56. This increased pressure also forces diaphragm 134 to expand outwards until it is prevented from so doing by piston 138. Thereafter the pressure in Bourdon tube 100 increases until it exceeds the predetermined setting of spring loaded nozzle 60 in conduit 56 leading to cylinder 11, which occurs generally at the initial phase of the discharge stroke. At this predetermined pressure, nozzle 60 opens and permits a definite amount of fuel to be injected into cylinder 11 throughout the remainder of the discharge stroke. Thereafter, at the commencement of the intake stroke, the pressure in Bourdon tube 100 is decreased to the point where spring loaded nozzle 60 closes. Also at the commencement of the intake stroke of Bourdon tube 100, diaphragm 134, due to its elastic properties, returns to its normal flat position. Passageway 131 is kept small so that the diaphragm 134 will not be drawn into it, but if the strength of diaphragm 134 is insufficient, a metal screen (not shown) may be arranged under it so that on the intake stroke, diaphragm 134 will not be withdrawn from its flat position into passageway 131. However, it is to be understood that even should diaphragm 134 be drawn back partially into passageway 131, the apparatus of the present invention would still be workable. However, it is essential that this amount of withdrawal be constant, so it is therefore preferable to employ such a metal screen. The edge 139' of opening 139 is rounded to permit easier expansion of the diaphragm into the chamber 132'.

In the above-described manner diaphragm 134 and its associated elements provide the necessary variable control device essential to the successful application of Bourdon tube 100 to automotive engines. By adjusting the position of piston 138 it is possible to regulate the amount of fuel pumped from substantially zero to an amount equivalent to the maximum pumping capacity of the Bourdon tube 100. It is, of course, necessary to select a Bourdon tube of such a capacity that it will pump at least the maximum amount of fuel required by cylinder 11. Also it is necessary to provide a maximum capacity for expansion chamber 132' which is substantially equal to the volume of the maximum pumping capacity of Bourdon tube 100 so that the amount of fuel pumped to cylinder 11 may be reduced to a low value or zero. Thus in the situation where piston 138 is in contact with diaphragm 134 and diaphragm 134 is therefore maintained in its flat position, the maximum charge of fuel will be pumped to cylinder 11. When piston 138 is withdrawn to its position farthest from the flat position of diaphragm 134, the minimum charge of fuel will be pumped to cylinder 11.

In the above-described manner this invention provides in effect a separate pumping and metering means for charging fuel to each cylinder. It is thus readily apparent from the drawings and foregoing description that the apparatus of this invention is simple, accurate, dependable and inexpensive, and that this invention is therefore economically practical for use especially in automotive engines of the passengers car and truck type. The elements of this invention are easily made and do not require any expensive exact machined parts as do the conventional individual fuel injection devices employed in aircraft and diesel engines. It is to be understood that the apparatus of this invention may be employed with any type of internal combustion engine operating with any number of strokes per cycle or having any number of cylinders, including a single cylinder engine. Likewise it is to be understood that this invention may be employed with stationary or mobile internal combustion engines. Although in the specific embodiment of this invention shown in Fig. 1, the fuel is shown as being charged directly to the individual cylinders, it is to be further understood that the fuel charge may be combined with the air entering each individual cylinder so that a combustible mixture is fed to the cylinder. In this case a spray nozzle or other atomization apparatus would be employed. However, it is preferable to inject the fuel directly into the individual cylinders, as better engine performance will normally be obtained.

The following is an example of the size and capacity required of Bourdon tube 100 when it is utilized with an automobile engine. A typical automobile engine, for example, may require a gasoline charge which varies from about 0–0.5 cubic centimeter per cylinder. The particular charge required will depend of course upon the

particular speed and load conditions involved in operating the automobile. A Bourdon tube which is constructed of steel and which is capable of withstanding a maximum bursting pressure of about 2,000 p. s. i. may be employed. This Bourdon tube has been preformed into an arc of about 200° on a 1.5 inch radius and has a wall thickness of about 0.06 inch. The circumference of the generally elliptically shaped interior of the Bourdon tube in transverse cross-section is about 1.14 inches with a minor axis of about 0.15 inch. By increasing the arc of the Bourdon tube about 15° by moving one end of the tube about 0.4 inch while maintaining the other end fixed, the volume of the interior of the Bourdon tube will be decreased by about 0.5 cubic centimeter. Thus about 0.5 cubic centimeter will be discharged from the Bourdon tube due to the change in volume of the tube, providing, of course, that the diaphragm of the adjusting mechanism is maintained in its flat position. If a fuel charge of less than 0.5 is required then the diaphragm is permitted to expand a slight amount by adjusting piston **138** so that a quantity of fuel less than 0.5 cubic centimeter is charged to the cylinder. Thus the present invention is ideally suited to intermittently pump accurate minute amounts of liquid. While this invention has been described specifically in connection with its application to liquid fuels and internal combustion engines, it is to be clearly understood that the apparatus of this invention may be employed to pump other kinds of liquids in other applications.

What is claimed is:

1. A pump of the character described adapted to intermittently discharge a definite amount of liquid therefrom which comprises a mounting block, an arcuate tube closed at one end and open at the other end, the open end of said tube being secured to said mounting block, an arm pivotally mounted on said mounting block at a position substantially coinciding with the center of the arc of said tube, the closed end of said tube being secured to said arm, means for turning said arm about its pivot, a source of liquid, said mounting block being provided with an inlet passageway which communicates at one end with the open end of said tube and which communicates at its other end with said source of liquid, said inlet passageway being provided with check valve adapted to permit passage of liquid into the interior of said tube through said inlet passageway at a predetermined liquid pressure in said tube and adapted to prevent liquid passing from the interior of said tube back to said source of liquid, said mounting block being also provided with an outlet passageway which communicates at one end with the open end of said tube, and at the opposite end with a spring loaded valve adapted to permit discharge of liquid from said tube through said outlet passageway at a predetermined liquid pressure in said tube and adapted to close said passageway after said liquid is discharged, said mounting block being further provided with a passageway communicating at one end with the interior of said tube through said outlet passageway, a diaphragm arranged with one side across the other end of said passage in fluid-tight relation therewith, said mounting block being further provided with a chamber bounded on one side by the side of said diaphragm opposite said passage, a piston disposed in said chamber and adapted to be positioned at a variable distance from said diaphragm, means for changing the position of said piston in said chamber in relation to said diaphragm.

2. A pump of the character described including a Bourdon-type, arcuately curved tube having a sealed end, and an opposite end defining a chambered portion, a fixed mount for said latter end, a support arm mounted at one end for pivotal oscillation, the other end of said arm being secured to said tube sealed end, inlet and outlet conduits each having an open end in communication with said tube chambered portion and a flow check means in each conduit holding against pressure in an upstream direction through each conduit, said conduits between said flow check means and with said tube forming a pump chamber, and a means adapted selectively to vary the discharge volume of said pump chamber, comprising a passageway defined in the wall of said outlet conduit, said passageway communicating with said conduit and opening outwardly therefrom, a fluid and pressure tight diaphragm closure for said passageway of a material resiliently deformable under pressure, said diaphragm closure disposed across said passageway so as substantially to resist deformation toward said outlet conduit, and an adjustable limit stop adapted to be disposed in variable contact relation to said diaphragm closure so as to limit deformation of said diaphragm closure outwardly and away from said outlet conduit within an adjustable, predetermined limit range.

3. A pump of the character described including a Bourdon-type, arcuately curved tube having a sealed end, and an opposite end defining a chambered portion, a fixed mount for said latter end, a support arm mounted at one end for pivotal oscillation, the other end of said arm being secured to said tube sealed end, inlet and outlet conduits each having an open end in communication with said tube chambered portion and a flow check means in each conduit holding against pressure in an upstream direction through each conduit, said conduits between said flow check means and with said tube forming a pump chamber, and a means adapted selectively to vary the discharge volume of said pump chamber, comprising a cylindrical fitting having a first end secured to one wall of said pump chamber outlet conduit and in substantial communication with said outlet conduit by way of a passageway defined in said wall, a flexible diaphragm separating the interior of said cylinder from said chamber, said diaphragm being substantially rigidly maintained against flexure toward said chamber, a piston-like limit stop extended into said cylinder through the other end thereof and disposed for reciprocal movement longitudinally thereof, said stop limiting flexure of said diaphragm into said cylinder, resilient means urging said stop longitudinally of said cylinder in one direction, means for moving said stop in an opposite direction longitudinally of said cylinder against the resistance of said resilient means, means for adjusting the extent of reciprocal travel of said stop, and a vent from said cylinder opening therefrom adjacent said diaphragm.

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