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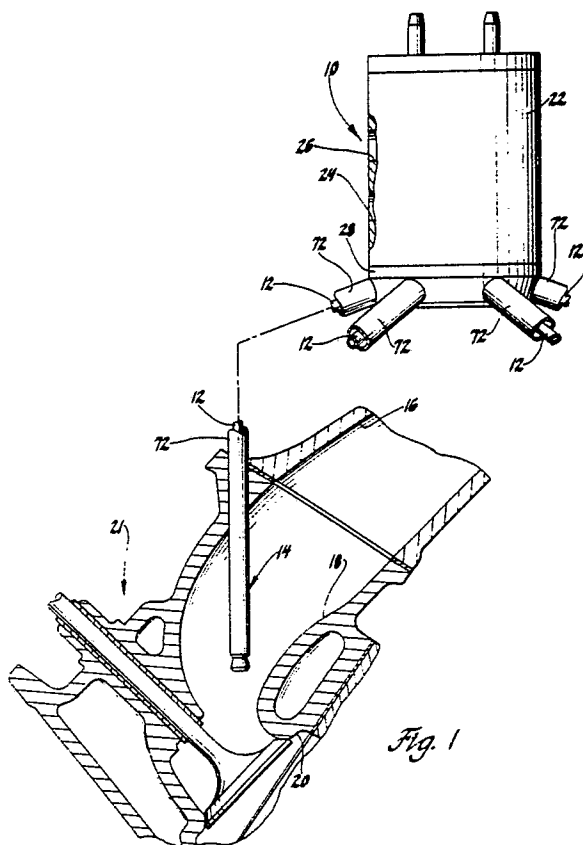
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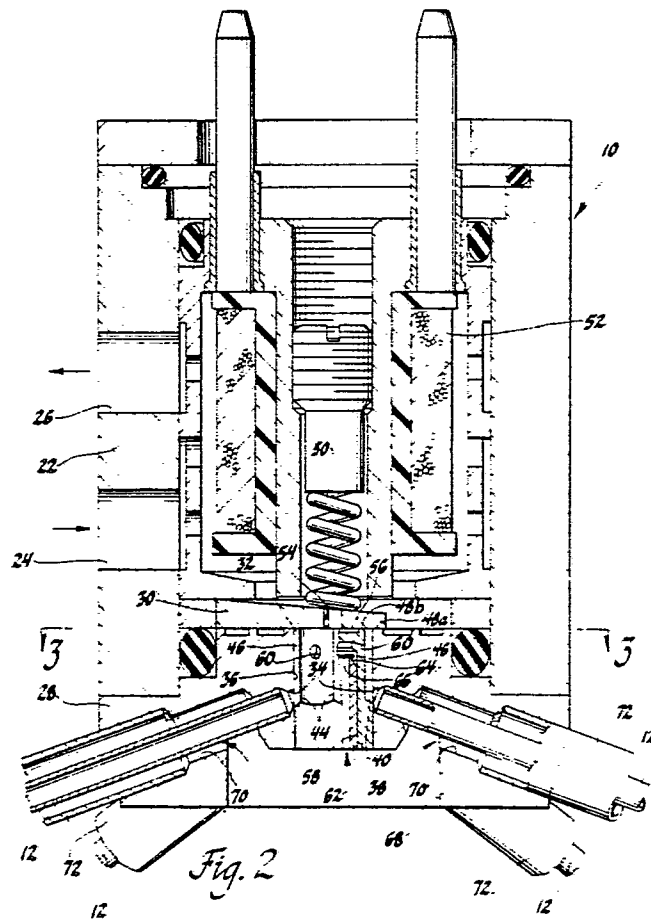
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(54) **Fuel injection apparatus.**

(57) In a fuel injection apparatus for a multi-cylinder internal combustion engine (21), a plurality of injection nozzles (14) discharge fuel adjacent the engine inlet ports (18), and a single fuel injector (10) meters the fuel to all of the injection nozzles. The fuel injector (10) comprises an injector base (28) having a plurality of fuel discharge passages (34) and an annular region (32) through which fuel is delivered to the fuel discharge passages, each of the fuel discharge passages being adaptable to direct fuel to one of the injection nozzles, the annular region including a valve surface (48), a single valve member (30) associated with the valve surface, the valve member being adapted to engage the valve surface to preclude fuel delivery to the fuel discharge passages, a solenoid (52) adapted to disengage the valve member from the valve surface to permit fuel delivery to the fuel discharge passages, characterised by air valve means (58, 64, 66) for controlling flow of air to the fuel discharge passages (34) and being adapted to preclude air flow to the fuel discharge passages when the valve member permits fuel delivery to the fuel discharge passages and to admit air to the fuel discharge passages when the valve member precludes fuel delivery to the fuel discharge passages.





FUEL INJECTION

This invention relates to a fuel injection apparatus for a multi-cylinder internal combustion engine in which a plurality of injection nozzles discharge fuel adjacent the inlet ports of the engine and a single fuel injector meters the fuel to all of the injection nozzles, to a fuel injector, and to an injection nozzle.

Current automotive engine fuel injection apparatus employ electromagnetic fuel injectors to meter and deliver the fuel to the engine. Throttle body fuel injection apparatus employ one or two fuel injectors that deliver the fuel into the air flowing through the engine throttle body, and the mixture of air and fuel then flows through the engine inlet manifold to the inlet ports of the engine combustion chambers. Port fuel injection apparatus on the other hand, typically employ individual fuel injectors to deliver fuel directly to each of the inlet ports.

A throttle body fuel injection apparatus with only one or two fuel injectors has a cost advantage over a port fuel injection apparatus with its several fuel injectors and the associated fuel rails. However, port fuel injection apparatus offer advantages in engine operation. Those comparative advantages present incentive for a fuel injection apparatus in which a single fuel injector meters fuel and a plurality of injection nozzles deliver the fuel to the engine inlet ports.

This invention permits a fuel injection apparatus to deliver fuel through a plurality of injection nozzles directly to the inlet ports and to employ a single fuel injector to meter the fuel to all of the injection nozzles.

According to one feature of this invention, a single fuel injector meters fuel through an annular region into a cylindrical chamber defined between a bore in the injector base and a plug received in the bore, and a plurality of fuel discharge passages open from the cylindrical chamber to direct fuel to injection nozzles. With this feature, a solenoid operated valve in the fuel injector may meter fuel to the fuel discharge passages with very little motion.

According to another feature of this invention, a fuel injector meters fuel through an annular region to a plurality of fuel discharge passages that direct the fuel to injection nozzles, and the fuel injector includes a valve member with an aperture opening into the centre of the annular region. With this feature, fuel flows to the annular region both around the valve member and through the aperture when the valve member is lifted from its valve seat. This feature accordingly further reduces the motion of the valve member that is required to meter fuel to the fuel discharge passages.

According to yet another feature of this invention, a single fuel injector meters fuel to a plurality of fuel discharge passages that direct the fuel to injection nozzles, and a rectifier valve allows air to flow into the fuel discharge passages when the fuel injector is not metering fuel into the fuel discharge passages. With this feature, the fuel maintains its discharge velocity through the fuel discharge passages to the injection nozzles. This feature also reduces the propagation of pressure waves through the fuel discharge passages as the fuel injector initiates and terminates fuel flow into the fuel discharge passages.

According to a further feature of this invention, a fuel injector has a base with a plurality of fuel discharge passages that receive the ends of fuel discharge lines through which fuel is directed to injection nozzles, the injector base has an air inlet surrounding the ends of the fuel discharge lines, and air lines surround the fuel discharge lines and direct air to the injection nozzles. With this feature, the fuel discharge lines are thermally insulated.

This invention is now described, by way of example of several embodiments, which are set forth in the following description and the accompanying drawings, in which:-

Figure 1 is a schematic view of fuel injection apparatus having a single fuel injector that meters fuel to six injection nozzles in accordance with this invention;

Figure 2 is an enlarged sectional view of the fuel injector of Figure 1, showing a valve member which is solenoid operated and which meters fuel through sectors of a cylindrical fuel distribution chamber to fuel discharge passages and fuel discharge lines that lead to the injection nozzles, a rectifier valve disc that admits air through the sectors to the fuel discharge passages and fuel discharge lines, and an air inlet for air lines that surround the fuel discharge lines;

Figure 3 is a view, indicated by the line 3-3 of Figure 2, of the fuel inlet side of the injector base of the fuel injector;

Figure 4 is an enlarged sectional view of the tip of the injection nozzles of Figure 1;

Figure 5 is a view, indicated by the line 5-5 of Figure 4, of an insert for the injection nozzles, showing the insert before its installation in the injection nozzle;

Figure 6 is an enlarged end view of the injection nozzles of Figure 1;

Figure 7 is an enlarged sectional view of a fuel injector for apparatus similar to the apparatus of Figure 1 but in which the fuel injector meters fuel to four injection nozzles in accordance with this

invention; in this fuel injector a valve member which is solenoid operated meters fuel through a cylindrical fuel distribution chamber to fuel discharge passages and fuel discharge lines that lead to the injection nozzles, a rectifier valve disc admits air through the fuel distribution chamber to the fuel discharge passages and fuel discharge lines, and an air inlet is provided for air lines that surround the fuel discharge lines;

Figure 8 is a view, indicated by the line 8-8 of Figure 7, of the fuel inlet side of the injector base of the fuel injector;

Figure 9 is an enlarged sectional view of another fuel injector for apparatus similar to that in Figure 1; in this fuel injector a valve member which is solenoid operated meters fuel through an open fuel chamber to fuel discharge passages and fuel discharge lines that lead to the injection nozzles, a diaphragm valve admits air to the fuel discharge passages and fuel discharge lines, and an air inlet is provided for air lines that surround the fuel discharge lines;

Figure 10 is a further enlarged view of a portion of the fuel injector of Figure 9, showing the diaphragm valve and its environment;

Figure 11 is an enlarged sectional view of another fuel injector that meters fuel to six injection nozzles in accordance with this invention; in this fuel injector a pair of (solenoid operated) valve members meter fuel and air directly to fuel discharge passages and fuel discharge lines that lead to the injection nozzles;

Figure 12 is a view indicated by the line 12-12 of Figure 11, showing the fuel inlet side of the injector base of the fuel injector of Figure 11;

Figure 13 is a view, indicated by the line 13-13 of Figure 11, showing the air inlet side of the injector base of the fuel injector of Figure 11;

Figure 14 is a schematic view of another fuel injection apparatus having a single fuel injector that meters fuel to three injection nozzles in accordance with this invention;

Figure 15 is an enlarged sectional view of the fuel injector of Figure 14, showing a (solenoid operated) valve member that meters fuel through a cylindrical fuel distribution chamber to fuel discharge passages and fuel discharge lines that lead to the injection nozzles, and an air inlet for air lines that surround the fuel discharge lines;

Figure 16 is an enlarged view of the tip of the injection nozzles of Figure 14;

Figure 17 is a sectional view of the tip of Figure 16, taken along line 17-17 of Figure 16;

Figure 18 is an enlarged view of another tip for the injection nozzles of Figure 14;

Figure 19 is a sectional view of the tip of Figure 18, taken along line 19-19 of Figure 18;

Figure 20 is a schematic view of yet another fuel injection apparatus having a single fuel injector that meters fuel to six injection nozzles in accordance with this invention;

Figure 21 is an enlarged sectional view of the fuel injector of Figure 20 showing a (solenoid operated) valve member that meters fuel directly to fuel discharge passages and fuel discharge lines that lead to the injection nozzles;

Figure 22 is an enlarged sectional view of the injection nozzles of Figure 20; and

Figure 23 is an enlarged sectional view of another tip for the injection nozzle of Figure 1.

Referring first to the fuel injection apparatus of Figures 1 through 6, a single fuel injector 10 receives fuel from a source of fuel at a desired pressure and meters fuel into six fuel discharge lines 12. Each fuel discharge line 12 leads to an injection nozzle 14 that delivers the metered fuel into the stream of air flowing through one of the inlet manifold runners 16 and one of the inlet ports 18 to one of the combustion chambers 20 of a six cylinder engine 21.

Fuel injector 10 has a housing 22 with a fuel inlet port 24 and an excess fuel outlet port 26 that establish a path for fuel flow through housing 22. Housing 22 is secured to an injector base 28. A valve member 30 which is solenoid operated controls fuel flow from housing 22 through an annular region 32 of injector base 28 to six fuel discharge passages 34 that receive fuel discharge lines 12.

Injector base 28 has a central bore 36 and includes a plug 38 received in central bore 36 to define a cylindrical fuel distribution chamber 40 between plug 38 and central bore 36. The upper portion of plug 38 has a hexagonal configuration, the points 44 of which engage central bore 36 to divide cylindrical fuel distribution chamber 40 into six sectors 46. Each sector 46 opens into one of the fuel discharge passages 34.

The surface 48a surrounding central bore 36 and the surface 48b at the perimeter of plug 38 form an annular valve surface bounding annular region 32. A spring 50 biases valve member 30 into engagement with surfaces 48a,b to interrupt fuel flow through annular region 32. When energized, a solenoid coil 52 lifts valve member 30 against the bias of spring 50 to permit fuel flow through annular region 32 and the sectors 46 of cylindrical fuel distribution chamber 40 to fuel discharge passages 34 and fuel discharge lines 12.

When valve member 30 is lifted from surfaces 48a,b, fuel flows through a cylindrical area between valve member 30 and surface 48a. That cylindrical area is determined both by the radius of central bore 36 and by the height to which valve member 30 is lifted above surfaces 48a,b. As the radius of central bore 36 is increased, the height to which

valve member 30 must be lifted may be decreased without restricting fuel flow into annular region 32. By using plug 38 to form the fuel flow region as an annular region 32 and to form the fuel distribution chamber as a cylindrical fuel distribution chamber 40, the radius is increased without increasing the desired area for the fuel flow region and the desired volume for the fuel distribution chamber. The use of an annular fuel flow region accordingly reduces the motion of the valve member 30 as it is lifted by solenoid coil 52.

To further reduce the motion of valve member 30 as it is lifted by solenoid coil 52, valve member 30 has an aperture 54 opening from housing 22 to a space 56 beneath valve member 30 within surface 48b. Thus when valve member 30 is lifted by solenoid coil 52, fuel flows into annular region 32 both around valve member 30 and through aperture 54 and space 56. It will be understood, therefore, that the clearance required between valve member 30 and surface 48a is less with aperture 54 providing a path for fuel flow between valve member 30 and surface 48b into annular region 32 than would be required if it were necessary for all fuel flow into annular region 32 to pass around valve member 30 and between valve member 30 and surface 48a.

Fuel injector 10 is controlled to meter fuel in a conventional manner by energizing solenoid coil 52 with a pulse width modulated current. As the pulse width is increased, valve member 30 is lifted for an increased length of time to increase the duration of fuel flow into fuel discharge lines 12.

Plug 38 has a recess 58 open to the atmosphere and six ports 60 opening slightly downwardly from recess 58 into the sectors 46 of cylindrical fuel distribution chamber 40. A hollow valve seat member 62 is received in recess 58 and has a valve seat 64 which is upwardly facing. A rectifier valve disc 66 of lightweight Mylar rests on valve seat 64. Recess 58, valve seat 64 and rectifier valve disc 66 define air valve means.

Injector base 28 has a larger recess 68 open to the atmosphere and six air passages 70 surrounding fuel discharge lines 12. Air passages 70 receive air lines 72 that are disposed concentrically about fuel discharge lines 12.

Further details of the construction of fuel injector 10 are set forth in US patent 4572436 and will not be repeated here.

Fuel discharge lines 12 and air lines 72 terminate in injection nozzles 14. Each injection nozzle 14 has a fluted insert 74 with a tapered tip 76 engaged in the end of fuel discharge line 12 and a tapered base 78 engaged in the end of air line 72.

Fluted insert 74 aligns fuel discharge line 12 within air line 72, and its flutes 80 deliver the fuel and air into the stream of air flowing through the inlet manifold runner 16.

In operation, the atmospheric pressure in larger recess 68 induces air to flow through air lines 72 to the subatmospheric pressure in the inlet ports 18, and the atmospheric pressure in recess 58 induces air to flow past rectifier valve disc 66 and through ports 60, sectors 46 of cylindrical fuel distribution chamber 40, and fuel discharge passages 34 and fuel discharge lines 12 to the subatmospheric pressure in inlet ports 18. When solenoid coil 52 lifts valve member 30 and fuel flows through annular region 32 into the sectors 46 of cylindrical fuel distribution chamber 40, the increased pressure in cylindrical fuel distribution chamber 40 stops air flow through ports 60 from recess 58 and engages rectifier valve disc 66 with its valve seat 64. When solenoid coil 52 is deenergized and spring 50 engages valve member 30 against surfaces 48a,b, air will again be induced to flow from recess 58 past rectifier valve disc 66 and through ports 60, sectors 46 of cylindrical fuel distribution chamber 40, and fuel discharge passages 34 and fuel discharge lines 12.

Air flow through the sectors 46 of cylindrical fuel distribution chamber 40 and the fuel discharge passages 34 and fuel discharge lines 12 allows the inertia of the fuel to maintain its discharge velocity, and reduces propagation of pressure waves through fuel discharge lines 12 as valve member 30 is lifted from and engaged with surfaces 48a,b. Such air flow also provides a source of air at substantially atmospheric pressure immediately below valve member 30, thereby providing an essentially constant pressure in the annular region 32 to which valve member 30 delivers fuel.

Fuel discharge passages 60 open from the bottom of sectors 46, while ports 60 open slightly downwardly into the upper portion of sectors 46. With this construction, it is thought that fuel flow through sectors 46 past ports 60 will create a suction tending to assist in quickly lifting rectifier valve disc 66 from its valve seat 64.

Air flow through air lines 72 thermally insulates fuel discharge lines 12, and provides a source of air at substantially atmospheric pressure at the tip of injection nozzles 14 where the fuel is introduced into the stream of air flowing through the inlet ports 18.

In the particular application for which this embodiment of the invention was developed, injection nozzle 14 is proportioned so that the vacuum in a zone 82 within air line 72 at the end of fuel discharge line 12 is about 10% of the vacuum in the intake port 18 at the end of the injection nozzle 14 (that is, the difference between the pressure in

zone 82 and the atmospheric pressure is about 10% of the difference between the pressure in intake port 18 and the atmospheric pressure). In that same application, fuel discharge line 12 is formed of tubing with a 0.864mm (0.034in) inside diameter and a 1.60 mm (0.063in) outside diameter, and air line 72 is formed of tubing with a 2.36mm (0.093in) inside diameter and a 3.00mm (0.118in) outside diameter. Other parts are sized accordingly.

Referring next to the fuel injector of Figures 7 and 8, a single fuel injector 110 receives fuel from a source of fuel at a desired pressure and meters fuel into four fuel discharge lines 112. Each fuel discharge line 112 leads to an injection nozzle that delivers the metered fuel into the stream of air flowing through one of the inlet manifold runners and one of the inlet ports to one of the combustion chambers of a four cylinder engine.

Fuel injector 110 has a housing 122 with a fuel inlet port 124 and an excess fuel outlet port that establish a path for fuel flow through housing 122. Housing 122 is secured to an injector base 128. A valve member 130 which is solenoid operated controls fuel flow from housing 122 through an annular region 132 of injector base 128 to four fuel discharge passages 134 that receive fuel discharge lines 122.

Injector base 128 has a central bore 136 and includes a plug 138 received in central bore 136 to define a cylindrical fuel distribution chamber 140 between plug 138 and central bore 136. The upper portion of plug 138 differs from the upper portion of plug 38 shown in Figures 2 and 3; plug 138 has a circular configuration, the circumference 144 of which is uniformly spaced from central bore 136. Cylindrical fuel distribution chamber 140 opens into the fuel discharge passages 134.

The surface 148a surrounding central bore 136 and the surface 148b at the perimeter of plug 138 form an annular valve surface bounding annular region 132. A spring 150 biases valve member 130 into engagement with surfaces 148a,b to interrupt fuel flow through annular region 132. When energized, a solenoid coil 152 lifts valve member 130 against the bias of spring 150 to permit fuel flow through annular region 132 and cylindrical fuel distribution chamber 140 to fuel discharge passages 134 and fuel discharge lines 112.

When valve member 130 is lifted from surfaces 148a,b, fuel flows through a cylindrical area between valve member 130 and surface 148a. That area is determined both by the radius of central bore 136 and by the height to which valve member 130 is lifted above surfaces 148a,b. As the radius of central bore 136 is increased, the height to which valve member 130 must be lifted may be decreased without restricting fuel flow into annular

region 132. By using plug 138 to form the fuel flow region as an annular region 132 and to form the fuel distribution chamber as a cylindrical fuel distribution chamber 140, the radius is increased without increasing the desired area for the fuel flow region and the desired volume for the fuel distribution chamber. The use of an annular fuel flow region accordingly reduces the motion of the valve member 130 as it is lifted by solenoid coil 152.

To further reduce the motion of valve member 130 as it is lifted by solenoid coil 152, valve member 130 has an aperture 154 opening from housing 122 to a space 156 beneath valve member 130 within surface 148b. Thus when valve member 130 is lifted by solenoid coil 152, fuel flows into annular region 132 both around valve member 130 and through aperture 154 and space 156. It will be understood, therefore, that the clearance required between valve member 130 and surface 148a is less with aperture 154 providing a path for fuel flow between valve member 130 and surface 148b into annular region 132 than would be required if it were necessary for all fuel flow into annular region 132 to pass around valve member 130 and between valve member 130 and surface 148a.

Plug 138 has a recess 158 open to the atmosphere and four ports 160 opening horizontally from recess 158 into cylindrical fuel distribution chamber 140 opposite fuel discharge passages 134. A hollow valve seat member 162 is received in recess 158 and has a valve seat 164 which is upwardly facing. A rectifier valve disc 166 of lightweight Mylar rests on valve seat 164. Recess 158, valve seat 164 and rectifier valve disc 166 define air valve means.

Injector base 128 has a larger recess 168 open to the atmosphere and four air passages 170 surrounding fuel discharge lines 112. Air passages 170 receive air lines 172 that are disposed concentrically about fuel discharge lines 112.

Fuel injector 110 is in other respects similar to fuel injector 10, and further details of construction are set forth in US patent 4572436 and will not be repeated here.

In operation, the atmospheric pressure in larger recess 168 induces air to flow through air lines 172 to the subatmospheric pressure in the inlet ports, and the atmospheric pressure in recess 158 induces air to flow past rectifier valve disc 166 and through ports 160, across cylindrical fuel distribution chamber 140, and through fuel discharge passages 134 and fuel discharge lines 112 to the subatmospheric pressure in the inlet ports. When solenoid coil 152 lifts valve member 130 and fuel flows through annular region 132 into cylindrical fuel distribution chamber 140, the increased pressure in cylindrical fuel distribution chamber 140 stops air flow through ports 160 from recess 158 and engages

rectifier valve disc 166 with its valve seat 164. When solenoid coil 152 is deenergized and spring 150 engages valve member 130 against surfaces 148a,b, air will again be induced to flow from recess 158 past rectifier valve disc 166 and through ports 160, cylindrical fuel distribution chamber 140, and fuel discharge passages 134 and fuel discharge lines 112.

Air flow through cylindrical fuel distribution chamber 140 and the fuel discharge passages 134 and fuel discharge lines 112 allows the inertia of the fuel to maintain its discharge velocity, and reduces propagation of pressure waves through fuel discharge lines 112 as valve member 130 is lifted from and engaged with surfaces 148a,b. Such air flow also provides a source of air at substantially atmospheric pressure immediately below valve member 130, thereby providing an essentially constant pressure in the annular region 132 to which valve member 130 delivers fuel.

Air flow through air lines 172 thermally insulates fuel discharge lines 112, and provides a source of air at substantially atmospheric pressure at the tip of the injection nozzles where the fuel is introduced into the stream of air flowing through the inlet ports.

Referring now to the fuel injector of Figures 9 and 10, a single fuel injector 210 receives fuel from a source of fuel at a desired pressure and meters fuel into six fuel discharge lines 212. Each fuel discharge line 212 leads to an injection nozzle that delivers the metered fuel into the stream of air flowing through one of the inlet manifold runners and one of the inlet ports to one of the combustion chambers of a six cylinder engine.

Injector 210 has a housing 222 with a fuel inlet port 224 and an excess fuel outlet port that establish a path for fuel flow through housing 222. Housing 222 is secured to an injector base 228. A valve member 230 which is solenoid operated controls fuel flow from housing 222 through an annular region 232 of injector base 228 to six fuel discharge passages 234 that receive fuel discharge lines 212.

Injector base 228 includes a plate 235 that has a central bore 236 leading to annular region 232. Annular region 232 opens directly into the fuel discharge passages 234.

The surface 248 surrounding central bore 236 forms an annular valve surface. A spring 250 biases valve member 230 into engagement with surface 248 to interrupt fuel flow through annular region 232. When energized, a solenoid coil 252 lifts valve member 230 against the bias of spring 250 to permit fuel flow through annular region 232 to fuel discharge passages 234 and fuel discharge lines 212.

Injector base 228 has another bore 258 opening from the atmosphere into annular region 232. A diaphragm 266 is sandwiched between the main portion of injector base 228 and its plate 235, overlying a valve seat surface 264 on annular region 232 and separating the central bore 236 from the bore 258. Diaphragm 266 has six apertures 267 aligned with fuel discharge passages 234. Bore 258, valve seat surface 264 and diaphragm 266 define air flow means.

Injector base 228 has a larger recess 268 open to the atmosphere and six air passages 270 surrounding fuel discharge lines 212. Air passages 270 receive air lines 272 that are disposed concentrically about fuel discharge lines 212.

Fuel injector 210 is in other respects similar to fuel injector 10, and further details of construction are set forth in US patent 4572436 and will not be repeated here.

In operation, the atmospheric pressure in larger recess 268 induces air to flow through air lines 272 to the subatmospheric pressure in the inlet ports, and the atmospheric pressure in bore 258 induces air to flow beneath diaphragm 266 and through fuel discharge passages 234 and fuel discharge lines 212 to the subatmospheric pressure in the inlet ports. When solenoid coil 252 lifts valve member 230 and fuel flows through central bore 236, the increased pressure in central bore 236 engages diaphragm 266 with annular region 232, thereby obstructing air flow from bore 258 to fuel discharge passages 234 and fuel discharge lines 212. When solenoid coil 252 is deenergized and spring 250 engages valve member 230 against surface 248, air will again be induced to lift diaphragm 266 from annular region 232 and flow from bore 258 through fuel discharge passages 234 and fuel discharge lines 212.

Air flow through fuel discharge passages 234 and fuel discharge lines 212 allows the inertia of the fuel to maintain its discharge velocity, and reduces propagation of pressure waves through fuel discharge lines 212 as valve member 230 is lifted from and engaged with surface 248. Such air flow also provides a source of air at substantially atmospheric pressure immediately below valve member 230, thereby providing an essentially constant pressure in the annular region 232 to which valve member 230 delivers fuel.

Air flow through air lines 272 thermally insulates fuel discharge lines 212, and provides a source of air at substantially atmospheric pressure at the tip of the injection nozzles where the fuel is introduced into the stream of air flowing through the inlet ports.

Referring to the fuel injector of Figures 11 through 13, a single fuel injector 310 receives fuel from a source of fuel at a desired pressure and meters fuel into six fuel discharge lines 312. Each fuel discharge line 312 leads to an injection nozzle that delivers the metered fuel into the stream of air flowing through one of the inlet manifold runners and one of the inlet ports to one of the combustion chambers of a six cylinder engine.

Fuel injector 310 has a housing 322a with a fuel inlet port 324a and an excess fuel outlet port that establish a path for fuel flow through housing 322a. Housing 322a is secured to an injector base 328. A valve member 330a which is solenoid operated controls fuel flow from housing 322a through an annular region 332a of injector base 328 to six fuel discharge passages 334a that extend to fuel discharge lines 312.

Annular region 332a includes a surface 348a. A spring 350a biases valve member 330a into engagement with surface 348a to interrupt fuel flow through annular region 332a. When energized, a solenoid coil 352a lifts or retracts valve member 330a against the bias of spring 350a to permit fuel flow through annular region 332a to fuel discharge passages 334a and fuel discharge lines 312.

Fuel injector 310 also has a housing 322b with an air inlet port 324b. Housing 322b is secured to injector base 328. A valve member 330b which is solenoid operated controls air flow from housing 322b through an annular region 332b of injector base 328 to six air discharge passages 334b that extend to fuel discharge lines 312.

Annular region 332b includes a surface 348b. A spring 350b biases valve member 330b into engagement with surface 348b to interrupt air flow through annular region 332b. When energized, a solenoid coil 352b retracts valve member 330b against the bias of spring 350b to permit air flow through annular region 332b to air discharge passages 334b and fuel discharge lines 312. Annular region 332b, surface 348b, valve member 330b and solenoid coil 352b define air valve means.

To reduce the motion of valve members 330a,b as they are retracted by solenoid coils 352a,b, valve members 330a,b have apertures 354a,b opening from housings 322a,b to the centre of annular regions 332a,b. Thus when valve members 330a,b, are retracted by solenoid coils 352a,b, fuel and air flow into annular regions 332a,b both around valve members 330a,b and through apertures 354a,b. It will be understood, therefore, that the clearance required between valve members 330a,b and surfaces 348a,b is less with apertures 354a,b providing paths for fuel and air flow between valve members 330a,b and surfaces 348a,b into annular

regions 332a,b than would be required if it were necessary for all fuel and air flow into annular regions 332a,b to pass around valve members 330a,b.

Fuel injector 310 is in other respects similar to fuel injector 10, and further details of construction are set forth in US patent 4572436 and will not be repeated here.

In operation, solenoid coils 352a,b are energized alternately. When solenoid coil 352b is energized, the pressure in housing 322b induces air to flow through air discharge passages 334b and fuel discharge lines 312 to the subatmospheric pressure in the inlet ports. When solenoid coil 352a is energized, fuel flows through annular region 332a to fuel discharge passages 334a and fuel discharge lines 312.

Air flow through the fuel discharge lines 312 allows the inertia of the fuel to maintain its discharge velocity, and reduces propagation of pressure waves through fuel discharge lines 312 as valve member 330a is lifted from and engaged with surface 348a. Such air flow also creates an essentially constant pressure in the annular region 332a to which valve member 330a delivers fuel.

Referring to the fuel injection apparatus of Figures 14 through 17, a single fuel injector 410 receives fuel from a source of fuel at a desired pressure and meters fuel into three fuel discharge lines 412. Each fuel discharge line 412 leads to an injection nozzle 414 that delivers the metered fuel into the stream of air flowing through one of the inlet manifold runners 416 and one of the inlet ports 418 to one of the combustion chambers 420 of a three cylinder engine 421.

Fuel injector 410 has a housing 422 with a fuel inlet port 424 and an excess fuel outlet port that establish a path for fuel flow through housing 422. Housing 422 is secured to an injector base 428. A valve member 430 which is solenoid operated controls fuel flow from housing 422 through an annular region 432 of injector base 428 to three fuel discharge passages 434 that receive fuel discharge lines 412.

Injector base 428 has a central bore 436 and includes a plug 438 received in central bore 436 to define a cylindrical fuel distribution chamber 440 between plug 438 and central bore 436. The upper portion of plug 438 has a cylindrical configuration, the circumference 444 of which is evenly spaced from central bore 436. Cylindrical fuel distribution chamber 440 opens into the fuel discharge passages 434.

The surface 448a surrounding central bore 436 and the surface 448b at the perimeter of plug 438 form an annular valve surface bounding annular region 432. A spring 450 biases valve member 430 into engagement with surfaces 448a,b to interrupt

fuel flow through annular region 432. When energized, a solenoid coil 452 lifts valve member 430 against the bias of spring 450 to permit fuel flow through annular region 432 and cylindrical fuel distribution chamber 440 to fuel discharge passages 434 and fuel discharge lines 412.

When valve member 430 is lifted from surfaces 448a,b, fuel flows through a cylindrical area between valve member 430 and surface 448a. That cylindrical area is determined both by the radius of central bore 436 and by the height to which valve member 430 is lifted above surfaces 448a,b. As the radius of central bore 436 is increased, the height to which valve member 430 must be lifted may be decreased without restricting fuel flow into annular region 432. By using plug 438 to form the fuel flow region as an annular region 432 and to form the fuel distribution chamber as a cylindrical fuel distribution chamber 440, the radius is increased without increasing the desired area for the fuel flow region and the desired volume for the fuel distribution chamber. The use of an annular fuel flow region accordingly reduces the motion of the valve member 430 as it is lifted by solenoid coil 452.

To further reduce the motion of valve member 430 as it is lifted by solenoid coil 452, valve member 430 has an aperture 454 opening from housing 422 to a space 456 beneath valve member 430 within surface 448b. Thus when valve member 430 is lifted by solenoid coil 452, fuel flows into annular region 432 both around valve member 430 and through aperture 454 and space 456. It will be understood, therefore, that the clearance required between valve member 430 and surface 448a is less with aperture 454 providing a path for fuel flow between valve member 430 and surface 448b into annular region 432 than would be required if it were necessary for all fuel flow into annular region 432 to pass around valve member 430 and between valve member 430 and surface 448a.

Injector base 428 has a recess 468 open to the atmosphere and three air passages 470 surrounding fuel discharge lines 412. Air passages 470 receive air lines 472 that are disposed concentrically about fuel discharge lines 412.

Fuel injector 410 is in other respects similar to fuel injector 10, and further details of construction are set forth in US patent 4572436 and will not be repeated here.

Fuel discharge lines 412 and air lines 472 terminate in injection nozzles 414. The end 475 of each injection nozzle 414 is closed, and each injection nozzle has four lateral apertures 477 to deliver the fuel and air into the stream of air flowing through the inlet manifold runner 416. Each lateral aperture 477 includes a small aperture 479 opening from fuel discharge line 412 into air line 472 and a larger aperture 481 opening from air line 472.

In operation, the atmospheric pressure in recess 468 induces air to flow through air lines 472 to the subatmospheric pressure in the inlet manifold runners 416. When solenoid coil 452 lifts valve member 430, fuel flows through annular region 432, cylindrical fuel distribution chamber 440, and fuel discharge passages 434 and fuel discharge lines 412 and is injected through the zone 482 within air line 472 at the end of fuel discharge line 412.

Air flow through air lines 472 thermally insulates fuel discharge lines 412, and provides a source of air at substantially atmospheric pressure at the tip of injection nozzles 414 where the fuel is introduced into the stream of air flowing through the inlet manifold runner 416.

In the particular application for which this embodiment of the invention was developed, fuel discharge line 412 is formed of tubing with a 0.864mm (0.034in) inside diameter and a 1.60mm (0.063in) outside diameter, and air line 472 is formed of tubing with a 2.95mm (0.116in) inside diameter and a 3.96mm (0.156in) outside diameter. Apertures 479 are 0.356mm (0.014in) in diameter, and apertures 481 are 1.02mm (0.040in) in diameter. Other parts are sized accordingly.

Referring to the injection nozzle of Figures 18 and 19, fuel discharge line 512 and air line 572 terminate in injection nozzle 514. The end 575 of injection nozzle 514 is closed by an insert 574, and the injection nozzle has four lateral apertures 577 to deliver the fuel and air into the stream of air flowing through the inlet manifold runner. Each lateral aperture 577 includes a small aperture 579 opening from fuel discharge line 512 into air line 572 and a larger aperture 581 opening from air line 572.

In the particular application for which this embodiment of the invention was developed, fuel discharge line 512 is formed of tubing with a 0.711mm (0.028in) inside diameter and a 1.60mm (0.063in) outside diameter, and air line 572 is formed of tubing with a 2.36mm (0.093in) inside diameter and a 3.00mm (0.118in) outside diameter. Small apertures 579 are 0.356mm (0.014in) in diameter, and larger apertures 581 are 0.635mm (0.025in) in diameter.

Referring to the fuel injection apparatus of Figures 20 through 22, a single fuel injector 610 receives fuel from a source of fuel at a desired pressure and meters fuel into six fuel discharge lines 612. Each fuel discharge line 612 leads to an injection nozzle 614 that delivers the metered fuel into the stream of air flowing through one of the inlet manifold runners 616 and one of the inlet ports 618 to one of the combustion chambers 620 of a six cylinder engine 621.

Fuel injector 610 has a housing 622 with a fuel inlet port 624 and an excess fuel outlet port 626 that establish a path for fuel flow through housing 622. Housing 622 is secured to an injector base 628. A valve member 630 which is solenoid operated controls fuel flow from housing 622 through an annular region 632 of injector base 628 to six fuel discharge passages 634 that extend to fuel discharge lines 612.

Annular region 632 includes a surface 648. A spring 650 biases valve member 630 into engagement with surface 648 to interrupt fuel flow through annular region 632. When energized, a solenoid coil 652 lifts valve member 630 against the bias of spring 650 to permit fuel flow through annular region 632 to fuel discharge passages 634 and fuel discharge lines 612.

To reduce the motion of valve member 630 as it is lifted by solenoid coil 652, valve member 630 has an aperture 654 opening from housing 622 to the centre of annular region 632. Thus when valve member 630 is lifted by solenoid coil 652, fuel flows into annular region 632 both around valve member 630 and through aperture 654. It will be understood, therefore, that the clearance required between valve member 630 and surface 648 is less with aperture 654 providing a path for fuel flow between valve member 630 and surface 648 into annular region 632 than would be required if it were necessary for all fuel flow into annular region 632 to pass around valve member 630 and between valve member 630 and surface 648.

Fuel injector 610 is in other respects similar to fuel injector 10, and further details of construction are set forth in US patent 4572436 and will not be repeated here.

Each fuel discharge line 612 terminates in an orifice 679 in an injection nozzle 614. Each injection nozzle 614 has an air line 672 opening from the atmosphere and terminating in an orifice 681. Injection nozzles 614 deliver the fuel and air into the stream of air flowing through the inlet ports 618.

In operation, the atmospheric pressure induces air to flow through air lines 672 to the subatmospheric pressure in the inlet ports 618. When solenoid coil 652 is energized, fuel flows through annular region 632 to fuel discharge passages 634 and fuel discharge lines 612.

Air flow through air lines 672 provides a source of air at substantially atmospheric pressure at the tip of injector nozzles 614 where the fuel is introduced into the stream of air flowing through the inlet ports 618.

Referring to the injection nozzle of Figure 23, fuel discharge line 712 and air line 772 terminate in injection nozzle 714. To form injection nozzle 714, the open end 775 of each air line 772 is reduced, and the open end of each fuel line 712 is spaced from the open end 775 of the associated air line 772.

Each fuel line 712 is formed with a helically coiled section 783 that embraces the inner wall 785 of the associated air line 772 to support the fuel discharge line 712 within the air line 772.

In the particular application for which this embodiment of the invention was developed, fuel discharge line 712 is formed of tubing with a 0.864mm (0.034in) inside diameter and a 1.57mm (0.062in) outside diameter, air line 772 is formed of tubing with a 3.05mm (0.120in) inside diameter and a 3.96mm (0.156in) outside diameter, and the helically coiled section 783 has a free overall diameter of at least 3.18mm (0.125in) to assure that it will be compressively engaged with the inside wall 785 of the air line 772. The open end 775 of each air line 772 is reduced to an inside diameter of 1.4mm (0.055in) over a length of 1.02mm (0.04in), and the spacing between the end of the fuel discharge line 712 and the open end 775 of the air line 772 is adjusted for the desired fuel spray characteristic.

Injection nozzles 714 may be employed to directly replace injection nozzles 14 in the Figure 1 embodiment. In another embodiment, however, the fuel injector shown in figure 2 is mounted in the top of an inlet manifold plenum with the terminals for the solenoid coil projecting outside and the concentric fuel and air lines extending inside the manifold through the manifold plenum and runners to injection nozzles 714. Such a construction presents an improved appearance and protects the concentric fuel and air lines against damage, while still allowing injection nozzles 714 to deliver metered fuel into the stream of air flowing through the inlet ports to the engine combustion chambers. In such a construction, of course, an air supply line must extend from a source of clean air to the base of the fuel injector.

Claims

1. A fuel injector (10) for metering fuel to a plurality of injection nozzles (14), the fuel injector comprising an injector base (28) having a plurality of fuel discharge passages (34) and an annular region (32) through which fuel is delivered to the fuel discharge passages, each of the fuel discharge passages being adaptable to direct fuel to one of the injection nozzles, the annular region including a valve surface (48), a single valve member (30) associated with the valve surface, the valve mem-

ber being adapted to engage the valve surface to preclude fuel delivery to the fuel discharge passages, a solenoid (52) adapted to disengage the valve member from the valve surface to permit fuel delivery to the fuel discharge passages, characterised by air valve means (58, 64, 66) for controlling flow of air to the fuel discharge passages (34) and being adapted to preclude air flow to the fuel discharge passages when the valve member permits fuel delivery to the fuel discharge passages and to admit air to the fuel discharge passages when the valve member precludes fuel delivery to the fuel discharge passages.

2. A fuel injector as claimed in Claim 1, characterised in that the air valve means comprises an opening (58, 158) in the injector base (28) through which air can flow to the fuel discharge passages (34), a valve seat (64, 164) surrounding the opening, and a rectifier valve (66, 166) associated with the valve seat, the rectifier valve being pressure responsive and thereby being adapted to engage the valve seat to preclude air flow through the opening when the valve member (30) permits fuel delivery to the fuel discharge passages and to disengage the valve seat to admit air to the fuel discharge passages when the valve member precludes fuel delivery to the fuel discharge passages.

3. A fuel injector as claimed in Claim 2, characterised in that the rectifier valve is a rectifier valve disc (66, 166).

4. A fuel injector as claimed in any one of Claims 1 to 3, characterised in that the injector base (28) has a central bore (36) and includes a plug (38) received in the central bore to define a fuel distribution chamber (40) between the plug and the central bore, the fuel discharge passages (34) opening from the fuel distribution chamber, and the valve surface (48) including a first portion (48a) surrounding the central bore and a second portion (48b) at the perimeter of the plug.

5. A fuel injector as claimed in Claim 4, characterised in that the plug (38) engages the central bore (36) at peripherally spaced locations (44) to divide the fuel distribution chamber (40) into a plurality of sectors (46), each of the fuel discharge passages (34) opening from one of the sectors.

6. A fuel injector as claimed in Claim 1, characterised in that the air valve means comprises an opening (258) in the injector base (228) through which air flows to the fuel discharge passages (234), the annular region (232) including a valve seat surface (264), and a diaphragm (266) overlying the valve seat surface, the diaphragm being pressure responsive and thereby being adapted to engage the valve seat surface to preclude air flow through the opening when the valve member (230) permits fuel delivery to the fuel discharge passages and to disengage the valve seat surface to

admit air to the fuel discharge passages when the valve member precludes fuel delivery to the fuel discharge passages.

7. A fuel injector as claimed in Claim 1, characterised in that the air valve means comprises an additional annular region (332b) in the injector base (328) through which air flows to the fuel discharge passages (334a,b), the additional annular region including an additional valve surface (348b), an additional single valve member (330b) associated with the additional valve surface, the additional valve member being adapted to engage the additional valve surface to preclude air flow to the fuel discharge passages, and an additional solenoid (352b) adapted to disengage the additional valve member from the additional valve surface to permit air flow to the fuel discharge passages.

8. A fuel injector (10, 410) for metering fuel to a plurality of injection nozzles (1, 414), the fuel injector comprising an injector base (28, 428) having a plurality of fuel discharge passages (34, 434) opening from a fuel distribution chamber (40, 440), each of the fuel discharge passages being adaptable to direct fuel to one of the injection nozzles, the injector base having an annular valve surface (48, 448a,b), a single valve member (30, 430) associated with the annular valve surface, the valve member being adapted to engage the annular valve surface to preclude fuel delivery into the fuel distribution chamber, and a solenoid (52, 452) adapted to disengage the valve member from the annular valve surface to permit fuel delivery to the fuel distribution chamber and thereby to the fuel discharge passages, characterised in that the injector base (28, 48) has a central bore (36, 436), and includes a plug (38, 438) received in the central bore to define the fuel distribution chamber (40, 440) between the plug and the central bore, and in that the annular valve surface includes a first portion (48a, 448a) surrounding the central bore and a second portion (48b, 448b) at the perimeter of the plug.

9. A fuel injector as claimed in Claim 8, characterised in that the plug (38) engages the central bore (36) at peripherally spaced locations (44) to divide the fuel distribution chamber (40) into a plurality of sectors (46), each of the fuel discharge passages (34) opening from one of the sectors.

10. A fuel injector (310, 610) for metering fuel to a plurality of injection nozzles (614), the fuel injector comprising a base (328, 628) having an annular valve surface (348, 648) and a plurality of fuel discharge passages (334a, 634) opening through the annular valve surface, each of the fuel discharge passages being adaptable to direct fuel to one of the injection nozzles, a single valve member (330a, 630) associated with said valve surface, the valve member being adapted to engage the annular

valve surface to preclude fuel delivery to the fuel discharge passages, and a solenoid (352a, 652) adapted to disengage the valve member from the annular valve surface to permit fuel delivery to the fuel discharge passages.

II. A fuel injector as claimed in Claim 10, characterised in that each of the fuel discharge passages including a first portion opening through the annular valve surface, each of the fuel discharge passages including a second portion extending at an angle to said first portion and being adaptable to direct fuel to one of the injection nozzles, and in that the injector base has an opening through which air flows to the fuel discharge passages, a valve seat surrounding the opening, and a rectifier valve disc associated with the valve seat, the rectifier valve disc being pressure responsive and thereby being adapted to engage the valve seat to preclude flow through the opening when the valve member permits fuel delivery to the fuel discharge passages and to disengage the valve seat to admit air to the fuel discharge passages when the valve member precludes fuel delivery to the fuel discharge passages.

12. Fuel injection apparatus for injecting fuel through a plurality of injection nozzles (14), the fuel injection apparatus comprising a fuel injector (10) having an injector base (28) with a plurality of fuel discharge passages (34) and an annular region (32) open to the fuel discharge passages, the annular region including a valve surface (48a,b), a valve member (30) associated with the valve surface, the valve member being adapted to engage the valve surface to preclude fuel delivery through the annular region to the fuel discharge passages, a solenoid (52) adapted to disengage the valve member from the valve surface to permit fuel delivery through the annular region to the fuel discharge passages, and a plurality of fuel discharge lines (12) respectively connected at one end to the fuel discharge passages and extending to the injection nozzles at the other end, characterised by the injector base further having an air inlet (68, 70) surrounding one end of each of the fuel discharge lines, and a plurality of air lines (72) connected at one end to the air inlet and respectively surrounding the fuel discharge lines and extending to the injection nozzles at the other end.

13. Fuel injection apparatus as claimed in Claim 12, characterised in that the fuel injector (10) comprises air valve means (58, 64, 66) for controlling flow of air to the fuel discharge passages (34) and being adapted to preclude air flow to the fuel discharge passages when the valve member permits fuel delivery to the fuel discharge passages and to admit air to the fuel discharge passages when the valve member precludes fuel delivery to the fuel discharge passages.

14. Fuel injection apparatus as claimed in Claim 12, characterised in that the annular region (32, 432) includes a fuel distribution chamber (40, 440), in that the injector base (28, 428) has a central bore (36, 436), and includes a plug (38, 438) received in the central bore to define the fuel distribution chamber (40, 440) between the plug and the central bore, and in that the valve surface (48, 448) includes a first portion (48a, 448a) surrounding the central bore and a second portion (48b, 448b) at the perimeter of the plug.

15. Fuel injection apparatus as claimed in Claim 12, characterised in that the fuel discharge passages (334a, 634) open through the valve surface (348, 648).

16. A fuel injection nozzle (414, 514) comprising a fuel discharge line (412, 512), an air line (472, 572) disposed concentrically about the fuel discharge line, a plurality of openings (479, 579) from the fuel discharge line into the air line, and a corresponding plurality of openings (481, 581) from the air line, each of the air line openings (481, 581) being aligned with its corresponding fuel discharge line opening (479, 579) and having a larger flow area than its corresponding fuel discharge line opening.

17. A fuel injection nozzle (714) comprising a fuel discharge line (712), an air line (772) disposed concentrically about the fuel discharge line, the end of the fuel discharge line opening into the air line, and the end (775) of the air line having a reduced opening, and wherein the fuel discharge line has a coiled section (783) engaging the inside (785) of the air line to support the fuel discharge line within the air line.

