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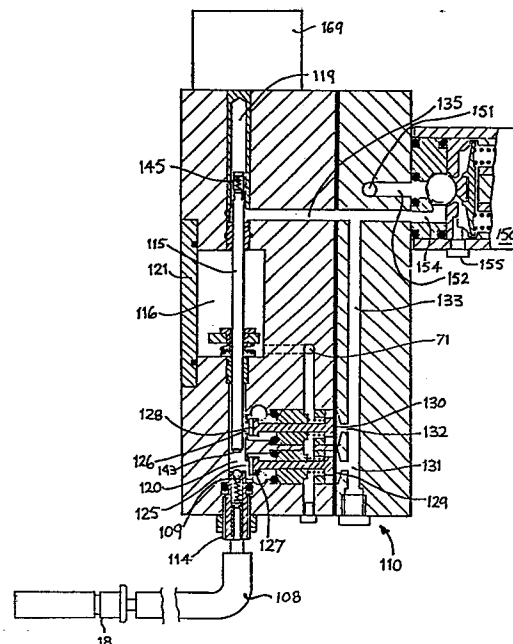
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Improved method of fuel injection.

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A method of injecting liquid fuel to an engine (120) comprising delivering a quantity of fuel into a conduit and propelling the fuel along the conduit by gas under pressure, and discharging the fuel from a fixed size constantly open nozzle (18) into an engine induction passage, the pressure and quantity of gas being sufficient to cause the fuel to issue from the nozzle at or near sonic speed.



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~~4~~BACKGROUND OF THE INVENTION

This invention relates to the delivery of measured quantities of liquid fuel into the induction passage of an internal combustion engine.

5 The various fuel injection systems currently in use, in internal combustion engines, operate on the basis of a column of liquid between the point of application of the injection force to the fuel and the delivery nozzle. These systems rely on the adding of a metered quantity of fuel to
10 the upstream end of the column to displace an equal quantity of fuel from the nozzle at the downstream end of the column. In order to achieve the required accuracy in the quantity of fuel delivered from the nozzle. The column of fuel must be free of gas, due to its compressible
15 nature.

It is also necessary for the nozzle to be selectively opened and closed to maintain the gas-free state of the column of fuel between successive deliveries, or to ensure sufficient delivery pressure for continuous
20 systems, to maintain the gas-free state of the fuel line.

These selectively openable nozzles are required to be high precision components in order to maintain metering integrity and/or consistent spray characteristics. Hence, manufacturing cost is high and susceptibility to fouling by
25 foreign materials in the fuel is prevalent. Additionally durability is a potential problem due to the frequency of opening of the nozzle for either a pulsed or continuous metering system. (In the latter case, the natural vibrational frequency of a spring-loaded nozzle is excited
30 even though output is nominally continuous.)

U.K. Patent No. 2,023,226 involves continuous injection of a fuel/air mixture into the inlet manifold of an internal combustion engine. Compressed air and fuel are delivered separately to a mixing chamber immediately
35 adjacent the injection nozzle, and the pressure in the mixing chamber actuates the valve in the nozzle to effect injection of the fuel/air mixture to the engine. The mixing

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chamber in the nozzle incorporates a porous sintered element, but it is believed this feature does not contribute significantly to proper atomization of the fuel. The required atomization is apparently achieved by the pressure drop through the valve, and the consequent sonic velocity. This injection system does not employ a constantly open injection nozzle, nor is the fuel conveyed to the nozzle by individual shots of air.

German patent No. 314,252 employs a constantly open nozzle and high pressure air to effect injection of fuel through the nozzle. A fuel dispensing surface (grid) is provided between a fuel storage chamber and the delivery nozzle, to assist atomization of the fuel. The disclosure relates to injectors for diesel engines, and it is not disclosed that the high pressure air contributes to atomization of the fuel.

Australian Patent No. 237,354 discloses an injection system wherein a constant supply of fuel is delivered to a constantly open nozzle as a continuous flow. There is no air associated with the conveying of the fuel to the respective nozzles, or the delivery of the fuel from these nozzles.

SUMMARY OF THE INVENTION

It is therefore the object of the present invention to provide a method of injecting metered quantities of fuel into an engine induction passage, that at least, reduces the above referred to problems in currently known methods.

With this object in view there is provided a method of delivering liquid fuel to an internal combustion engine comprising delivering a pre-determined quantity of liquid fuel into a conduit, admitting a gas to the conduit upstream of the quantity of fuel at a pressure and for a period sufficient to propel the quantity of fuel through the conduit and discharge the fuel through a fixed size constantly open nozzle at the downstream end of the conduit.

Accordingly, by this method each measured quantity

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of fuel is transported through the conduit and delivered from the nozzle independently, avoiding the necessity of maintaining the conduit full of fuel and free of gas, as required in the currently used systems.

5 It has been found that if the gas pressure and nozzle design is selected so the air issues therefrom at or near sonic speed, a high degree of atomisation of the fuel can be achieved.

10 Preferably the conduit is selected so that the frictional drag between the fuel and the internal surface of the conduit will result in at least portion of the fuel forming an emulsion with the propelling gas, during passage through the conduit. This emulsion is characterised by a high surface area to volume ratio.

15 The motion of the liquid fuel through the conduit will be resisted by shear stresses at the conduit walls, and under the action of these stresses, the inner core of liquid fuel will progress faster than that fuel at the walls. The velocity of the gas being faster than the liquid
20 fuel at the walls creates shear stresses over the liquid surface, breaking off droplets and entraining them in the gas flow creating the mixture of gas and liquid fuel.

 The variables of gas pressure, conduit length and conduit diameter may be varied within respective ranges to
25 achieve the desired mixing of the fuel and air. However, the provision of a minimum gas dose relative to the quantity of fuel makes the determination of conduit diameter, one of ensuring the smallest diameter which will pass the gas and fuel in the time available. In this way
30 the maximum surface to volume ratio is obtained and hence maximum break-up of droplets. Empirical tests define a satisfactory minimum gas dose.

 Preferably the nozzle is of a construction that creates a film of fuel immediately prior to discharge from
35 the nozzle, at least in the lower portion of the range of discharge rates encountered during operation, that is then broken up into fine droplets prior to issuing from the

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nozzle.

5 The breaking up is largely achieved by the movement of the propelling gas past a surface in the nozzle, which surface is in use, wetted by a film of fuel. This may be effected by providing, in the path of the fuel, a surface that diverges in the direction of movement of the fuel through the nozzle. Conveniently, the surface is generally conical and leads to an annular discharge port in the nozzle.

10 The creating of the film of fuel has the effect of increasing the surface area of fuel in contact with the propelling gas to assist atomisation. When handling quantities of fuel in the lower portion of the nozzle range, the film of fuel will not fully occupy the passage through the nozzle and therefore portion of the propelling gas will flow over the exposed surface of the fuel film. 15 The shear stresses created on the surface of the film will break off droplets of fuel to further promote atomisation of the fuel.

20 The fuel film is created by virtue of the change of direction of movement of the fuel by the presence of the divergent surface, which for convenience is frusto-conical and terminates in an annular delivery opening. The fuel with its implicit inertia will impinge on the cone surface and will spread thereover by virtue of its tendency to 25 continue to travel in its initial trajectory before meeting the surface.

As a guide to the surface area to be provided on the cone, the area is normally made sufficient to allow approximately half of the normal fuel pulse dose to be 30 resident thereon, assuming a film thickness equal to the width of the annular delivery opening. The final design may be empirically determined to optimise the nozzle shape.

DETAILED DESCRIPTION OF THE INVENTION

The invention will now be described in greater detail with reference to the accompanying drawings, in which:

5 Fig. 1 is a sectional view of one embodiment of injection nozzle constructed in accordance with the invention;

 Fig. 2 is a cross-sectional view of the nozzle of Fig. 1 taken along arrows 2-2;

10 Fig. 3 is a sectional view of another embodiment of the nozzle of the invention.

 Fig. 4 is a plan view of the metering apparatus applicable to a six cylinder engine and described in applicant's copending application based on Australian Patent Application No. PF 2123/81; and

15 Fig. 5 is a sectional view of the metering apparatus of Fig. 4, taken along the line 5-5 in Fig. 4.

 Fig. 1 shows one design of a nozzle having a frusto-conical film forming surface and an annular delivery opening. The nozzle body 5 is adapted at one end 6 to be coupled to a flexible fuel line. At the other end the body has an internal tapered bore 7 communicating with the passage 8 extending from the one end 6 of the body. The deflector member 9 is mounted in the bore 7 and has an external tapered surface 10. The angle of the tapered bore 7 is less than the angle of the surface 10 so that the annular passage 11 formed therebetween is tapered towards the annular delivery opening 12.

20 In one specific construction of the nozzle the taper of the bore 7 is 6° and the taper of the external surface 10 is 8° . The width of the annular opening is in the range of 0.1 to 0.15 mm at the exit. The axial length of the annular passage formed between the tapered surfaces is 10 to 12 mm.

35 As can be seen in Figure 2, a sectional view from arrows II-II in Figure 1, the shank 4 of the deflector

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member 9 is received in a central bore 3 with four bores 2 spaced thereabout to provide paths for the flow of fuel and gas to the nozzle. The bores 2 intersect the central bore 3 and the shank 4 is a press fit with the lands formed by the intersecting bores 2 and 3.

In an alternate construction as shown in figure 3, the nozzle has a parallel bore 15 of approximately 1.5 mm diameter and 1.0 to 2.0 mm long. This bore opens at the forward end into a co-axial expansion chamber 16 of a diameter of 6.0 mm and a length of 5.0 mm. The face 17 of the chamber through which the bore 15 enters is in a plane at right angles to the bore and chamber axis. The high rate of expansion produced by the high velocity air and fuel issuing from the bore 15 into the chamber, produces fine atomisation of the fuel.

In use it has been found that each of the nozzles illustrated achieve improved atomisation if the gas speed at the exit from the annular opening 11 (Figure 1) or bore 15 (Figure 3) is sonic or of that order. This speed can be achieved if the pressure drop across the nozzle opening is of 1 BAR or more.

The measured quantity of fuel may be measured and delivered into the conduit for delivery to either of the nozzles shown in Figures 1 and 3, by the metering apparatus disclosed in the applicant's co-pending application based on Australian Patent Application No. PF2123/81 and hereinafter described with reference to Figs. 4 and 5 of the accompanying drawings.

The metering apparatus comprises a body 110, having incorporated therein six individual metering units 111 arranged in side by side parallel relationship. The nipples 112 and 113 are adapted for connection to a fuel supply line and a fuel return line respectively, and communicate with respective galleries within the block 110 for the supply and return of fuel from each of the metering units 111. Each metering unit 111 is provided with an individual fuel delivery nipple 114 to which a line may be connected

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to communicate the metering unit with the injection nozzle.

Fig. 5 shows the metering rod 115 extending into the air supply chamber 119 and metering chamber 120. Each of the six metering rods 115 pass through the common leakage
5 collection chamber 116 which is formed by a cavity 116 provided in the body 110 and the coverplate 121 attached in sealed relation to the body 110.

Each metering rod 115 is axially slidable in the body 110 and the extent of projection of the metering rod
10 into the metering chamber 120 may be varied to adjust the quantity of fuel displacable from the metering chamber. The valve 143 at the end of the metering rod located in the metering chamber is normally held closed by the spring 145 to prevent the flow of air from the air supply chamber 119
15 to the metering chamber 120. Upon the pressure in the chamber 119 rising to a predetermined value the valve 143 is opened to admit the air to the metering chamber, and thus displace the fuel therefrom. The quantity of fuel displaced by the air is the fuel located in the chamber 120
20 between the point of entry of the air to the chamber, and the point of discharge of the fuel from the chamber, that is the quantity of fuel between the air admission valve 143 and the delivery valve 109.

Each of the metering rods 115 are coupled to the
25 crosshead 161, and the crosshead is coupled to the actuator rod 160 which is slidably supported in the body 110. The actuator rod 160 is coupled to the motor 169, which is controlled in response to the engine fuel demand, to adjust the extent of projection of the metering rods into the
30 metering chambers 120, and hence the position of the air admission valve 143 so the metered quantity of fuel delivered by the admission of the air is in accordance with the fuel demand.

The fuel delivery nipples each incorporate a
35 pressure actuated delivery valve 109 which opens in response to the pressure in the metering chamber 120 when the air is admitted thereto from the air supply chamber

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119. Upon the air entering the metering chamber through the valve 143 the delivery valve 109 also opens and the air will move towards the delivery valve displacing the fuel from the metering chamber through the delivery valve. The
5 valve 143 is maintained open until sufficient air has been supplied to displace the fuel between the valves 143 and 109 from the chamber along the delivery line 108 and through the nozzle 18, which is preferably a nozzle as described with reference to Figs. 1 and 2 or 3.

10 Each metering chamber 120 has a respective fuel inlet port 125 and a fuel outlet port 126 controlled by respective valves 127 and 128 to permit circulation of fuel through the chamber. Each of the valves 127 and 128 are spring-loaded to an open position, and are closed in
15 response to the application of air under pressure to the respective diaphragms 129 and 130 located in diaphragm cavities 131 and 132. Each of the diaphragm cavities are in constant communication with the air conduit 133 and the conduit 133 is also in constant communication with the air
20 supply chamber 119 by the conduit 135. Thus, when air under pressure is admitted to the chamber 119 to effect delivery of fuel, the diaphragms 129 and 130 close the fuel inlet and outlet ports 125 and 126.

The control of the supply of air to the conduit 133,
25 and hence the supply of air to the supply chamber 119 and the diaphragm cavities 131 and 132, is controlled in time relation with the cycling of the engine through the solenoid operated valve 150. The common air supply conduit 151 connected to a compressed air supply via nipple 153,
30 runs through the body with respective branches 152 providing air to the solenoid valve of each metering unit. The operation of the solenoid valve 150 may also be controlled to vary the duration of the period that air is supplied to the air chamber 119, to ensure the fuel
35 displaced from the metering chamber is delivered through the nozzle 18.

The admission of the air to the metering chamber may

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be controlled by an electronic processor, activated by signals from the engine that sense the fuel demand of the engine. The processor may be programmed to vary the frequency and duration of admission of the air to the metering chamber.

Full details of the operation of the metering apparatus can be obtained from applicant's co-pending application based on Australian Patent Application No. PF2123/81 and that disclosure is thereby incorporated in this specification.

The quantity of air used to propel each measured quantity of fuel is conveniently the same for all quantities of fuel within the range required for a particular engine. The use of a constant quantity of air simplifies the construction of the metering apparatus and the control equipment used therewith.

In applying the present invention to a four cylinder 1600 cc capacity engine 4,000 mm³ of air measured at S.T.P. per metered pulse to each cylinder is used throughout the full range of fuel supply which ranges from 4 to 80 mm³ per metered pulse. These volumes correspond to a 4 mg of air with 3-60 mg of fuel per injection. Under normal operating conditions, the amount of fuel may range from 5-30 mg per injection. It is considered preferable for the volumetric ratio of gas to fuel (volume at S.T.P.) be at least 50 to 1. If the ratio is significantly less than 50:1 it has been found that there is a delay in the response of the engine to changes in the metered quantity of fuel delivered.

It is believed that a high ratio of air to fuel reduces the amount of fuel that is left as a residue on the conduit and nozzle walls. The greater the amount of air passing through the conduit after each metered quantity of fuel, the less is the amount of fuel remaining on the wall of the conduit.

It is also believed that fuel stripped from the wall of the conduit by the continuing flow of air, after the

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delivery of the main portion of the fuel, is more finely atomised and thus improves combustion efficiency.

It is therefore advantageous to use a volumetric air to fuel ratio substantially greater than 50:1, and, from a performance point of view only, it would be preferable to increase the ratio of air to fuel. This can be achieved by the use of suitable control equipment that varies the period that air is admitted to the conduit as the fuel quantities increase. Also it is desirable to increase the period that air is admitted during the starting of the engine because of the improved atomisation achieved with the greater quantity of air.

It has been found experimentally that incorporating the present invention in a fuel injection system for a 1600cc capacity four cylinder engine and injecting methanol as fuel at a volumetric air-fuel ratio of 50:1 gives a measured spray from an injector nozzle as illustrated in Figure 1 of 20 microns (Sauter) mean droplet diameter, and with a volumetric air-fuel ratio of 400:1 gives a mean diameter of 5 microns. This is of an order of magnitude finer than existing systems and it will be appreciated that the finer atomization gives benefits in many ways to an engine's operation.

As an example, the above conditions would allow better cold starting of an engine running on 100% methanol, a capability unmatched by existing injection systems.

In the above description the propelling gas has been referred to as air, however the use of air is not essential for the operation of the invention. In practice it is proposed to use a fuel-air gas mixture to propel the fuel, the proportions of fuel and air effectively being unimportant. Further details of the use of the fuel-air gas mixture are disclosed in the applicant's co-pending application based on Australian Patent Application No. PF2126/81 and that disclosure is hereby incorporated in this specification.

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WE CLAIM:

1. A method of delivering liquid fuel to an internal combustion engine comprising delivering a predetermined quantity of liquid fuel into a conduit, admitting a gas to the conduit upstream of the quantity of fuel at a pressure and for a period sufficient to propel the quantity of fuel through the conduit and discharge the fuel through a fixed size constantly open nozzle at the downstream end of the conduit.

2. A method of delivering a metered quantity of liquid fuel to an internal combustion engine; said method comprising:

filling a chamber with fuel, the chamber having a selectively openable discharge port in communication therewith and with a conduit terminating in a fixed size constantly open nozzle;

admitting gas to said chamber to displace fuel from the chamber upon opening of the discharge port;

continuing the supply of gas to the chamber at a pressure to propel the displaced fuel along the conduit and discharge that fuel through the nozzle; and

controlling the quantity of fuel displaceable by the admission of said gas to the chamber.

3. A method as claimed in any one of claims 1 to 2 wherein the pressure of gas admitted to the conduit is selected so the fuel issues from the nozzle at a speed of the order of sonic speed.

4. A method as claimed in any one of claims 1 to 3 wherein at least part of the fuel forms an emulsion with the gas during passage through the conduit.

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5. A method as claimed in claim 4 wherein the friction drag between the fuel and the internal surface of the conduit, and the speed of the gas in the conduit, are selected so that at least a portion of the fuel is broken up into droplets to form an emulsion with the gas.
6. A method according to claim 2 or any one of claims 3 to 5 when appended to claim 2 wherein the control of the quantity of fuel displaced is effected by adjusting the relative positions of entry of the gas to and of the discharge of the fuel from said chamber, whereby the fuel capacity of the chamber between said positions is varied.
7. A method according to claim 6 wherein the position of entry of said gas to the chamber is moved relative to the position of discharge of gas from said chamber.
8. Apparatus for delivering liquid fuel to an internal combustion engine comprising means to deliver a predetermined quantity of fuel into a conduit that terminates at a fixed size constantly open nozzle, means to admit gas to the conduit upstream of the fuel at a pressure and for a period sufficient to propel the fuel to and discharge it through the nozzle.
9. Apparatus as claimed in claim 8 including means to supply the gas at a pressure so that the fuel has a speed of the order of sonic speed as it issues from the nozzle.
10. Apparatus as claimed in claim 8 or 9 wherein the nozzle has a passage leading to a delivery orifice, said passage decreasing in cross-section from the end remote from the orifice to the end at the orifice.

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11. Apparatus as claimed in claim 10 wherein the orifice is of annular shape, and the passage is of annular shape having inner and outer surfaces, at least one of said surfaces being of a conical or frusto-conical form.

12. Apparatus as claimed in claim 11 wherein the inner surface of the passage diverges outwardly towards the orifice.

13. Apparatus as claimed in claim 11 or 12 where the outer surface diverges outwardly towards the orifice.

14. Apparatus as claimed in any one of claims 8 to 13 including:

- a body having a chamber formed therein;
- a fuel discharge port selectively openable to the chamber;
- a gas inlet port selectively openable to the chamber to admit gas to the chamber;
- a conduit communicating said discharge port with the fixed size constantly open nozzle;
- whereby, on admission of gas to the chamber and opening of said discharge port, fuel in the chamber is displaced from the chamber, propelled along the conduit and discharged through the nozzle by the gas; and
- means to control the quantity of fuel displaceable from the chamber by the admission of the gas.

15. Apparatus as claimed in claim 14 wherein the means to control the quantity of fuel discharged comprises means to adjust the relative positions of entry of the gas to and of discharge of the fuel from the chamber.

16. Apparatus as claimed in claim 15 wherein said means adjusts the position of the gas inlet port.

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17. Apparatus according to claim 15 or 16 including a movable member extending into the chamber and movable relative to the chamber, the gas inlet port being formed in said movable member.

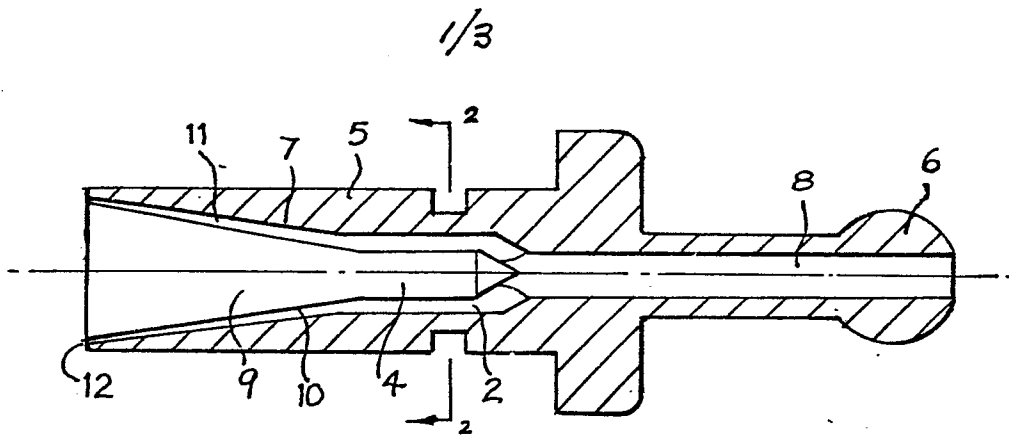


FIG. 1.

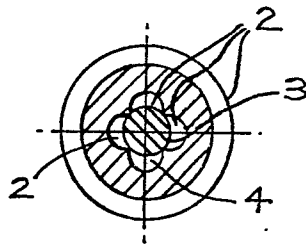


FIG. 2.

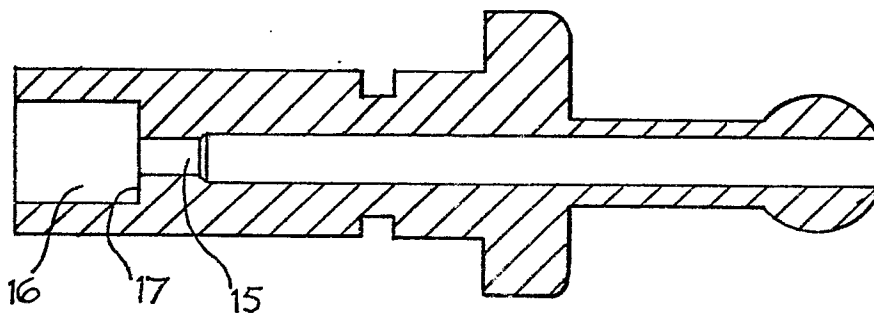


FIG. 3.

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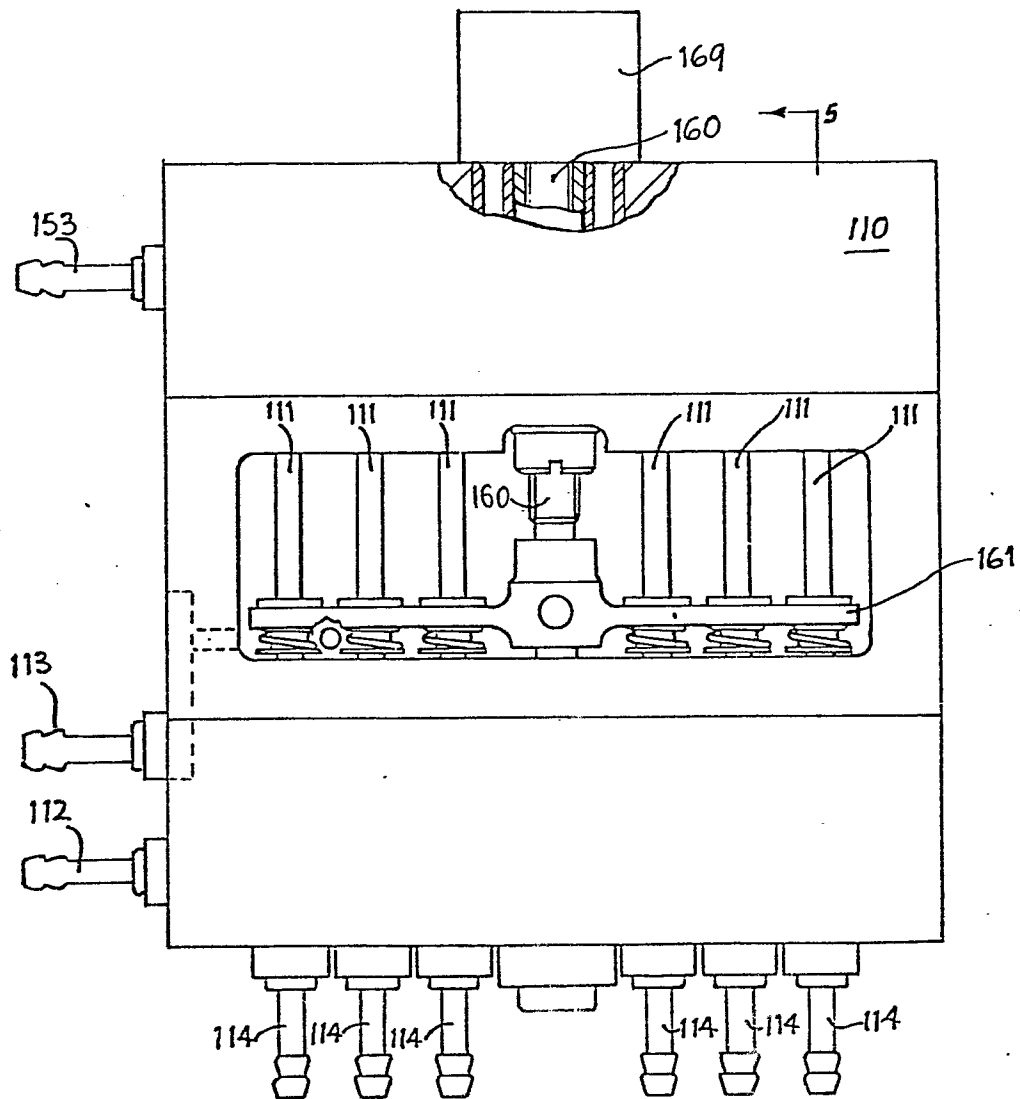


FIG. 4

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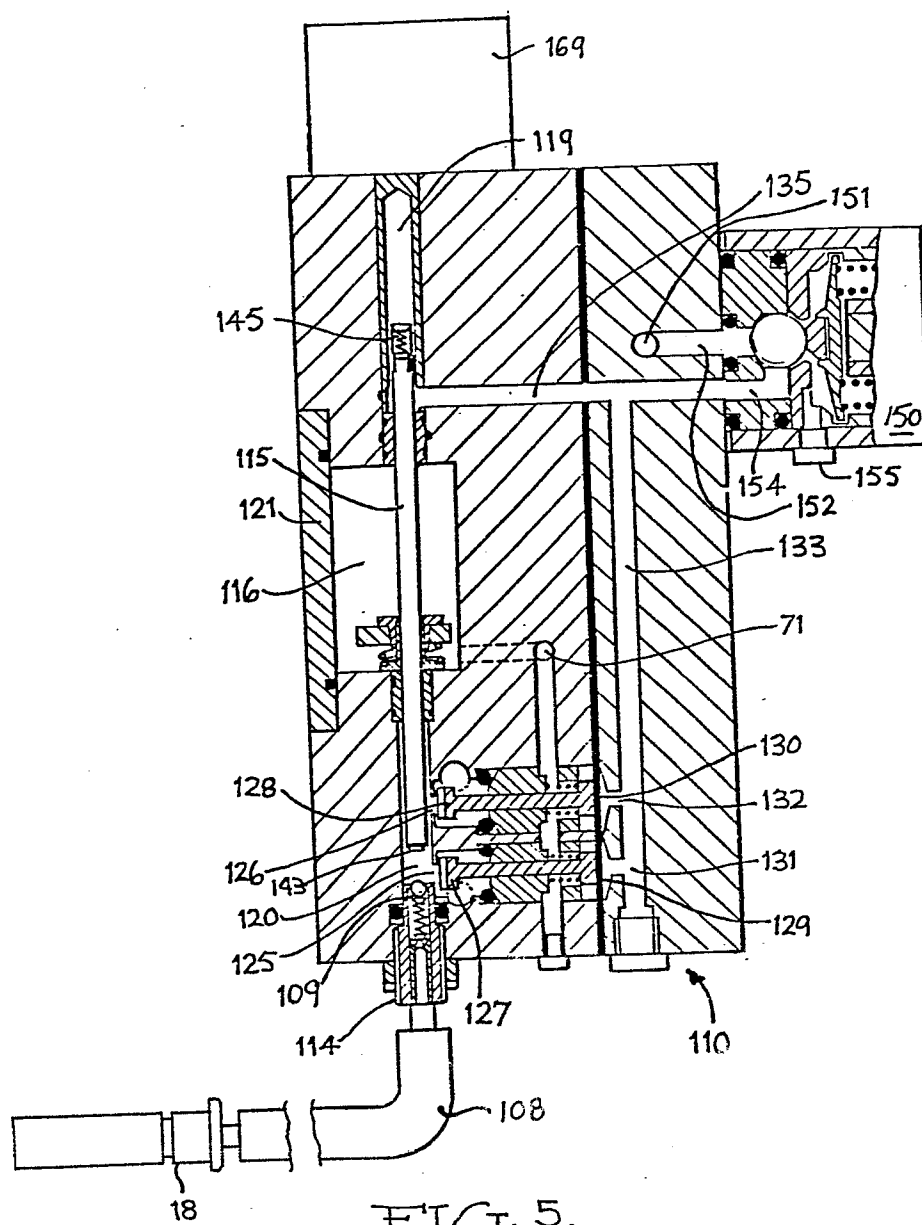


FIG. 5.

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European Patent
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EUROPEAN SEARCH REPORT

Application number

EP 82 30 7027

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
A	--- DE-C- 896 738 (WILLE) *Column 3, line 40 to column 5, line 28; figure 1*	1, 4, 5, 8, 10, 11	F 02 M 67/02
A	--- DE-C- 833 736 (DAIMLER) *Column 4, line 88 to column 6, line 85; figures 1-3*	1, 2, 4, 5, 8, 10, 11, 14	
A	--- DE-A-1 930 629 (POLITECHNIKA KRAKOWSKA) *Page 3, line 17 to page 5, line 5; figures 1-8*	1	
D, A	--- GB-A-2 023 226 (DAIMLER) *Page 1, line 122 - page 2, line 51; figures 1, 2*	3	TECHNICAL FIELDS SEARCHED (Int. Cl. 3) F 02 M F 02 D
A	--- GB-A-2 018 906 (ORBITAL) -----		
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 16-02-1983	Examiner SCHMID R.
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			