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(54) **Improved fuel delivery system.**

(57) Fuel delivery system (20) for supplying pressurized fuel from a fuel source (200) to at least one flow means such as an electromagnetic injector (141) which meters fuel therefrom in response to actuation commands received, comprising fuel rail means (100) interconnecting the fuel source (200) with the flow means (141) for delivering fuel from the fuel source (200) to said flow means (141), anti-reflection means (300) disposed between said fuel source (200) and said fuel rail means (100) for controlling the magnitude of the reflected pressure waves generated by the operation of said flow means (141).

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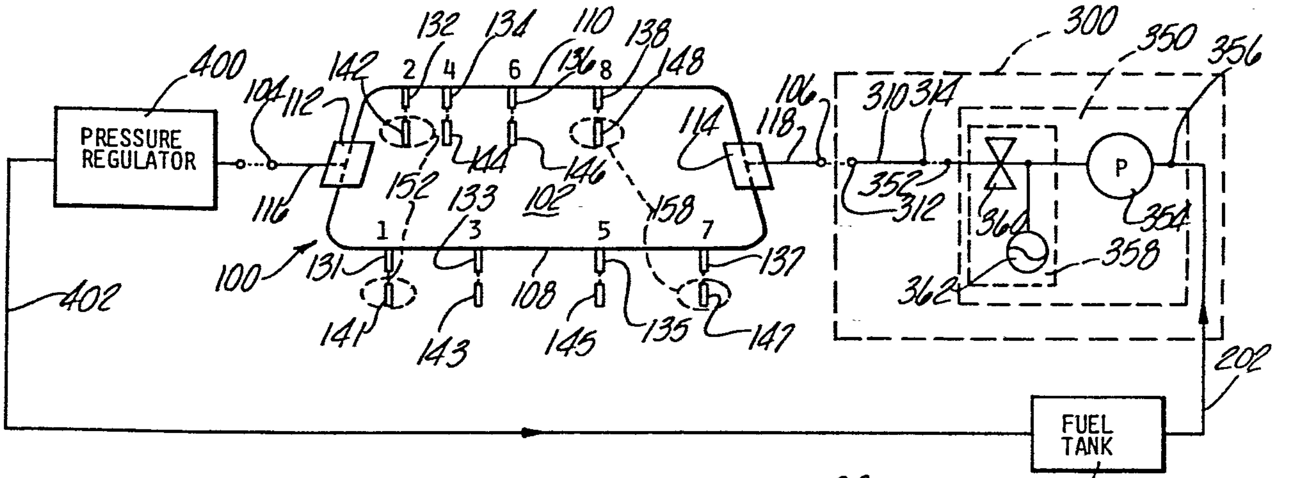

PRESSURE REGULATOR
FUEL TANK
P
400
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IFig-1

IMPROVED FUEL DELIVERY SYSTEM

The invention relates to an improved fuel delivery system and more particularly to a system for delivering fuel to a fuel injected engine comprising a fuel rail for transmitting fluid from a pressurized source to a flow device means such as a flow valve or a fuel injector. In particular, the invention controls the generation of unwanted pressure waves occurring each time a flow device means or fuel injector meters fuel therefrom.

Fuel injection systems for injecting a quantity of fuel into an engine cylinder in timed relationship to the combustion cycle are known in the prior art. One goal of a fuel injection system is to precisely meter a determinable quantity of fuel to each cylinder in response to engine demands. Precise metering permits optimum fuel utilization and further permits the minimization of pollutants contained in the exhaust gas. Fuel metering is often performed in an open loop fashion ; that is, the quantity of fuel delivered is not measured directly. Such systems control the time during which a particular injector is held open. Thus, if the assumption is made that the pressure in the fuel rail remains constant during the periods an injector is open, then the quantity of fuel delivered to the engine during these periods is determinable. As will be shown below this assumption cannot always be made.

Consider for the moment a fuel system comprising a fuel tank, a fuel line, fuel pump, a fuel rail having a plurality of injectors attached thereto, a pressure regulating means and a return line to the fuel tank. The fuel pump extracts fuel from the fuel tank which is distributed under pressure to the individual injectors by means of a fuel rail. The fuel pump and pressure regulating means cooperate to maintain the fuel pressure within the fuel rail at a substantially constant quiescent pressure. Therefore, by maintaining a constant pressure in the fuel rail precise fuel metering can be achieved, in theory, by controlling the duration an injector is open. A problem associated with prior art fuel delivery systems is that as each injector is rapidly opened and closed a pressure wave is created in the fuel rail. The pressure wave travels up and down the fuel rail causing the pressure at any point along the fuel rail to periodically increase and decrease as the pressure wave passes. This perturbed and uncontrolled pressure fluctuation causes errors in the quantity of fuel delivered during subsequent actuation of the injectors. In addition, the magnitude of the reflected wave may cause components of the fuel delivery system to vibrate.

It will become apparent from a reading of the described embodiments that the present invention is applicable to fluid delivery systems in general and not limited to fuel rails for fuel injection systems for spark or compression ignited engines.

A broad object of the present invention is to provide a fuel delivery system in which the pressure pulsations within a fuel delivery system are minimized.

A second object of the present invention is to control the number of reflected pressure waves generated each time an injector or group of injectors operates.

Another object of the invention is to reduce and/or eliminate any further reflections of the pressure wave by other fuel system components.

A further object of the invention is to provide a fuel delivery system which achieves a controlled reflection wave while not requiring exacting dimensional tolerances of its component parts.

To this end, the invention proposes an improved delivery system for supplying pressurized fluid from a fuel source to at least one flow means which meters fluid therefrom in response to actuation commands received, comprising : fluid rail means interconnecting the fluid source with the flow means for delivering fluid from the fluid source to said flow means characterized in that it comprises anti-reflection means disposed between said fluid source and said fuel rail means for controlling the magnitude of the reflected pressure waves generated by the operation of said flow means.

An advantage of the present invention is that it is applicable to fuel systems operating at low pressures such as 1,4 to 5,6 kg/cm^2 as used in a spark ignited engine or at a high pressure such as 350 to 1050 kg/cm^2 as used in a compression ignited system.

Another advantage of the present invention is that the fuel rail design is adaptable to a variety of injector firing orders.

A further advantage of the present invention is that the controlled reflection design allows for predictable flow calculations for each injector. The significance of this is that a unique method of flow compensation can now be made within an associated electronic control unit to equalize injector flow within individual injectors.

The invention will now be described with reference to the accompanying drawings wherein :

- Figure 1 illustrates the present invention as applied to a continuous flow fuel delivery system ;

- Figure 2 illustrates an alternate embodiment of a fuel delivery system ;

- Figure 3 illustrates a time history of a pressure wave;

- Figure 4 illustrates a time history of pressure waves created in the system of Figure 2 ;

- Figure 5 illustrates the present invention as applied to a non-continuous flow fuel delivery system ;

- Figure 6 illustrates a side view of an impedance matching connector ;

- Figure 7 illustrates a sectional view through section 7-7 of Figure 6 ;

- Figure 8 illustrates a further embodiment of the present invention as applied to a diesel engine ;

- Figure 9 illustrates another embodiment of the present invention ;

- Figure 10 illustrates another embodiment of the present invention ;

- Figure 11 illustrates another embodiment of the present invention.

Fuel delivery systems for internal combustion engines having fuel injectors include a variety of configurations applicable to a wide range of operating conditions. As an example, Figure 1 illustrates the application of the present invention in a continuous flow fuel delivery system for a spark ignited engine. This type of system operates at relatively low fluid pressure (1,4 to 2,8 kg/cm^2) and at low flow rates and may utilize any of the commonly known electromagnetically actuated fuel injectors. In addition, this type of system may further be characterized as a steady fluid flow system in that during fuel injection periods only a small fraction of the quiescent flow is diverted from the system into the engine. A second type of fuel delivery system such as is shown in Figure 5 is similary operated at relatively low pressure levels (4,2 to 5,6 kg/cm^2) but utilizes either a pressure actuated poppet valve injector or the previously mentioned electromagnetically actuated injector. This system may be characterized as a dead ended or non-continuous flow system. A third type of fuel delivery system is often used in conjunction with combustion ignition engines. This system is similar to the low pressure system shown in Figure 5 in that it is often a non-continuous flow system, however, operating at relatively high flow rates and high pressures 350 to 1050 kg/cm^2.

Several embodiments of the invention are disclosed illustrating its applicability to controlling reflections of pressure waves for each of these varied systems.

The preferred embodiment of the fuel delivery system 20 will be described in the context of a fuel delivery system comprising a fuel injection system for an internal combustion engine, however its teachings are applicable to the delivery of pressurized fluids wherein the elimination of pressure puslation, banging or other oscillation is required to insure accurate fluid delivery.

Figure 1 illustrates a fuel delivery system 20 for an eight cylinder (V-8) internal combustion engine. Upon reading the disclosure it can be seen that the invention is not so limited and may be practiced in conjunction with other engine types and injector configurations.

In particular, the fuel delivery system 20 comprises a fuel rail 100 such as a hollow conduit having a medial portion 102. The medial portion 102 can be formed by one or more fluid carrying tubes such as tubes 108 and 110. The respective ends of each tube (108 and 110) are connected in fluid communication by a pair of connectors 112 and 114, such as a pair of t-connectors. Additionally, each connector 112 and 114 is further adapted to receive one end of an associated tube 116 and 118. The other ends of tubes 116 and 118 therein forming the inlet and outlet ends 104 and 106, respectively. Inspection of Figure 1 further reveals that each tube 108, 110 contains a plurality of connectors 131-138 adapted to receive a like plurality of fluid flow device means 141-148. Inasmuch as the preferred embodiment of the invention is described in the context of an automotive environment the contemplated flow device means are electromagnet injectors such as that used in fuel injection systems as illustrated by Kiwior in U.S. Patent 4 030 668. Other flow devices means can be substituted including any number of solenoid or pressure actuated flow valves including pressure actuated valves for diesel engine application.

For clarity, Figure 1 has the odd numbered connectors, i.e. connectors 131, 133, 135, 137, and the odd numbered injectors, i.e. injectors 141-147 are located along tube 108 while the even numbered connectors 132, 134, 136, 138 and injectors 142-148 are located along tube 110. It is desirable, however, though not a requirement of the invention that each injector be mounted as close to its respective tube as possible and furthermore that each injector be rigidly connected thereto. Consequently, each connector 131-138 may comprise a link such as the rigid tube taught by Werthheimer et al in U.S. Patent 3 776 209.

Fluid is pumped from a reservoir such as fuel tank 200 through conduit 202 to the input end 106 of the fluid rail 100 by a fluid means 300. The exit end 104 of the fluid rail 100 is connected to a regulating means such as a pressure regulator 400. It should be apparent that a pressure regulator per se is not essential to the invention. As an example, a pressure compensated fluid pump of the known variety can be substituted for the fluid means 300. In addition, it has been found that when used it is desirable to locate the pressure regulator 400 as close to the injectors as possible. This can be accomplished by eliminating tube 116 and connecting the pressure regulator 400 directly to connector 112.

Return conduit 402 connects the output of the pressure regulator 400 to the fuel tank 200 thereby defining the continuous flow closed loop fuel system. Referring again to the pump means 300 disposed between the fluid rail 100 and the fuel tank 200, the function of the fluid means 300 is to deliver pressurized fluid to the fluid or fuel rail 100. In addition, the fluid means 300 includes means for absorbing unwanted pressure waves. The fluid means 300 as illustrated in Figure 3 includes a receiving means 310 which may be a connecting line or pipe and a pump means 350. The input of the pump means 350 is connected at its entrance 356 with conduit 202 and at its exit end 352 with the receiving means. In the illustrated embodiment of the invention, the pump means 350 comprises a fuel pump 354 and a pressure filter network 358 comprising an orifice 360 and accumulator 362, the significance of which is described below. The pressure filter network 358 is disposed between the pump 350 and the receiving means. The receiving means 310 is a pipeline 310 adapted to mate at end 312 to the fluid or fuel rail 100 and to mate at opposite end 314 with pump means 350. As will be discussed later, the pressure filter network 358 may be incorporated into the receiving means at a location proximate the outlet end 312. During quiescent or non-injecting periods fuel is taken from the reservoir or fuel tank 200 by the pumping action of the fluid means 300. In its simplest form the fluid means 300 is a pump which can either be driven directly by the engine or by an electrical pump. As previously mentioned, it may be possible to eliminate the pressure regulator 400 from the fuel system 20 by employing a pressure compensating fuel pump. Pressurized fluid enters the fluid rail at end 106. Pressurized fluid flows through the pressure regulator 400 and then back into the fuel tank 200 through conduit 402. The pressure regulator 400 and fluid means 300 cooperate to maintain a constant quiescent pressure throughout the fluid rail 100 for any given quiescent rate of fluid flow (cm^3/s).

Attention is again directed to the fluid rail 100 of the system shown in Figure 1. The eight injectors (141-148) form four pairs (152, 154,156,158) of injectors, that is, injectors 141 and 142 form pair 152, injectors 143 and 144 form a second pair 154 and so on. Each injector of each pair is located the same distance from input end 106 as well as the same distance from the exit end 104. This dual ended mounting symmetry requires that the flow paths to each injector through the fuel rail 100 be the same length. Furthermore, it is required that the other injector pairs 154, 156, 158, similarly by symmetrically located along their respective tubes 108 and 110. It is not required, however, that each injector pair be located an equal distance from other injector pairs. While it is preferred that each flow path (tubes 108, 110) have identical cross sections, it has been found that a tolerance error of ±10 percent does not appreciably affect performance.

Reference is now made to Figure 2 which illustrates an alternate embodiment of the present invention and which further illustrates the fuel delivery system tested. It should be recalled that it is desirable to connect the pressure regulator 400 directly to the fuel rail 100. It has been found through experimentation that if pipe 116 is greater than 15 cm, it may be necessary to add, as shown in Figure 2, an additional accumulator 600 to system between the pressure regulator 400 and fuel rail 100. The additional accumulator may also be required if the response time of the pressure regulator is too slow. In addition if the pipe 116 is greater than 15 cm it will be necessary to size this pipe so that its admittance is twice that of the fuel rail 100.

The fuel delivery systems as described in Figures 1 and 2 have been designed to permit a single reflection of pressure waves therein. One mode of operation of the fuel delivery system of Figure 1 is that symmetrically located injector pairs 152 would be operated together. As an example, injectors 141 and 142 which form pair 152 may be simultaneously operated. This would be followed by injector pair 154 and injector pair 156 and finally injector pair 158 therein defining a continuous sequential mode of paired operation. Alternatively, any number of pairs may be opened together ; such as pair 152 and 156, followed after a period of time by the opening of injector pairs 154 and 158. As a further example, all eight injectors may be opened simultaneously. One skilled in the art will appreciate that the dynamic flow conditions will be determinable from the number of injectors being opened and the quiescent flow. Consequently, for each specific system design, the size of the orifice 360, will vary to accomodate the different flow rates. When individual or symmetrically located injector pairs are operated pressure and flow waves are created. The pressure within the fuel rail 100 will momentarily drop to a lower pressure (P) from its designed (P_d) or quiescent (P_o) pressure condition because of the fluid or fuel taken from the fuel rail 100 and delivered to the engine. These pressure waves will travel toward the regulator 400 end of the fuel rail and toward the entrance end 106 of the fuel rail. Waves impinging upon the pressure regulator 400 will be reflected back into the fuel rail 100. The pressure regulator 400 acts as a zero impendance terminating reflector for all significant frequencies contained in the pressure wave. A true zero impendance termination would reflect all incident pressure waves. Consider pressure waves within the fuel rail 100 that are travelling toward input end 106. As this wave enters the pipe 310 part or all of the wave will be reflected, in prior art systems, back into the fuel rail 100. In addition, the wave may continue travelling down pipe 310 and will be reflected, in prior art systems, by the pump or other fuel system components.

As can be seen by the preceding description, prior art fuel delivery systems are susceptible to having multiple reflections propagating up and down the various fuel carrying conduits therein disrupting the desired pressure characteristics. In systems requiring the simultaneous operation of symmetrically located injector a plurality of waves are created. These waves propagate within the fuel rail 100 and may amplify the magnitude of reflected pressure waves.

To further illustrate the creation of pressure waves in a fuel system, consider the time histories shown in Figure 3. Figure 3 represents test date illustrative of the operation of prior art systems. To approximate the effect of a prior art system, the orifice and accumulators shown in Figure 2 have been removed. During the above-mentioned test injectors 141 and 142 were simultaneously activated to open as indicated by the wave form shown on line 2 of Figure 3, and represents the current signal activating the injector. The pressure fluctuations in the fuel rail 100 as a function of time at points A and B proximate injectors 141 and 142 are shown in Figure 3, lines 1 and 3. It can be seen that as the injector opens the pressure in the system drops from the quiescent or designed pressure (2,8 kg/cm^2). As the injector closes, the pressure at points A and B of Figure 2 momentarily return to the quiescent value. Shortly thereafter the first reflected wave (from the regulator 400) and later reflections arrive and cause the pressure at points A and B to oscillate for about 0.02 seconds after the valves close.

Returning now to a discussion of the fuel rail 100 as shown in either Figures 1 or 2. A fuel rail is basically a conduit designed to carry a determinable quantity of fluid at a predetermined rate and pressure. Under such conditions, the conduit presents at its entrance end an admittance Y_{FR} to the incident flow change. In addition, pipeline 310 presents an admittance Y_{PL} to flow. Techniques for measuring and specifying resistance to flow, including the admittance or the impedance (the reciprocal of admittance) of a conduit or configuration of conduits are known in the art. As an example, the characteristic impedance Z_o of a pipe is given by $Z_o = RC/gA$ where R is the density of the fluid (kg/cm^3), C is the velocity of propagation (cm/s), A is the cross-sectional area of the pipe (cm^2) and g is the gravity constant. In addition, the impendance of an orifice under small flow change conditions can be expressed as $Z = 2\Delta P/Q_o$ when ΔP is the quiescent pressure drop across the orifice at a flow rate of Q_o.

To achieve the control of reflected waves requires the matching of the admittance of the various fluid carrying members of the fuel delivery system. Consider the previously described mode of operation wherein symmetrically positioned injectors or pairs of injectors are operated together. In particular, if the admittance of the pipeline 310 is maintained at twice that of the individual tubes 108 and 110 of fuel rail 100 the arriving pressure waves from each tube 108 and 110 resulting from injector pair operation will combine in the pump line 310. The resulting pressure at the entrance 312 of the pump line 310 will be equal to the pressure in each tube 108 and 110 and hence, no reflection will occur.

Furthermore, if the terminating admittance of the pump Y_P is made equal the characteristics admittance of the pipeline Y_{PL} pressure and flow waves are similarly absorbed at the pump end. Those skilled in the art will appreciate the difficulties inherent in matching the impedance or admittance of the pump 354 to that of the pipeline 310. Impendance matching can be achieved by incorporating the fluid filter network 358 into the system and can be accomplished by specifying the cross-sectional area A_o of the orifice 360. The area can be determined with reference to the following equations :

$$Q_o = KA_o\sqrt{P_p - P_o} \qquad \text{1a}$$

$$Q_o + \Delta Q = KA_o\sqrt{P_p - P_o - \Delta P} \qquad \text{1b}$$

$$\Delta P = \Delta Q Z_o \qquad \text{1c}$$

$$\Delta Q = KA_i \frac{\sqrt{P_o - P}}{2} \qquad \text{1d}$$

where :

Q_o is the quiescent orifice flow,

K is the orifice constant given by $K = C_d\sqrt{2g/R}$

where :

C_d is the orifice discharge constant,

ΔQ is the flow disturbance,

A_o is the orifice area,

P_p is the pump pressure

P_o is the quiescent line pressure,

ΔP is the pressure drop on the line due to ΔQ,

A_i is the injector metering area, and

Z_o is the characteristic impedance of the line.

The above equations are solved simultaneously for A_o and P_p.

In systems wherein the maximum flow is approximately equal to the quiescent flow Q_o because only a small portion of the total flow is diverted during injector or injector pair the area may be obtained from a supplemental equation given by :

$$A_o = \frac{2\ Z_o\sqrt{P_o}}{K}$$

An alternative impendance matching means is achieved by substituting a laminar flow restrictor for the orifice. Laminar flow restrictors comprise a conduit having a set of capillary tubes or alternatively having a porous material displaying a linear relationship between flow and the pressure drop thereacross. However, the laminar flow restrictor is temperature sensitive and will therefore yield the designed admittance (or impedance) at only one given temperature.

Reference is now made to Figure 4 which illustrates improved performance for the same operative conditions as Figure 3. Figure 4 represents test data for the system as shown in Figure 2, using a Greer accumulator having a volume of 246 cm^3 charged to 1,4 kg/cm^2 of nitrogen and an orifice having a diameter of 1,6 mm. It is desirable that either accumulator 362 or 600 be sized to have an admittance which is less than the admittance of the orifice 360 for all significant frequencies contained in the pulse-like pressure waves. The reason for this is that it is desirable for the accumulator 362 to function as the mechanical analog of an electrical short circuit. In addition, it is necessary for the accumulator to be responsive to each pressure wave therein requiring the accumulator to have a rapid response time. Consequently, the accumulators used are of the low-mass gas filled variety. Alternatively, a spring-mass accumulator may be used. Returning now to Figure 4, it can be seen that by incorporating the features of the present invention into the continuous flow fuel delivery system of Figures 1 or 2 results in an improved system displaying a controlled single reflection pressure wave and an order of magnitude improvement in performance as compared to the results of Figure 3.

While it is preferable to locate the pressure filter network 358 as close to the pump 354 as possible an alternative embodiment to the previously described fuel delivery system can be achieved by locating the pressure filter network 358 proximate the junction of the fuel rail 100 and pipeline 310 in Figure 2. In this case the first fluid source means 310 can now be viewed of as comprising the combination of network 358 and pipeline 310 while the second fluid source means would obviously consist of only the pump 354. The orifice size if chosen so that the admittance of the orifice is twice that of the fuel rail 100.

The test results in Figures 3 and 4 are for the following dynamic conditions for two injector (141 and 142) simultaneous operation: pump 354 output pressure is 4,2 kg/cm^2, the regulator maintained pressure is 2,8 kg/cm^2, flow Q_o of 6 cm^3/s which is developed upon each injection. The pressure drop P_o across the orifice at the above flow rate is 0,203 kg/cm^2 and the orifice flow constant K was assumed to be 956 cm^2/sec kg$^{\frac{1}{2}}$. Utilizing the orifice sizing equation, i.e. $Q_o = KA_o \ P_o$ the area A_o can be found to be 0,01406 cm^2, diameter 1,337 mm and the orifice admittance is 5,873 cm^5/kg sec. In addition the admittance of the fuel rail was assumed to be 2,936 cm^5/kg sec. The pipeline admittance was chosen twice that of the fuel rail and the accumulator capacitance was 0,091 cm^5/kg. The system tested utilized standard pipelines to achieve as closely as possible the required 2:1 admittance match for the system of Figure 2. The pipeline 310 was fabricated of 9,525 mm tubing which has an inner diameter of 7,747 mm and each tube 108 and 110 utilized 12,7 mm tubing which has an inner diameter of 10,95 mm.

A feature of the present invention is that it is amenable to a variety of fuel delivery system configurations. As a further example of this, consider the dead ended or non-continuous flow system as shown in Figure 5.

Reference is briefly made to Figures 6 and 7 which illustrate the impedance matching connector 112 or 114 used in the embodiments of Figures 1 and 2. In particular, these figures shown a t-connector 500 having an inner bore 502 having a pair of inwardly directed bosses 504 at its ends. Each boss 504 is adapted to receive one of the fluid carrying tubes 108 and 110. The inner diameter of bore 502 is equal to that of tubes 108 and 110. A second bore 510 intersects bore 502 to provide fluid communications therethrough. In addition, bore 510 contains an inwardly directed boss 512 adapted to receive pipeline 310 wherein the inner diameter of bore 510 is equal to that of pipeline 310.

Having achieved a controlled reflection fuel delivery system exhibiting a single reflection pressure wave in response to injector operations, the following discussion is related to fuel delivery systems exhibiting no reflections i.e., a zero reflection fuel delivery system. To achieve a zero reflection fuel delivery system, it is required to select the fuel conduit characteristic impendances to match the injector impendance and then provide terminating impendances such as the previously described orifice-accumulator network at the fuel rail ends so that pressure waves set in motion can only propagate to these terminating impedances where they are absorbed. If the proper conduit sizes and terminating impendances are used, there will be no reflections and/or oscillations within the fuel delivery system. The zero reflection system permits a further improvement in cycle-to-cyle repeatability in fuel metering as compared to the single reflection system.

The following discussions further illustrate the applicability of the present invention to various fuel delivery systems such as a high pressure injection system for diesel engine application using injectors such as that disclosed in U.S. Patent 4 068 640 which is expressly incorporated by reference.

Diesel injectors typically operate at high applied pressures. These pressures may range from 210 kg/cm^2 to more than 1050 kg/cm^2. In addition, fuel delivery systems for high pressure application need not incorporate a fuel return line such as line 402. One reason for this is to conserve engine power required to circulate the fluid in a high pressure continuous type of system.

One such high pressure system is shown in Figure 8. The system is similar to those fuel delivery systems previously described and consists of a variable displacement pump 354, and a pressure filter network comprising orifice 360 and accumulator 362 supplying pressurized fuel to a fuel rail 660 which has at least one injector 700 disposed along its path. The system of Figure 8 further includes a second accumulator 640 and second orifice 650 connected to the fluid rail 660 at a location downstream of the injector 700. The following discussion is illustrative of the operation of the fuel delivery system of Figure 8. As an example, assume that the injector 700 is of the type which operates at a pressure P of 1050 kg/cm^2 and requires a flow rate Q, of 164 cm^3/sec, therein defining a parameter known as the injector impedance which is $Z_i = P/Q$. In addition, the specifications of the above parameters further determines the pressure and flow rates requirements of the fluid rail 660. If, however, injector 700 is of the known type of injector having means for amplifying the pressure within the fluid rail 660, such as an intensifier, prior to injection from the injector 700 the operating pressure and flow rate required within the fluid rail 660 are scaled accordingly. As an example, if the intensifier has a6:1 pressure ratio, the pressure in the fluid rail during injection is one-fifth that of the required injector pressure or 210 kg/cm^2. In addition, the required fluid flow rate through the fluid rail is five times that required by the injector or 820 cm^3/sec. Consider the operation of the system of Figure 8. Recalling that Figure 8 represents a dead ended embodiment it can be shown that during quiescent or non-injecting periods the quiescent injector flow is zero. The pressure within the fluid rail 660 is maintained at a quiescent or designed level by virtue of the cooperation between the pump 354 and regulator 400. In the present example the pump pressure can be 420 kg/cm^2. When an injector is actuated, fluid is removed from the rail and is supplied to the injector from both directions, causing a plurality of pressure waves to propagate within the rail ; one wave directed towards accumulator 362 and another wave directed towards accumulator 640. As injector 700 opens, the pressure in the line will drop from the normal pump pressure. Using the above parameter values for the situation involving a pressure intensifier, it can be shown that pressure within the rail will be reduced by 210 kg/cm^2 and that each side of the rail must deliver 41 cm^3/sec of flow. To achieve proper fluid delivery, it is required to match the admittance or impedance of the fluid rail 660 to that of the injector. The impedance Z_r of the fluid rail satisfying this requirement is given by the change in pressure ΔP from the quiescent P_o to that value of reduced pressure P_r resulting from the injector opening divided by the flow 2.5Q. It should again be noted that the quiescent flow is zero. Z_r is given by . $Z_r = \Delta P/2.5Q$. Using the above euqation the cross-sectional area of the rail A_r can be derived from the previously disclosed equation $A_r = RC/gZ_r$. A system so configured will prevent reflections from originating at the junction of the fuel rail 660 to the injector 700.

To further prevent pressure waves propagating within the fluid rail 660 from being reflected by either end of the fuel rail each end must be terminated with an impedance matching network. Proper orifice sizing is determinable from injector flow rates and the resulting pressure P_r and can be found from equations similar to equations la-d.

Alternative design philosophies may require orifice impedance matching to be designed about flow rates other than maximum injector flow rates as above. As an example, if the injector control philosophy is such as to require many injector activations for its associated cylinder event it may be desirable to size the orifices based upon a mid-range flow rate such as the average flow.

The average flow from each accumumator during a full injector cycle is zero, hence, the fluid removed during injection periods will be returned to each accumulator during non-injector periods by the pump 354.

To de-couple the interaction of the pressure waves created when many injectors are connected to a single rail 660 it may be necessary to provide each injector with its respective fluid carrying conduit. One such embodiment using a pressure compensated pump is shown in Figure 9 wherein a plurality of conduits 670a through 670n each being adapted to be connected to its representative injector 700a through 700n. In addition, each conduit 670 contains at its ends separate orifices 361 and 651. Each conduit 670 and orifice combination 351, 361 terminate in a pair of connectors such as header 710a and 710b.

Figure 10 illustrates an alternative dead ended fuel delivery system for supplying fuel to a plurality of injectors 700. The advantage of this alternate embodiment as compared to that shown in Figure 9 is the elimination of an accumulator, header and a set of orifices. It should be noted that fluid flow to each injector in a single conduit 680 system requires an appropriate increase in cross-sectional area to handle the increased flow. In the case of using conduits having a circular cross-section the area of conduit 680 is 2 times larger than the diameter of conduit 670 of Figure 9.

One skilled in the art of fuel injection systems for engines will appreciate that the pressure within the fluid rail will deviate from the designed pressure upon operation of any particular flow device means when fluid is injected into its respective combustion chamber as in a multipoint fuel injection system or injected into the intake manifold as is the case in a single point injection systems. As previously discussed, prior art fuel injection systems attempt to control the volume of fuel delivered by varying the injector open time, t_i, as a function of engine operating conditions. To achieve the desired flow through a particular injector such as injector 141 of Figure 1 it is necessary to modify the nominal injector open period to compensate for the pressure deviations within the fluid rail. More particularly, the pressure variations which arise from incident pressure waves generated upon injector opening and closing, and the incident pressure wave and incident and reflected waves arising from the operation of other fuel injectors which are connected to the same fluid carrying member. These waves are shown on line 2 of Figure 11. Each of the above cases can be solved only when the fuel delivery system is of the previously described single reflection or zero reflection variety.

Having controlledthe number of reflected pressure waves generated it is now possible to vary the injector open time to correct the amount of fuel delivered. Recalling that a pressure wave results in a reduced flow because of the associated drop in fuel rail pressure during injector open periods, the actual flow Q_A can be determined from the following equation : $Q_A = kA\sqrt{P_d - \Delta P}$. The desired flow Q_d is calculated by assuming a constant designed fluid rail pressure P_d and is given as : $Q_d = kA\sqrt{P_d}$. For the situation wherein each injector is commanded to open for an uncorrected duration t_i, the actual volume of fluid delivered V, the lost volume V_L and desired volume V_{max} of fluid delivered during an injector open period are given by :

$$V_{max} = Q_d t_i \qquad (1)$$

$$V = V_{max} - V_L = Q_d t_i - Q_L f(t) \qquad (2)$$

where Q_L is the lost flow and given by $Q_d - Q_A$ and f(t) can be a function of time proportional to a) the uncorrected duration t_i b) the transition T_i required for a wave to travel to the regulator and return and c) the time required for an incident pressure wave created by the operation of another injector (j) to arrive at the i^{th} injector location.

In general, it is required of a control means (not shown), such as a mini-computer or microprocessor to compute a correction factor which when multiplied by the uncompensated time period t_i will yield a corrected time period t_{ic} which will then permit the desired volume of fuel to be metered to the engine. The corrected injector time period t_{ic} can be obtained by first substituting t_{ic} for t_i in equation 2, dividing the modified equation 2 by the parameter $Q_d t_i$ and subsequently setting the ratio $V/Q_d t_i$ equal to unity.

Following this procedure the corrected time t_{ic} can be solved for as a function of t_i, Q_L, Q_d and f(t) and is given by equation 3 :

$$\frac{t_{ic}}{t_i} = 1 + \frac{Q_L f(t)}{Q_d t_i} = 1 + \frac{V_L}{V_m} \qquad (3)$$

Reference is again made to the time histories shown in Figure 11 in particular, lines 1 through 3 which show linear pulse trains which are illustrative of one of the various pressure conditions achieved at the location of injector 141 in each of the previously described embodiments in response to injector operation. More particularly, line 1 shows the idealized pressure profile in the fluid carrying member deeding injector 141. The pressure therein is normally at a quiescent or desired level P_d. Upon the opening of injector 141 the pressure therein drops to a reduced level P_r. It is apparent that the actual volume of fluid delivered V during an injection cycle is different from the desired volume of fluid V_d because of the reduced pressure. Line 2 represents the reflection of the incident pressure wave wherein T_i is the time required for the incident pressure wave to travel down the fluid rail to be reflected by the pressure regulating means and return to the location of injector 141. For the zero reflection case, the time T_i is infinite. Line 3 shows the total pressure within the fluid rail at the location of injector 141.

As can be seen for the above case, the uncorrected injection time is less than the transit time T_i and, in addition, the resultant pressure is also not effected by the arrival of incident pressure waves from another injector. The lost volume of fuel V_L, after pulse correction, can be shown to be $V_L = Q_L t_{ic}$. Substituting $Q_L t_{ic}$ into equation 3, and solving for t_{ic} yields :

$$t_{ic} = (1/(1 - Q_L/Q_d))t_i.$$

In a similar fashion, the lost volume and corrected injector open time t_{ic} can be computed for other pressure wave profiles such as thecase shown in lines 1, 4 and 5, which illustrate a case in which the reflected wave (line 4) arrives while injector 141 is still open (line 1). The resulting pressure profile is shown in line 5.

C L A I M S

1. An improved fuel delivery system (20) for supplying pressurized fluid from a fuel source (200) to at least one flow means (141) which meters fluid therefrom in response to actuation commands received, comprising fluid rail means (100) interconnecting the fluid source with the flow means for delivering fluid from the fluid source to said flow means, characterized in that it comprises anti-reflection means (300) disposed between said fluid source and said fuel rail means for controlling the magnitude of the reflected pressure waves generated by the operation of said flow means.

2. A system according to claim 1, characterized in that said fuel rail means (100) comprises inlet means (106, 114, 118), for permitting fluid to flow therefrom, and at least one fluid carrying conduit (108) having a predetermined admittance to fluid flowing thereghrough, interconnecting in fluid communication said inlet means, said exit means, and the flow means.

3. A system according to claim 2, characterized in that said fuel rail means (100) includes a plurality of fluid carrying conduits (108, 110) each of said conduits individually interconnecting said inlet means and said exit means and each of said conduits having the same predetermined admittance.

4. A system according to claim 3, characterized in that said anti-reflection means (300) comprises receiving means (310) having an admittance to fluid flow thereghrough equal to the sum of the respective admittances of each of said fluid carrying conduits (108, 110) and further having an entrance end (314) receiving the pressurized fluid and an exit end (312) connected to said inlet means (106) of said fuel rail means (100).

5. A system according to claim 4, characterized in that said anti-reflection means (300) further comprises pump means (350) including a pump (354) connected between said entrance end (314) and said fluid source (200) for supplying pressurized fluid to said receiving means (310) and including a first filter means (358) located proximate said pump (354) comprising first orifice means (360) for developing a pressure drop thereacross in proportion to the fluid flow therein and a first abosrbing means (362) for absorbing pressure waves incident thereon wherein the admittance of said orifice (360) is equal to the admittance of said receiving means (310).

6. A system according to claim 5, characterized in that said receiving means (310) is a fluid conduit.

7. A system according to claim 6, characterized in that said first absorbing means (362) is an accumulator.

8. A system according to claim 7, characterized in that said first orifice means (360) is a linear flow restrictor.

9. A system according to claim 8, characterized in that it further includes pressure regulating means (400), connected to and in fluid communication with said exit means (104) of said fluid rail means (100) for regulating the pressure within said fluid rail means at a determinable pressure level.

10. A system according to claim 5, characterized in that it further includes a second filter means connected in fluid communication with said exit means (112) including a second absorbing means (600) for absorbing pressure waves incident thereon.

11. A system according to claim 10, characterized in that said second absorbing means (600) is an accumulator.

12. A system according to claim 11, characterized in that it further includes pressure regulating means (400) connected in fluid communication with said second filter means and said exit means (112) for regulating the pressure within said fluid rail means (100) at a determinable pressure level.

13. A system according to claim 12, characterized in that said second filter means includes a second orifice means (650) interconnecting said second absorbing means (640) and said exit means (112) for developing a pressure drop thereacross in proportion to fluid flow therethrough.

14. A system according to claim 13, characterized in that said system further includes a return conduit means (402) in fluid communication with said exit means (112) and the fluid source (200) for returning fluid to said fluid source.

15. A system according to claim 4, characterized in that it further includes pressure regulating means (400) connected to said exit means (112) of said fuel rail means (100) for regulating the pressure within said fluid rail means (100) at a determinable pressure level.

16. A system according to claim 4, characterized in that said anti-reflection means (300) further includes a third filter means interconnecting said receiving means with said inlet means comprising third orifice means (651) for developing a pressure drop thereacross in proportion to the fluid flow therethrough ; and a third aborbing means (640)for abosrbing pressure waves incident thereon wherein the admittance of said orifice is equal to the admittance of said receiving means.

17. A system according to claim 16, characterized in that said third absorbing means (640) is an accumulator.

18. A system according to claim 17, characterized in that said
4 orifice means (651) is a linear flow restrictor.

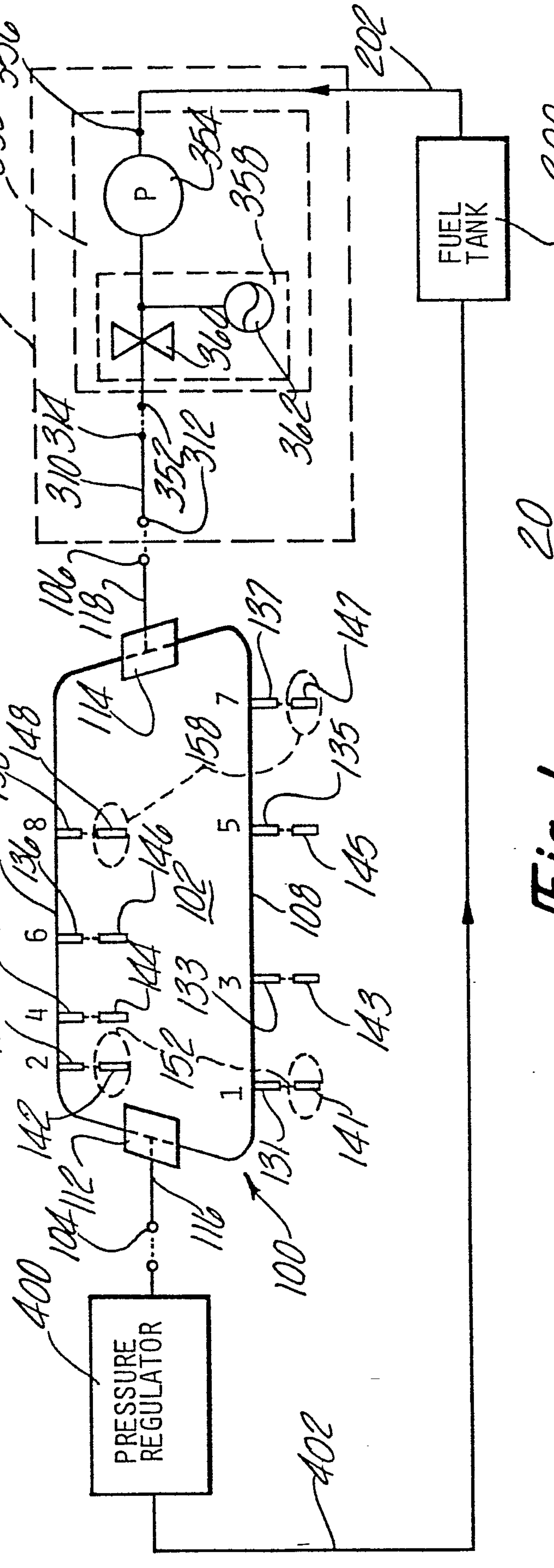


Fig-1

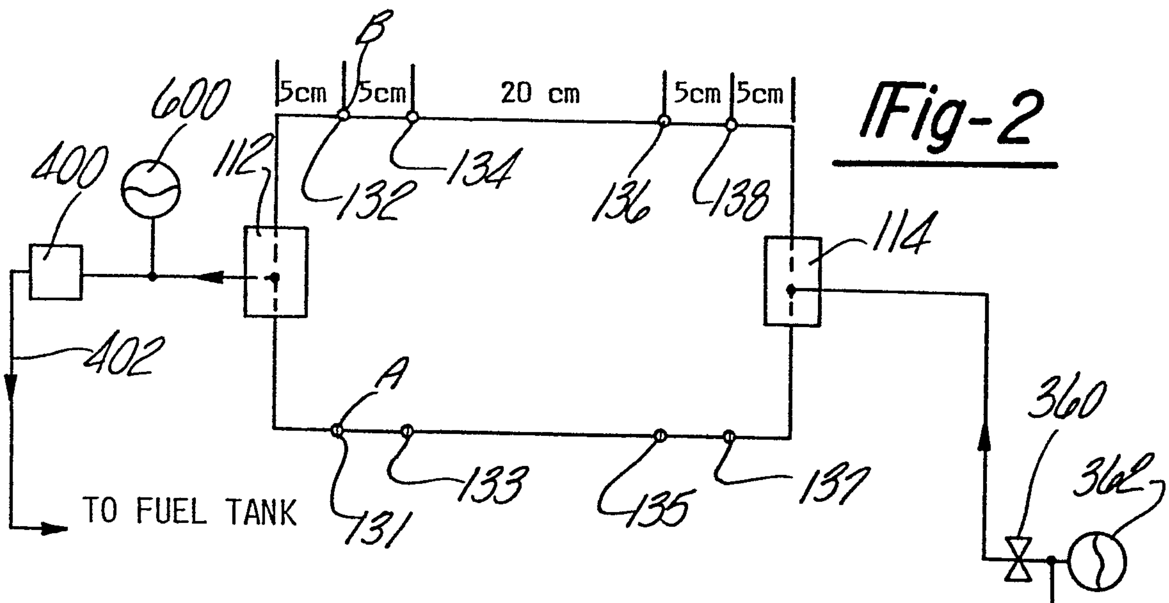


Fig-2

Fig-3

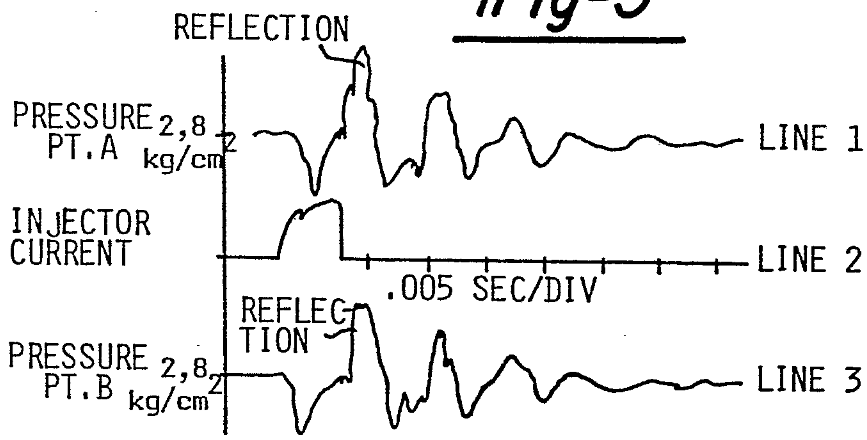
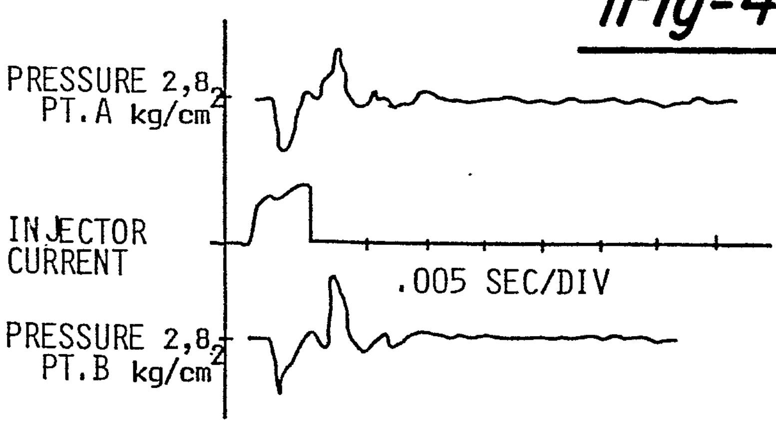


Fig-4



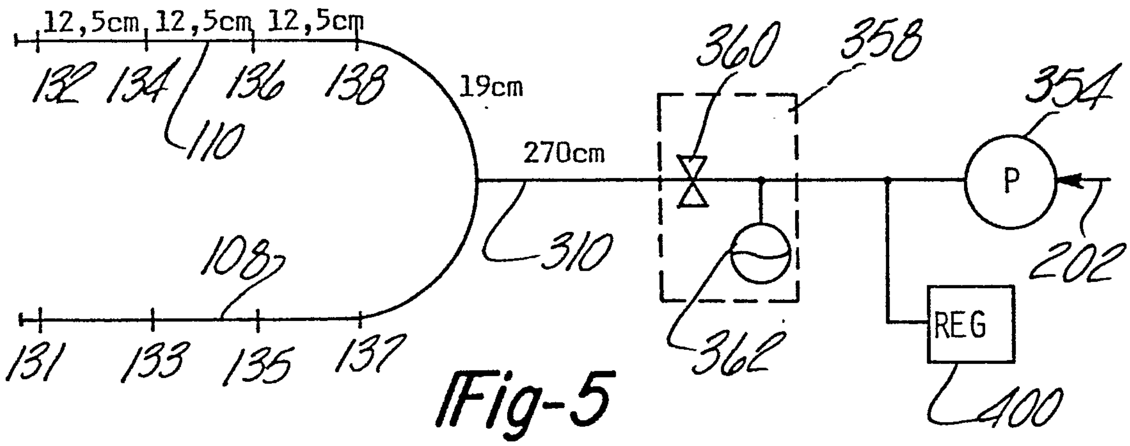


Fig-5

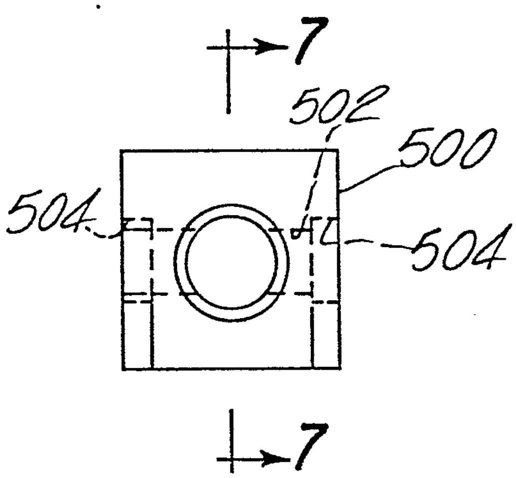
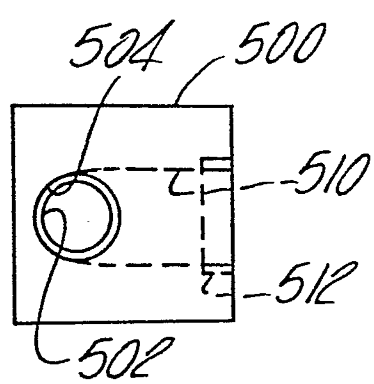


Fig-6

Fig-7



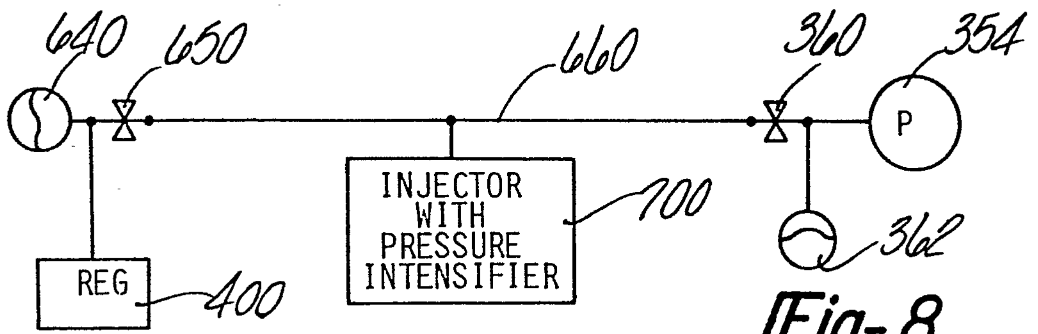


Fig-8

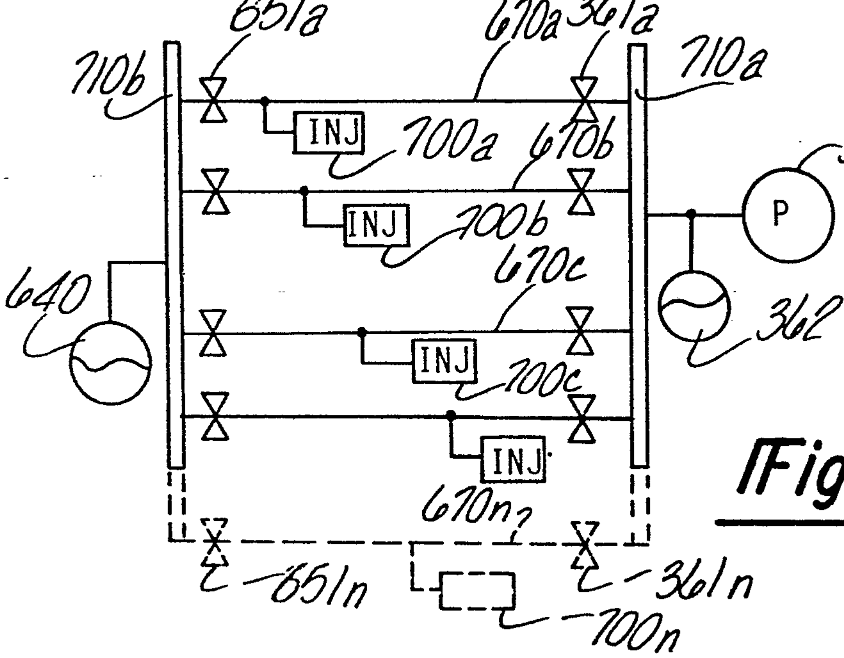


Fig-9

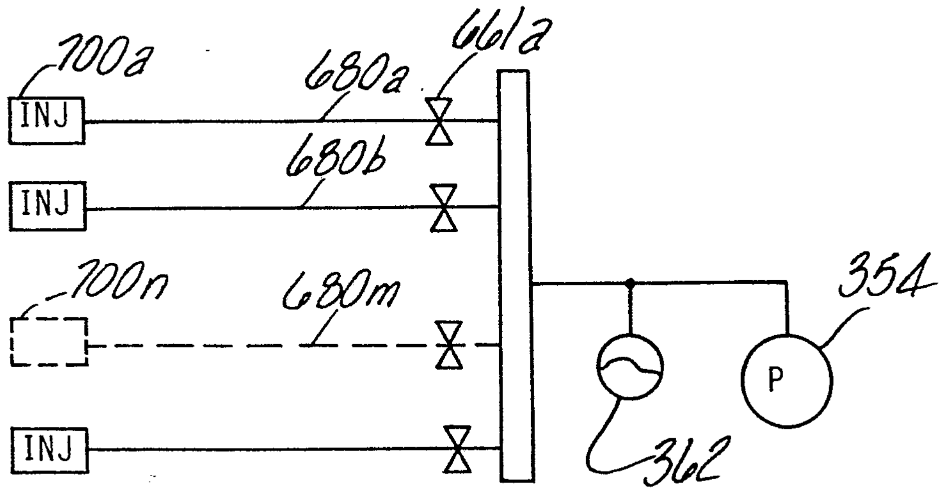


Fig-10

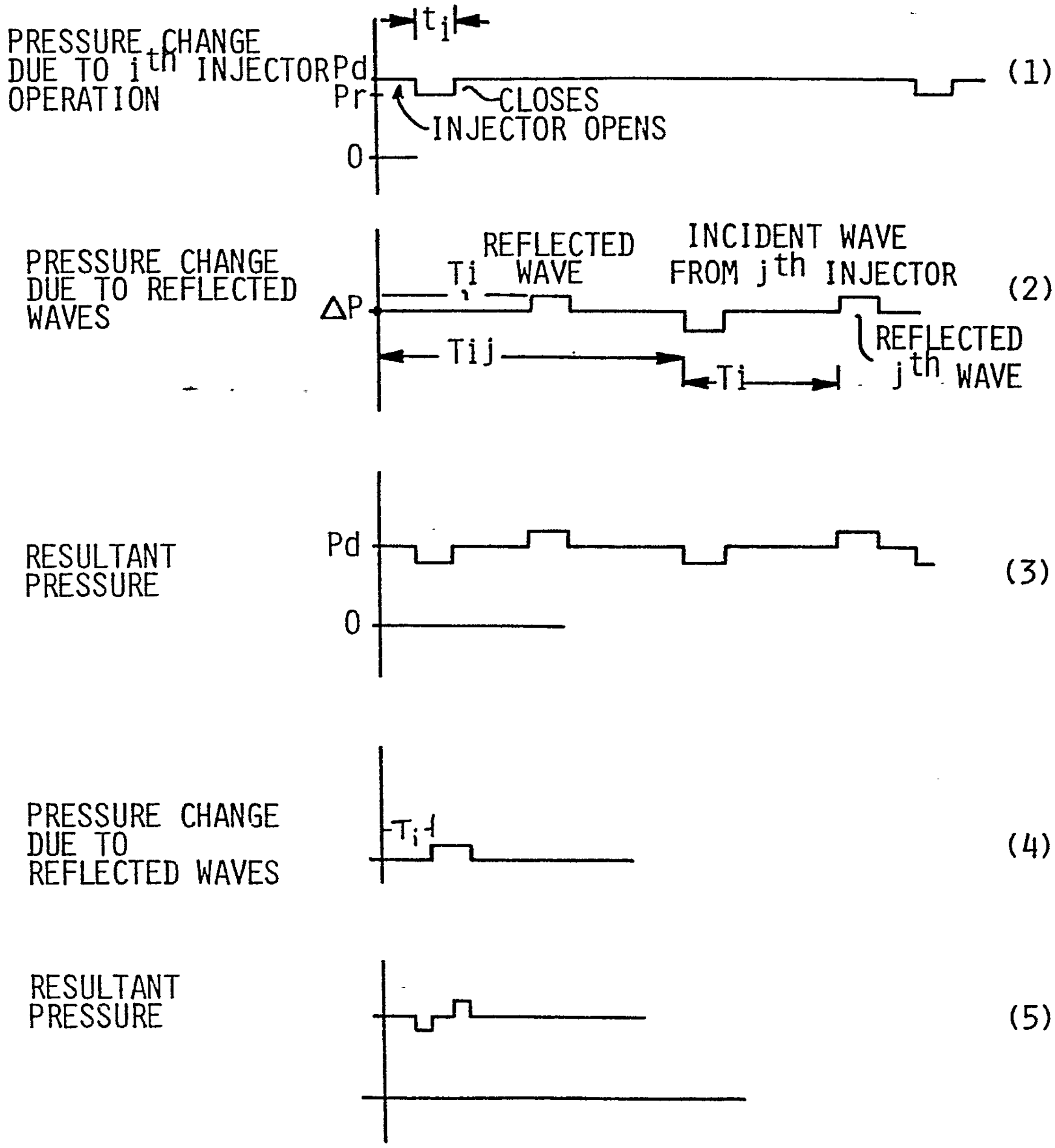

PRESSURE CHANGE DUE TO i th INJECTOR OPERATION
Pd
Pr
0
t i
CLOSES
INJECTOR OPENS
(1)
PRESSURE CHANGE DUE TO REFLECTED WAVES
ΔP
Ti
REFLECTED WAVE
INCIDENT WAVE FROM j th INJECTOR
Tij
Ti
REFLECTED j th WAVE
(2)
RESULTANT PRESSURE
Pd
0
(3)
PRESSURE CHANGE DUE TO REFLECTED WAVES
Ti
(4)
RESULTANT PRESSURE
(5)

Fig-11

European Patent Office

EUROPEAN SEARCH REPORT

0019529

Application number

EP 80 40 0636

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim
X	US - A - 3 507 263 (LONG) * Column 3, line 25 - column 8, line 55; figures 1-7 *	1-7,9-17
X	FR - A - 2 330 869 (ALLIED CHEMICAL CORPORATION) * Page 8, line 11 - page 10, line 8; page 23, lines 34-38; page 29, lines 8-25; page 31, line 17 - page 34, line 3; figures 1,2,12 *	1-7,9-17
	DE - A - 2 705 083 (BOSCH) * Page 4, line 2 - page 8, line 24; figures *	1,2,5,7,9
A	FR - A - 1 435 462 (N.V. PHILIPS)	
A	US - A - 2 727 470 (LUDWIG)	

CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)

F 02 M 55/00
55/02

TECHNICAL FIELDS SEARCHED (Int.Cl. 3)

F 02 M
F 16 L

CATEGORY OF CITED DOCUMENTS

X: particularly relevant
A: technological background
O: non-written disclosure
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T: theory or principle underlying the invention
E: conflicting application
D: document cited in the application
L: citation for other reasons

&: member of the same patent family, corresponding document

X The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	05-08-1980	HAKHVERDI

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