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(71) Applicant (for all designated States except US): **DONALDSON COMPANY, INC.** [US/US]; 1400 West 94th Street, P.O. Box 1299, Minneapolis, Minnesota 55440-1299 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **ANGELO, Theodore, G.** [US/US]; 838 Idaho Avenue West, St. Paul, Minnesota 55117 (US). **ANDERSON, Mike, D.** [US/US]; 2817 106th Street West, Bloomington, Minnesota 55431

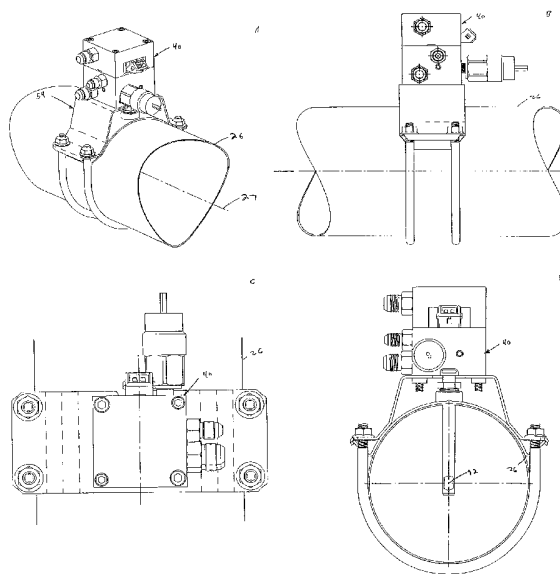
(US). **WAY, Paul, A.** [US/US]; 2022 3rd Street NW, New Brighton, Minnesota 55112 (US). **STEINBRUECK, Edward, A.** [US/US]; 16671 N. Hillcrest Court, Eden Prairie, Minnesota 55346 (US). **WAGNER, Wayne, M.** [US/US]; 120 Redwood Drive, Apple Valley, Minnesota 55124 (US). **GEBHARD, Brett, M.** [US/US]; 9214 Columbus Avenue South, Bloomington, Minnesota 55420 (US). **CATES, Phillip** [US/US]; 422 North Oak Street, Owatonna, Minnesota 55060 (US). **KONOPACKI, Jeffery, Michael** [US/US]; W11649 State Road 23, Ripon, Wisconsin 54971 (US). **SUHRE, Blake, Robert** [US/US]; 1241 East Deerfield Parkway, Suite 202, Buffalo Grove, Illinois 60089 (US).

(74) Agent: **BRUESS, Steven, C.**; MERCHANT & GOULD P.C., P.O. Box 2903, Minneapolis, Minnesota 55402-0903 (US).

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(54) Title: SYSTEM FOR DISPENSING FUEL INTO AN EXHAUST SYSTEM OF A DIESEL ENGINE



(57) Abstract: A system is disclosed for dispensing fuel into the transient flow of an exhaust system to control exhaust emissions. A controller initiates the delivery of fuel into the exhaust when an emissions control device, such as a diesel particulate filter, requires increased exhaust temperatures for regeneration. In operation, pressurized fuel and pressurized air are supplied to a fuel delivery device, wherein a fuel injector pre-mixes fuel with air. The fuel-air mixture is then dispensed into the exhaust flow through a nozzle, causing a rapid pressure drop in the mixture that results in the pressurized air expanding rapidly, breaking the fuel spray into fine particles.



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**SYSTEM FOR DISPENSING FUEL INTO AN EXHAUST SYSTEM OF A
DIESEL ENGINE**

Cross-Reference to Related Application

This application is being filed on 15 November 2005, as a PCT International Patent application in the name of Donaldson Company, Inc., a U.S. national corporation, applicant for the designation of all countries except the US, and Theodore G. Angelo, Mike D. Anderson, Paul A. Way, Edward A. Steinbrueck, Wayne M. Wagner, Brett M. Gebhard, Phillip Cates, Jeffrey Michael Konopacki, and Blake Robert Suhre, all citizens of the U.S., applicants for the designation of the US only, and claims priority to U.S. Provisional Patent Application Serial No. 60/628,864, filed November 15, 2004, and U.S. Utility Patent Application Serial No. 11/016,345, filed December 16, 2004, which applications are hereby incorporated by reference in their entirety.

Technical Field

The present disclosure relates generally to diesel engine exhaust systems. More particularly, the present disclosure relates to systems and methods for controlling diesel engine exhaust emissions.

Background

Vehicles equipped with diesel engines may include exhaust systems that have diesel particulate filters for removing particulate matter from the exhaust stream. With use, soot or other carbon-based particulate matter accumulates on the diesel particulate filters. As particulate matter accumulates on the diesel particulate filters, the restriction of the filters increases causing the buildup of undesirable back pressure in the exhaust systems. High back pressures decrease engine efficiency. Therefore, to prevent diesel particulate filters from becoming excessively loaded, diesel particulate filters should be regularly regenerated by burning off (i.e., oxidizing) the particulates that accumulate on the filters. Since the particulate matter captured by diesel particulate filters is mainly carbon and hydrocarbons, its chemical energy is high. Once ignited, the particulate matter burns and releases a relatively large amount of heat.

Systems have been proposed for regenerating diesel particulate filters. Some systems use a fuel fed burner positioned upstream of a diesel particulate filter to cause regeneration (see U.S. Patent No. 4,167,852). Other systems use an electric heater to regenerate a diesel particulate filter (see U.S. Patent Nos. 4,270,936; 4,276,066; 4,319,896; 4,851,015; and British Published Application No. 2,134,407).

Detuning techniques are also used to regenerate diesel particulate filters by raising the temperature of exhaust gas at selected times (see U.S. Patent Nos. 4,211,075 and 3,499,260). Self regeneration systems have also been proposed. Self regeneration systems can use a catalyst on the substrate of the diesel particulate filter to lower the
5 ignition temperature of the particulate matter captured on the filter. An example of a self regeneration system is disclosed in U.S. Patent No. 4,902,487.

In addition to particulate filters for removing particulate matter, exhaust systems can be equipped with structures for removing other undesirable emissions such as carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx).
10 Catalytic converters are typically used to remove CO and HC. NOx can be removed by structures such as lean NOx catalysts, selective catalytic reduction (SCR) catalysts and lean NOx traps.

Lean NOx catalysts are catalysts capable of converting NOx to nitrogen and oxygen in an oxygen rich environment with the assistance of low levels of
15 hydrocarbons. For diesel engines, hydrocarbon emissions are too low to provide adequate NOx conversion, thus hydrocarbons are required to be injected into the exhaust stream upstream of the lean NOx catalysts. SCR's are also capable of converting NOx to nitrogen and oxygen. However, in contrast to using HC's for conversion, SCR's use reductants such as urea or ammonia that are injected into the
20 exhaust stream upstream of the SCR's. NOx traps use a material such as barium oxide to absorb NOx during lean burn operating conditions. During fuel rich operations, the NOx is desorbed and converted to nitrogen and oxygen by catalysts (e.g., precious metals) within the traps.

Summary

25 The present disclosure relates to a system for delivering fuel into the exhaust stream of a diesel engine to control emissions. A fuel delivery device dispenses a mixture of fuel and pressurized air into the exhaust flow. This system causes the fuel to be well-atomized within the exhaust stream without requiring excessive fuel pressure, thereby uniformly raising the temperature of the exhaust stream to a
30 temperature suitable for regeneration of the diesel particulate filter without creating hot spots or exceeding a temperature that would damage the diesel particulate filter. Further, this system causes the fuel to be well-atomized within the exhaust stream without requiring an excessively small nozzle orifice that would be prone to plugging.

Brief Description of the Drawings

Figure 1 schematically illustrates an exhaust system having features that are examples of inventive aspects in accordance with the principles of the present disclosure;

5 Figure 2A shows an isometric view of a fuel injection arrangement having features that are examples of inventive aspects in accordance with the principles of the present invention;

Figure 2B is a side view of the arrangement of Figure 2A;

Figure 2C is a top view of the arrangement of Figure 2A;

10 Figure 2D is an end view of the arrangement of Figure 2A;

Figure 3 is an exploded view of the arrangement of Figures 2A-2D;

Figure 4 is an isometric view of one embodiment of a fuel supply device that is part of the arrangement of Figure 3;

15 Figure 5 is an exploded view of the embodiment of the fuel supply device of Figure 4;

Figure 6 is a detail view of a portion of the sealing mechanism apparent in Figure 3;

Figure 7 is a side view of the fuel supply device of Figure 4;

Figure 8 is a cross-sectional view taken along section line 8-8 of Figure 7;

20 Figure 9 is a cross-sectional view taken along section line 9-9 of Figure 7;

Figure 10 is a cross-sectional view taken along section line 10-10 of Figure 7;

Figure 11 is a cross-sectional view taken along section line 11-11 of Figure 7;

25 Figure 12 shows a first perspective view of a passage layout for the fuel supply device of Figure 4;

Figure 13 shows a second perspective view of a passage layout for the fuel supply device of Figure 4;

30 Figure 14 shows a third perspective view of a passage layout for the fuel supply device of Figure 4;

Figure 15 is an end view of an alternative embodiment of a fuel supply device;

Figure 16 is a cross-sectional view of the fuel supply device of Figure 15 taken along section line 16-16; and

35 Figure 17 is an alternative cross sectional view of the fuel supply device of Figure 15.

Detailed Description

The present disclosure relates to a system for regenerating a diesel emissions control device, such as a diesel particulate filter. The system includes a fuel supply device positioned upstream in the exhaust flow from the diesel particulate filter. A controller governs the rate at which fuel is dispensed by the fuel supply device. The controller interfaces with input sources that provide data representative of characteristics of the exhaust gas being conveyed through the exhaust system. Based on the characteristics of the exhaust gas and catalyst system, the controller causes the fuel supply device to dispense fuel into the exhaust stream at a rate sufficient to cause the controlled regeneration of the diesel particulate filter. In one embodiment, the fuel supply device is positioned upstream from a catalytic converter (i.e., a diesel oxidation catalyst (DOC)) that is positioned upstream from the diesel particulate filter. The diesel particulate filter may or may not include a catalyst. The desired fuel injection rate is preferably selected such that when the fuel combusts within the catalytic converter, the temperature of the exhaust gas exiting the catalytic converter and traveling to the diesel particulate filter is in the range of 500 to 700°C. In a more preferred embodiment, the temperature of the exhaust gas exiting the catalytic converter is in the range of 550 to 650°C. In a most preferred embodiment, the gas exiting the catalytic converter is about 600°C.

In alternative embodiments, the fuel injector can inject fuel directly into the diesel particulate filter without having a preheating process provided by combustion within an upstream catalytic converter. In such embodiments, the fuel ignites with a catalyst on the diesel particulate filter thereby causing oxidation of the particulate matter on the filter.

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I. System Overview

Figure 1 illustrates an exhaust system 20 having features that are examples of inventive aspects in accordance with the principles of the present disclosure. The system includes an engine 22 (e.g., a diesel engine), a fuel tank 24 for supplying fuel (e.g., diesel fuel) to the engine 22, and an exhaust conduit 26 for conveying exhaust gas away from the engine 22. The system 20 also preferably includes a muffler 28 positioned along the conduit 26. The muffler 28 includes an inlet pipe 30 and an outlet pipe 32. The inlet pipe 30 preferably includes a structure for distributing flow as described in U.S. Patent No. 6,550,573, that is hereby incorporated by reference in its entirety.

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Preferably, a number of structures for treating exhaust gas are positioned within the muffler 28. For example, a catalytic converter 34 (i.e., a diesel oxidation catalyst (DOC)) is shown mounted within the muffler near the inlet end of the

muffler 28. Also, a diesel particulate filter 36 is preferably mounted immediately downstream from the catalytic converter 34, adjacent to the outlet end of the muffler 28. Moreover, an optional lean NOx filter 38 is shown mounted within the muffler 28 upstream of the catalytic converter 34. Alternatively, the catalytic converter 34, diesel particulate filter 36, and optional lean NOx filter 38 may be housed within separate enclosures in the exhaust conduit 26. It will be appreciated that the catalytic converter 34 and the diesel particulate filter 36 function to treat the exhaust gas that passes through the conduit 26. Other structures for treating the exhaust gas such as Selective Catalytic Reduction (SCR) catalysts, lean NOx catalytic converters, and NOx traps/absorbers can also be provided along the conduit 26.

The system further includes a fuel supply device 40 for dispensing fuel into the exhaust stream. Controller 42 regulates the supply of compressed air and pressurized fuel into fuel supply device 40. Fuel pump 44 draws fuel (i.e., diesel fuel) from tank 24 through filter 46, supplying pressurized fuel to fuel supply device 40. A high pressure switch 41 is positioned downstream of the fuel pump 44 and trips if the fuel supply pressure exceeds a threshold value, for instance where a restriction is formed in the fuel passages. A low pressure switch 43 is positioned downstream of the fuel pump 44 and trips if the fuel supply pressure drops below a threshold value, for instance where a fuel leak develops in the system. The fuel pump 44, fuel filter 46, and fuel pressure switches 41, 43 may be housed within a pump box 45. Further, if fuel pump 44 is an electrically-driven fuel pump, pump box 45 may also contain associated electrical relays. Excess fuel is returned from fuel supply device 40 to fuel tank 24 by way of return fuel line 48. Pressurized air is provided to fuel supply device 40 from an air tank 50. It will be appreciated that the air tank 50 can be provided with pressurized air by the vehicle air compressor, or can be provided by an auxiliary air compressor (e.g., an electric air compressor). A solenoid valve 52 controls air flow to the fuel supply device 40. A check valve can also be used to prevent fuel from entering the compressed air line.

The fuel supply device 40 preferably dispenses fuel into the exhaust stream at a location between the engine 22 and catalytic converter 34. Preferably, the fuel supply device 40 inputs fuel into the conduit 26 at a location approximately 36 inches from the catalytic converter 34. In one embodiment, fuel is supplied to the exhaust stream at a location within 24 inches of the catalytic converter 34. In another embodiment, the fuel is supplied at a location within 48 inches of the catalytic converter.

The fuel dispensed into the exhaust conduit 26 by the fuel supply device 40 combusts within the catalytic converter 34, thereby generating heat. Preferably, sufficient fuel is dispensed into the exhaust gas so that the combustion within the

catalytic converter 34 raises the temperature of the exhaust gas exiting the catalytic converter 34 to a temperature above the combustion temperature of the particulate matter accumulated on the diesel particulate filter 36. In this manner, by burning fuel in the catalytic converter 34, sufficient heat is generated to cause regeneration of the diesel particulate filter 36. Preferably, the rate that fuel is dispensed into the exhaust stream is also controlled to prevent temperatures from exceeding levels which may be detrimental to the diesel particulate filter 36.

II. Controller

The controller 42 functions to control the rate that fuel is dispensed by the fuel supply device 40 to cause regeneration of the diesel particulate filter 36. The controller 42 interfaces with a number of sensing devices or other data inputs that provide data representative of the exhaust gas traveling through the conduit 26. This data may include the temperature, pressure, and mass flow of the exhaust gas. The controller 42 can use this data to determine the rate that fuel should be dispensed into the exhaust gas stream to regenerate the diesel particulate filter 36 in a controlled manner.

To promote a controlled and efficient regeneration of the diesel particulate filter 36, it is desirable for the temperature of the exhaust gas exiting the catalytic converter 34 to have a target temperature in the range of 500 to 700°C, as indicated above. Thus, the rate that fuel is dispensed upstream of the catalytic converter 34 is preferably selected so that upon combustion of the fuel within the catalytic converter 34, the exhaust gas exiting the catalytic converter is within the target temperature range.

The controller 42 can also be used to determine when the diesel particulate filter 36 is in need of regeneration. Any number of strategies can be used for determining when the diesel particulate filter 36 should be regenerated. For example, the controller 42 can initiate regeneration of the diesel particulate filter 36 when the pressure sensors indicate that the back pressure in the exhaust conduit 26 exceeds a predetermined level. The controller 42 can also initiate regeneration of the filter 36 at predetermined time intervals. The controller 42 can also be programmed to delay regeneration if conditions of the exhaust system are not suitable for regeneration (e.g., if the exhaust flow rate or exhaust temperature is not suitable for controlled regeneration). For such an embodiment, the controller 42 can be programmed to monitor the operating conditions of the exhaust system and to initiate regeneration only when predetermined conditions suitable for regeneration have been satisfied.

An example of a control system is disclosed in PCT application PCT US04/18536, filed June 10, 2004, entitled Method of Dispensing Fuel into Transient Flow of an Exhaust System, that is hereby incorporated by reference in its entirety.

5 III. Diesel Particulate Filter

The diesel particulate filter 36 can have a variety of known configurations. An exemplary configuration includes a monolith ceramic substrate having a “honey-comb” configuration of plugged passages as described in United States patent No. 4,851,015 that is hereby incorporated by reference in its entirety. Wire mesh
10 configurations can also be used. In certain embodiments, the substrate can include a catalyst. Exemplary catalysts include precious metals such as platinum, palladium and rhodium, and other types of components such as base metals or zeolites.

The diesel particulate filter 36 preferably has a particulate mass reduction efficiency greater than 75%. More preferably, the diesel particulate filter 36 has a
15 particulate mass reduction efficiency greater than 85%. Most preferably, the diesel particulate filter 36 has a particulate mass reduction efficiency equal to or greater than 90%. For purposes of this specification, the particulate mass reduction efficiency is determined by subtracting the particulate mass that enters the diesel particulate filter from the particulate mass that exits the diesel particulate filter, and
20 by dividing the difference by the particulate mass that enters the diesel particulate filter.

 IV. Catalytic Converter

The catalytic converter 34 can have a variety of known configurations.
25 Exemplary configurations include substrates defining channels that extend completely therethrough. Exemplary catalytic converter configurations having both corrugated metal and ceramic substrates are described in United States patent No. 5,355,973, that is hereby incorporated by reference in its entirety. The substrates preferably include a catalyst. For example, the substrate can be made of a catalyst,
30 impregnated with a catalyst or coated with a catalyst. Exemplary catalysts include precious metals such as platinum, palladium and rhodium, and other types of components such as base metals or zeolites.

In one non-limiting embodiment, the catalytic converter 34 can have a cell density of at least 200 cells per square inch, or in the range of 200-400 cells per
35 square inch. A preferred catalyst for the catalytic converter is platinum with a loading level greater than 30 grams/cubic foot of substrate. In other embodiments the precious metal loading level is in the range of 30-100 grams/cubic foot of substrate. In certain embodiments, the catalytic converter can be sized such that in

use, the catalytic converter has a space velocity (volumetric flow rate through the DOC/ volume of DOC) less than 150,000/hour or in the range of 50,000-150,000/hour.

5 V. Fuel Supply Device

In one embodiment, a fuel supply device capable of achieving relatively high levels of atomization at relatively low injection pressures is used. In one embodiment, twin-fluid atomization (e.g., effervescent atomization) is used. For example, in one twin-fluid embodiment, two fluids (e.g., fuel and air/gas) are pre-
10 mixed before reaching an injection orifice. The fluids can be pre-mixed by using an injector to meter fuel into a chamber where it mixed with a supply of gas/air to form a two-phase fuel-gas mixture. The mixture is forced, via pressure differential, through an orifice and into the exhaust stream. The drop in pressure of the mixture upon entering the exhaust stream causes rapid expansion. This rapid expansion
15 breaks the liquid portion of the mixture into fine droplets providing a high level of atomization.

One possible embodiment of fuel supply device 40 is shown mounted to exhaust conduit 26 in Figures 2A-2D. Figure 3 shows an exploded view of the fuel supply device 40 of Figures 2A-2D. Support base 54 comprises a curved plate 56
20 that corresponds with the external profile of the exhaust conduit 26. The base 54 also includes an offset plate 101 including a relatively flat surface 58 that is offset from the surface of exhaust conduit 26. In one embodiment, the surface 58 is spaced at least one-half inch from the surface of exhaust conduit 26 to provide a gap (e.g., an air gap) that minimizes undesirable heat transfer from the hot exhaust gas within
25 exhaust conduit 26 to fuel supply device 40. In certain embodiments, insulation material such as fiberglass can be used within the gap.

Support base 54 further comprises a pair of flanges 55 that extend in a direction generally normal to exhaust conduit 26. The flanges 55 define fastener openings 57. A pair of U-bolts 60 and corresponding nuts 62 secure support base 54
30 to exhaust conduit 26. The shanks of U-bolts 60 extend through the openings 57 of flanges 55. Fuel supply device 40 is secured to support base 54 by means of two bolts 64 that extend through fuel supply device 40 to engage nuts 66 secured to support base 54.

Referring now to Figures 4 and 5, fuel supply device 40 comprises a housing
35 (e.g., a manifold) including an upper housing block 68 and a lower housing block 70. Provision is made in lower housing block 70 for a pressurized air inlet fitting 72 which is threaded into lower housing block 70. Air inlet fitting 72 seats against O-ring 74, which in turn secures orifice plate 76 within a counterbore within lower

housing block 70. Orifice plate 76 limits the quantity of pressurized air that can enter fuel supply device 40. Provision is made in upper housing block 68 for a fuel inlet fitting 78 which is threaded into upper housing block 68. A passageway 300 (see Figures 10 and 13) communicates between fuel inlet fitting 78 and fuel pressure regulator 80. If the fuel pressure exceeds a preset value, fuel pressure regulator 80 will open, allowing pressurized fuel to flow into a passageway 302 (see Figures 10-13) that communicates with fuel return fitting 82, from which it flows through fuel return line 48 to the fuel tank. This causes the fuel pressure to drop. When the fuel pressure drops below a preset value, fuel pressure regulator 80 will then close, causing the fuel pressure to build. In this way, the fuel pressure is maintained within a suitable range.

An additional passageway 304 (see Figures 9, 12 and 13) in upper housing block 68 allows fuel communication between fuel inlet fitting 78 and the inlet of fuel injector 84. In one embodiment, fuel injector 84 is a customary gasoline-engine style fuel injector that comprises an internal electrical solenoid that actuates a needle valve to control fuel flow through a discharge opening. Fuel injector 84 is preferably a Synerject DEKA IV short injector, but other injectors can be used as well. A cylindrical surface is provided in upper housing block 68 to allow upper O-rings on the body of fuel injector 84 to securely seal against the supply fuel pressure. Upper housing block 68 also comprises a clearance portion 69 that enables electrical connection to be made to the fuel injector 84. Further, a cylindrical surface is provided in lower housing block 70 to allow lower O-rings on the body of fuel injector 84 to securely seal against the discharge fuel pressure and pressurized air. Bolts 95 secure upper housing block 68 to lower housing block 70.

In one embodiment, the fuel return passage 302 within the lower housing block 70 forms a cooling passage structure (see Figure 8) including a plurality of sections of passageway. In the depicted embodiment, the cooling passage structure includes a plurality of parallel lengths of passage adjacent the bottom of the block. Tortuous or convoluted pathways can also be used. These sections increase the total passage length and surface area of return fuel flowing within lower housing block 70, promoting heat transfer out of lower housing block 70 into the return fuel. The ends of the sections are sealed with press-fit plugs 85.

A region 306 (see Figures 7 and 9) is provided in lower housing block 70 that allows fluid communication between the outlet end of the fuel injector 84, the pressurized air inlet fitting 72, and a nozzle tube 86. This region 306 forms a pre-mixing chamber. An air passage 310 (see Figures 7, 13 and 14) provides fluid communication between the inlet fitting 72 and the region 306. The entry of nozzle tube 86 defines a chamfer 89 which promotes efficient fluid flow into nozzle tube

86. As best shown at Figure 5, nozzle tube 86 is retained within region 306 by means of U-clip 88, which engages with slot portions 91 of nozzle tube 86 and holes 97 in lower housing block 70. Further, nozzle tube O-ring 90 is installed in annular groove 93 of nozzle tube 86 and seals the fuel-air mixture from escaping from the joint between nozzle tube 86 and lower housing block 70. A fuel atomization nozzle orifice 92 is provided near the lower end of nozzle tube 86.

The fuel pressure regulator 80 is preferably a differential fuel pressure regulator that references the pressure of the pre-mixing chamber and is used to ensure that the pressure difference between the fuel supply and the pre-mixing chamber is constant. In one embodiment, passage 310 (shown at Figure 14) is in fluid communication with the regulator 80 to allow the regulator to reference the pressure of the pre-mixing chamber. The regulator 80 regulates pressure by routing fuel back to the supply tank through the return passage 302 and return line 48. In one embodiment, fuel is continuously cycling, even when the unit is not injecting fuel into the exhaust stream.

In one non-limiting embodiment, nozzle tube 86 has an outside diameter of approximately 3/8 inch and an inside diameter of approximately 1/8 inch. It is preferred to minimize the amount of volume within nozzle tube 86 so as to improve the transient response of the fuel delivery device 40, but the nozzle tube 86 inner diameter preferably is not so small as to cause excessive flow restriction of the fuel-air mixture therein. It is also preferred that the diameter of the fuel atomization nozzle orifice 92 be in the range of 0.04 to 0.07 inches for proper atomization. In another embodiment, the injection nozzle defines a single orifice having a diameter in the range of .02-.10 inches. In another embodiment, the nozzle may include a plurality of orifices of a diameter such that the total equivalent flow area is comparable to the flow area of a single-hole orifice embodiment.

In the depicted embodiment, the wall section of the nozzle tube 86 includes a thinned portion 87 near the fuel atomization nozzle orifice 92 so as to reduce the ratio of orifice length to orifice diameter, in order to promote more complete atomization. In one embodiment, the ratio of the orifice length to the orifice diameter is 1.0.

The tube 86 projects downwardly from the lower block 70 and extends across the spacing between the offset plate 58 and the curved plate 56. The tube further extends through the plate 56, and through hole 96 and into the interior of the conduit 26. The length of nozzle tube 86 is preferably sized so that nozzle orifice 92 is located at approximately the central axis 27 (see Figure 2) of exhaust conduit 26 when fuel delivery device 40 is mounted to exhaust conduit 26, and that nozzle orifice 92 is facing downstream within the exhaust conduit 26. In one embodiment,

the tube 86 projects at least 2 inches outwardly from the bottom of the block 70. Of course, the length of the tube will vary with different applications and may be less than 2 inches in certain embodiments.

5 In one embodiment, air flow is regulated using a flow regulator such as orifice plate 76. The orifice plate 76 is located adjacent the air inlet 72 and has an orifice diameter of about .02-.03 inches. The orifice plate 76 controls air flow rates without requiring regulation of the incoming air pressure. However, in other embodiments, air pressure regulators can be used to regulate the air pressure provided to the mixing chamber.

10 It will be appreciated that to maintain desired liquid to fuel ratios within the mixing chamber, the size of the orifice plate 76 is dependent upon the size of the dispensing orifice 92. In certain embodiments, example gas to liquid mixing ratios in the range of .1-2.3, or in the range of .3-.7, are used. In one embodiment, the air flow rate preferably does not exceed 1 standard cubic foot per minute (SCFM). In
15 another embodiment, air flow is regulated in the range of .25-5 SCFM. By using relatively low air flow rates, existing sources of compressed air provided on a vehicle (e.g., compressed air for brakes and suspension) can be used as an air supply for the injector system.

Pressure within the mixing region 306 is monitored by a pressure switch 94
20 which is threaded into lower housing block 70. The pressure switch 94 is in fluid communication with the air passage 310 (see Figure 13). Electrical connection 51 is provided from pressure switch 94 to controller 42. Pressure switch thereby is able to communicate with controller 42 to facilitate controlling the pressure and detecting failure conditions.

25 Referring now to Figure 3, support base 58 is positioned over opening 96 in exhaust conduit 26. Packing material 98 is positioned circumferentially around nozzle tube 86. Referring now to Figure 6, boss 100 is attached to support base 58 and contains internal threads. Gland nut 104 is threaded into boss 100. To seal the exhaust gases within exhaust conduit 26 so as to prevent exhaust gases from leaking
30 between opening 96 and nozzle tube 86, gland nut 104 is tightened against packing material 98, which forces packing material 98 against exhaust conduit 26 and also causes packing material 98 to expand radially inward into sealing contact against nozzle tube 86. Packing material 98 is preferably a graphite material.

In operation, when controller 42 determines that fuel should be dispensed
35 into the exhaust stream, controller 42 sends an electrical signal to solenoid valve 52 to initiate a flow of pressurized air to fuel delivery device 40. Approximately simultaneously, controller 42 sends an electrical signal to fuel injector 84 by way of electrical connection 53 to initiate a flow of fuel within fuel delivery device 40.

Fuel discharged by fuel injector 84 is mixed with pressurized air in pre-mixing chamber 106, forming a multi-phase fuel-air mixture. Fuel-air mixing can also occur in nozzle tube 86. In one embodiment, the fuel pressure provided to the injector is at least 30 pounds per square inch (psi) greater than the air pressure provided at the air inlet 72. In other embodiments, the fuel pressure is in the range of 30–50 psi greater than the air pressure. (All pressures given are gauge pressures.) In still other embodiments, the fuel pressure is at least 40 psi greater than the air pressure. In certain embodiments, the air pressure provided to the inlet 72 is in the range of 10–50 psi or 20–40 psi, and the fuel pressure provided to the injector is in the range of 40–150 psi. In other embodiments, the air pressure is about 30 psi, and the fuel pressure is about 70 psi. Because the diameter of the orifice in the air inlet orifice plate 76, the air supply pressure in tank 50, and the fuel pressure regulator setting 80 are all fixed mechanically, the controller 42 adjusts the fuel dispensing rate by regulating the on-cycle time of the electric signal provided to the fuel injector 84.

In one embodiment, the multi-phase fuel-air mixture is dispensed into the exhaust stream through nozzle orifice 92. The pressure of the mixture drops rapidly as it travels through the orifice, from a pressure of preferably approximately 40–60 psi inside the nozzle tube 86 to a pressure of preferably approximately 0.1 to 3.0 psi inside the exhaust conduit 26. This rapid decrease in pressure causes the air that is entrained within the air-fuel mixture to expand rapidly, thereby providing turbulence and mixing within the fuel spray that causes the fuel to atomize into small particles. Smaller fuel particles are advantageous because they combust more effectively and uniformly in the catalytic converter 34.

An alternative embodiment of fuel delivery device 240 is shown in Figures 15–17. Fuel delivery device 240 comprises an upper housing block 268 and a lower housing block 270. A pressurized air inlet fitting 272 threads into lower housing block 270 and is in fluid communication with pre-mixing chamber 206. Upper housing block 268 contains a fuel inlet port 278 which is in fluid communication with a fuel pressure regulator 280. If the fuel pressure exceeds a preset value, fuel pressure regulator 280 opens a fluid communication passageway to fuel return port 282. Fuel return line 48 (not shown) is attached to fuel return port 282, providing a passageway for the fuel to return to fuel tank 24.

Upper housing block 268 further comprises a cylindrical surface that receives fuel injector 284, formed with appropriate dimensions to allow the O-rings on the top of fuel injector 284 to properly seal the fuel in the fuel passageway in the upper housing block 268. Similarly, a cylindrical surface is provided in lower housing block 270 to receive injector 284 and to allow the lower O-rings on the

body of fuel injector 284 to securely seal against the discharge fuel pressure and pressurized air present in pre-mixing chamber 206. Lower housing block 270 additionally comprises a threaded cylindrical surface 210. Referring now to Figure 15, internally-threaded boss 208 is attached to exhaust conduit 26. Fuel delivery
5 device 140 is secured to exhaust conduit 26 by being threaded into boss 208. Referring now to Figure 16, fuel dispensing tube 286 is threaded into lower housing block 270 and passes through an opening in exhaust conduit 26. Fuel dispensing tube 286 preferably is partially curved so as to form an end portion that is approximately coaxial with the exhaust conduit 26. A delivery nozzle 212 is
10 attached to the end portion of fuel dispensing tube 286 from which the fuel-air mixture is dispensed.

In the above embodiments, fuel is injected into the exhaust stream to raise exhaust temperatures to a target temperature suitable for regenerating a diesel particulate filter. In other embodiments, the fuel injection systems disclosed herein
15 can be used to inject fuel into an exhaust stream for other purposes, such as to provide hydrocarbons to promote the conversion of NO_x at a lean NO_x catalyst or to provide hydrocarbons for regenerating NO_x traps. In yet other embodiments, the fuel injection systems disclosed herein can be used to inject a reductant, such as ammonia or urea, into an exhaust stream for use with a selective catalytic reduction
20 system for reducing NO_x emissions. A variety of control models can be used to control fuel injection rates for these alternative systems.

It will be appreciated that the specific dimensions disclosed herein are examples applicable for certain embodiments in accordance with the principles of the disclosure, but that other embodiments in accordance with this disclosure may or
25 may not include such dimensions.

What is claimed is:

1. A system for dispensing a mixture of liquid and air into an exhaust stream comprising:
 - 5 an injector housing defining an air passage and a liquid passage;
an air inlet for providing pressurized air to the air passage of the injector housing;
a liquid inlet for providing liquid to the liquid passage of the injector housing;
 - 10 a mixing location in fluid communication with the air passage;
an injector mounted within the injector housing for injecting liquid from the liquid passage into the mixing location, wherein the liquid injected by the injector mixes with pressurized air from the air passage at the mixing location;
 - a dispensing tube that projects outwardly from the injector housing, the
15 dispensing tube including an orifice spaced from the injector housing for dispensing the mixture of liquid and air into the exhaust stream.
2. The system of claim 1, wherein the mixing location includes a mixing chamber defined at least partially within the injector housing.
20
3. The system of claim 1, wherein the mixing location includes a mixing chamber defined at least partially within the dispensing tube.
4. The system of claim 1, further comprising a pressure regulator mounted to
25 the injector housing for regulating the liquid pressure provided to the injector.
5. The system of claim 4, further comprising a liquid return outlet in fluid communication with the liquid pressure regulator for returning liquid from the injector housing back to a source of liquid.
30
6. The system of claim 5, further comprising a cooling passage structure defined by the injector housing, the cooling passage structure providing fluid communication between the liquid pressure regulator and the liquid return outlet.
- 35 7. The system of claim 1, wherein the injector housing includes a first block coupled to a second block, and wherein the injector is mounted between the first and second blocks.

8. The system of claim 7, further comprising a liquid pressure regulator mounted between the first and second blocks.
9. The system of claim 8, further comprising a liquid return outlet in fluid communication with the liquid pressure regulator, the liquid return outlet and the air inlet being defined by the second block and the liquid inlet being defined by the first block.
10. The system of claim 1, further comprising a pressure sensor mounted to the injector housing for determining a pressure at the mixing location.
11. The system of claim 1, further comprising a pressurized air flow regulating orifice for regulating air flow through the air passage.
12. The system of claim 1, wherein the orifice diameter is approximately 0.04 to 0.07 inches.
13. The system of claim 1, further comprising a pump box for providing liquid to the liquid inlet, the pump box containing a pump, a liquid filter and one or more safety switches.
14. The system of claim 1, wherein the pressure of the liquid within the liquid passage is approximately 30 to 50 pounds per square inch (gauge) greater than the pressure of the supply air.
15. The system of claim 1, wherein the pressure is approximately 40 to 60 pounds per square inch gauge pressure at the mixing location.
16. An apparatus for dispensing a substance into an exhaust stream within an exhaust conduit comprising:
a mounting base including a first portion having a curved surface for engaging an exterior surface of the exhaust conduit, and a second portion including a mounting surface offset from the curved surface by a spacing;
one or more fasteners for securing the mounting base to the exhaust conduit;
and
an injector housing mounted at the mounting surface of the mounting base and a tube through which the substance is dispensed, the tube extending from the injector housing across the spacing and through the curved surface, wherein the tube

is adapted to project into the exhaust conduit when the apparatus is mounted to the exhaust conduit.

17. The apparatus of claim 16, wherein the one or more fasteners include at least one u-bolt.

18. The apparatus of claim 16, wherein the spacing includes an air gap of at least one-half of an inch.

19. An exhaust system for treating engine exhaust, the exhaust system comprising:
an exhaust conduit receiving exhaust from a combustion engine;
a treatment device positioned within the exhaust conduit for treating the exhaust; and
an injector device mounted to the exhaust conduit at a location between the treatment device and the engine, the injector device including:
an injector housing positioned outside the exhaust conduit, the injector housing defining an air passage and a liquid passage;
an air inlet for providing pressurized air to the air passage of the injector housing;
a liquid inlet for providing liquid to the liquid passage of the injector housing;
a mixing location in fluid communication with the air passage;
an injector mounted within the injector housing for injecting liquid from the liquid passage into the mixing location, wherein the liquid injected by the injector mixes with pressurized air from the air passage at the mixing location;
a dispensing tube that projects outwardly from the injector housing, the tube extending from the injector housing, through a wall of the exhaust conduit, to an interior of the exhaust conduit, the dispensing tube including an orifice for dispensing the mixture of liquid and air into the exhaust within the exhaust conduit.

20. The exhaust system of claim 19, wherein the orifice is located adjacent a central axis of the exhaust conduit.

35

FIG. 1

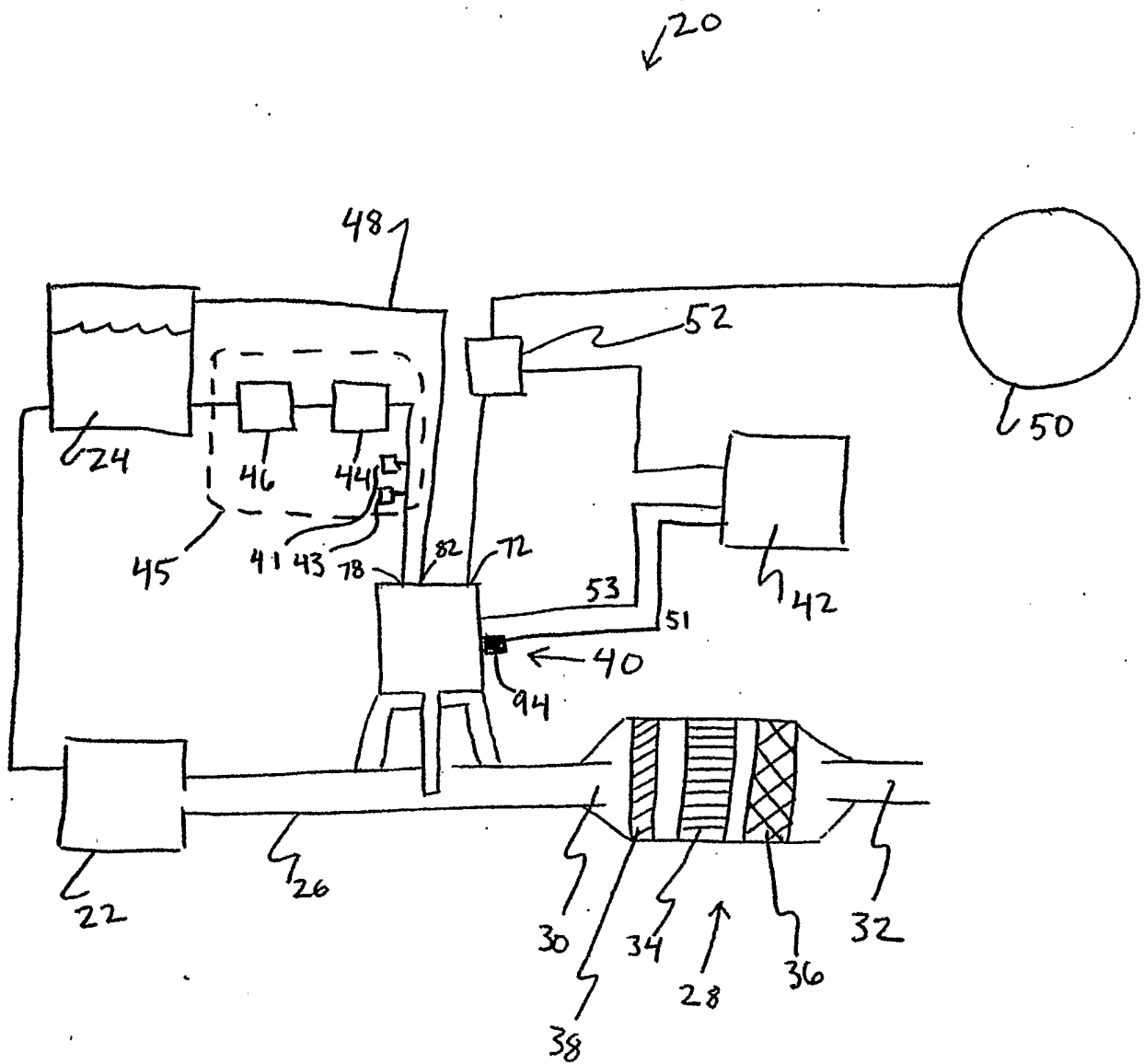
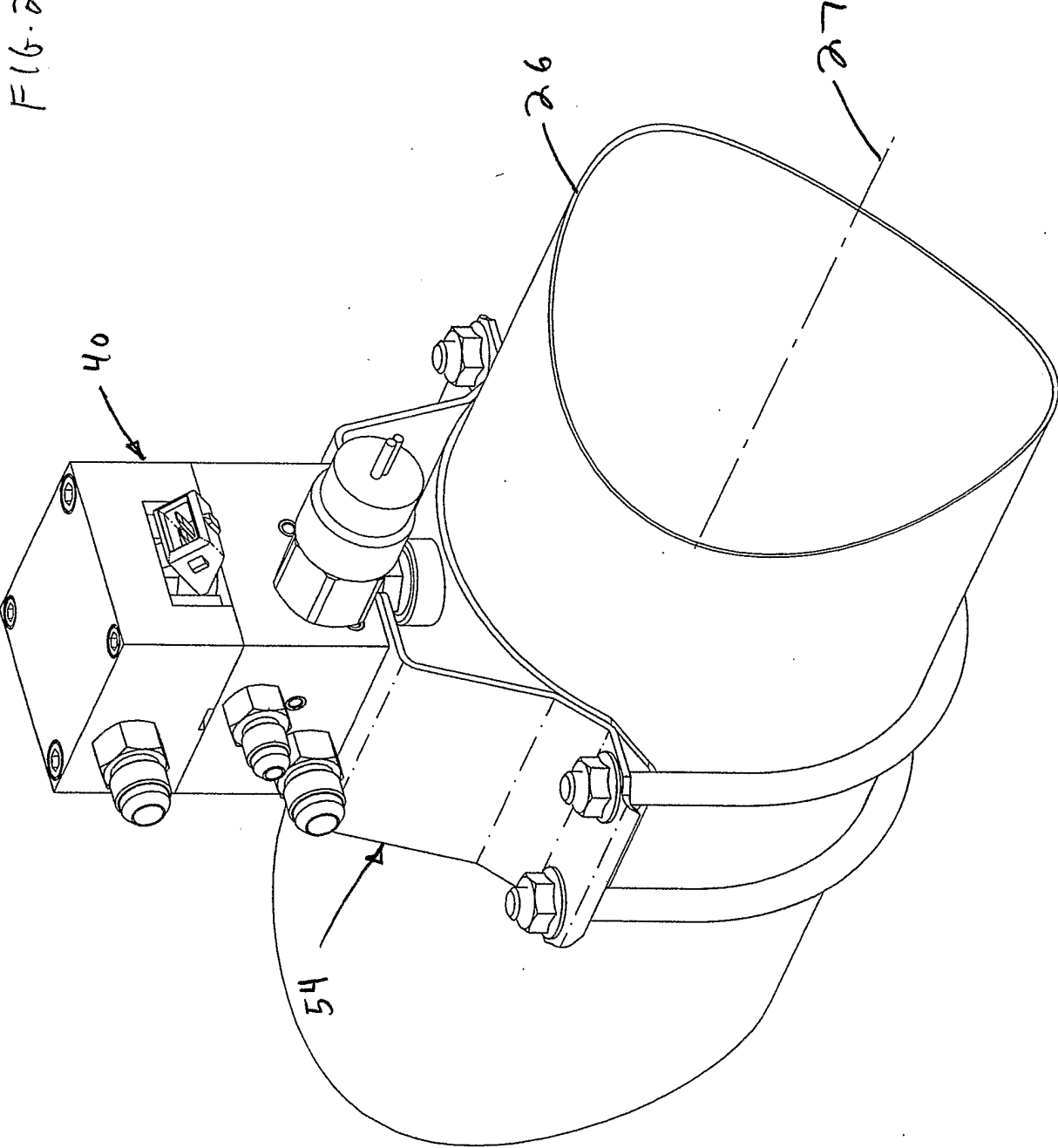


FIG. 2A



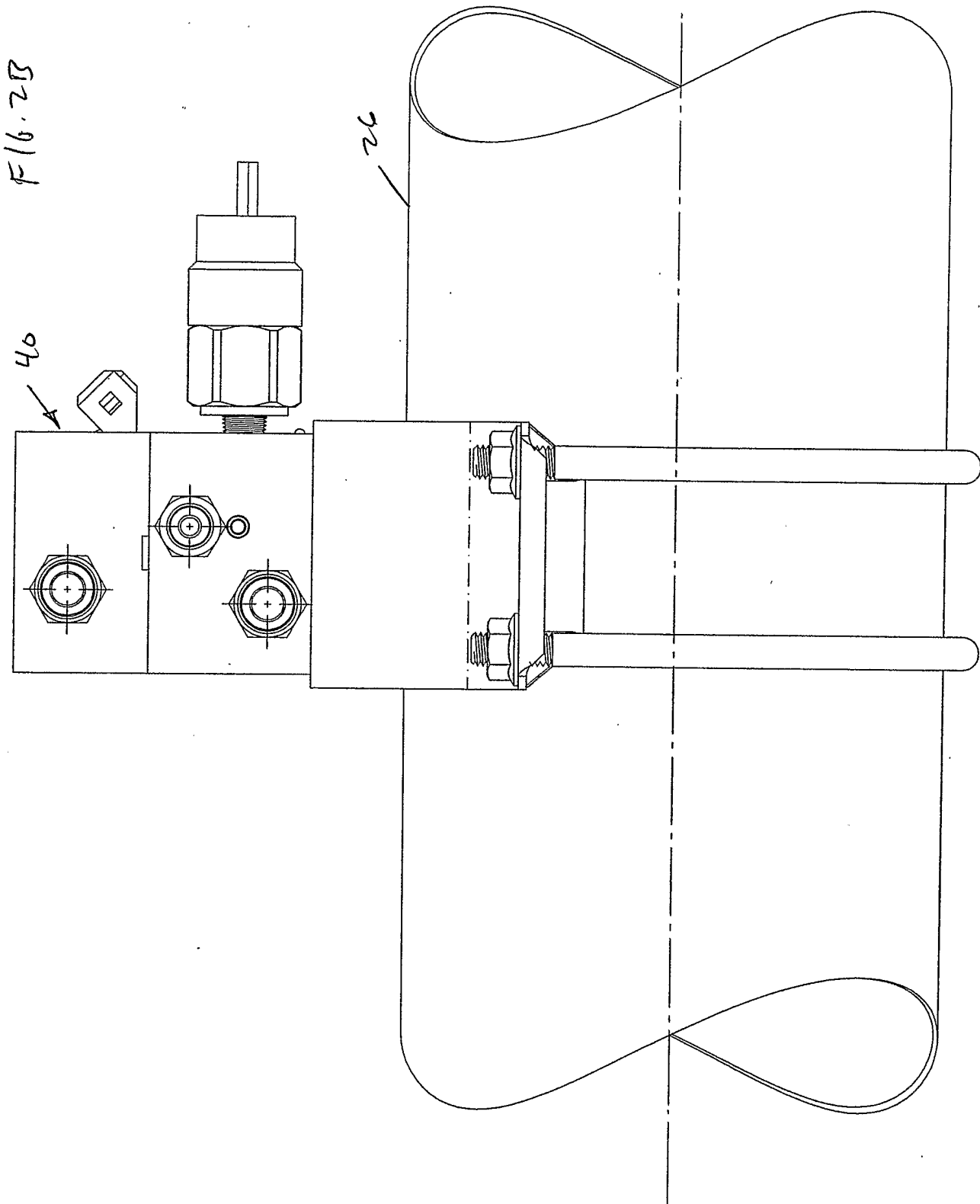


FIG. 2C

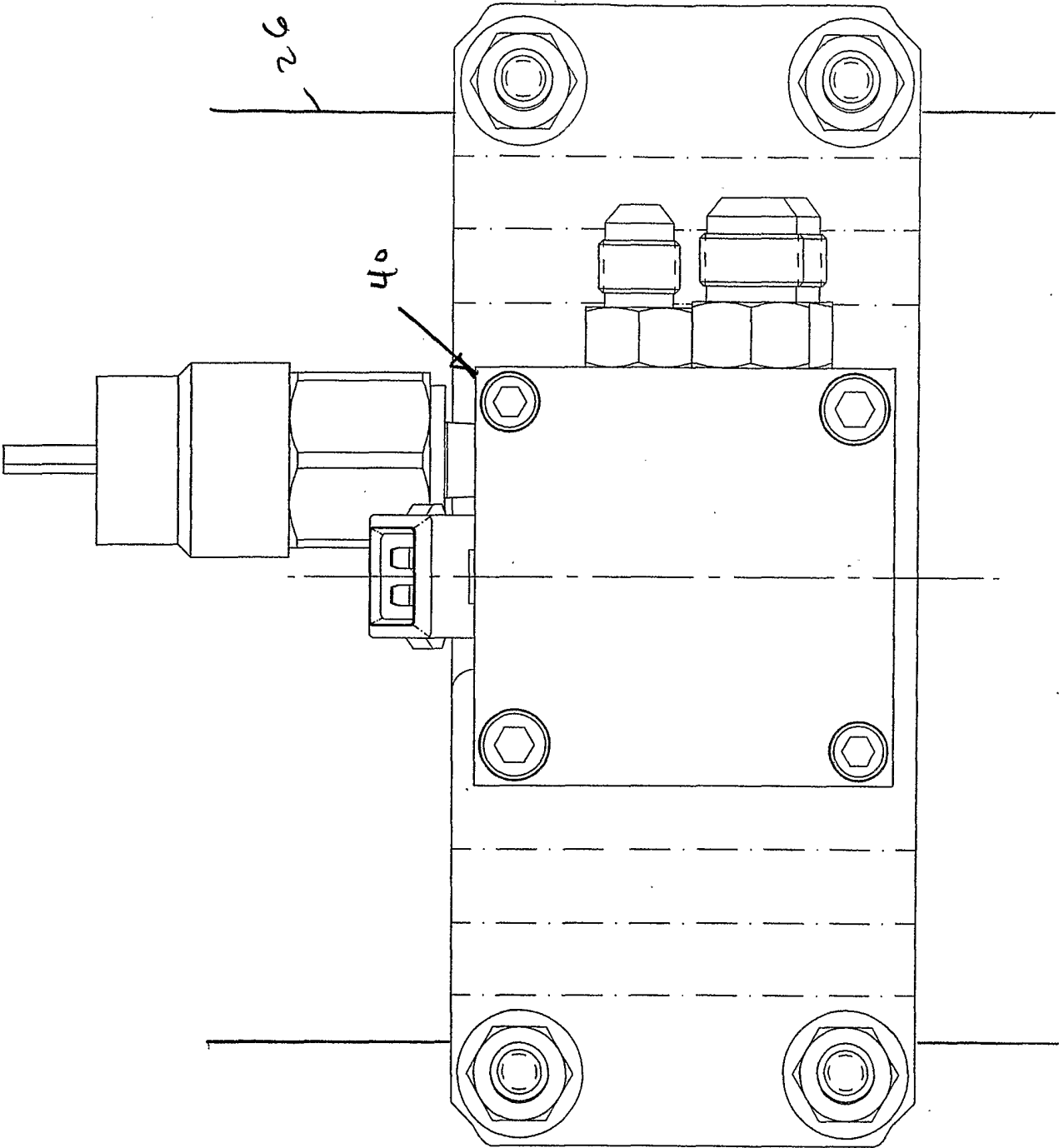
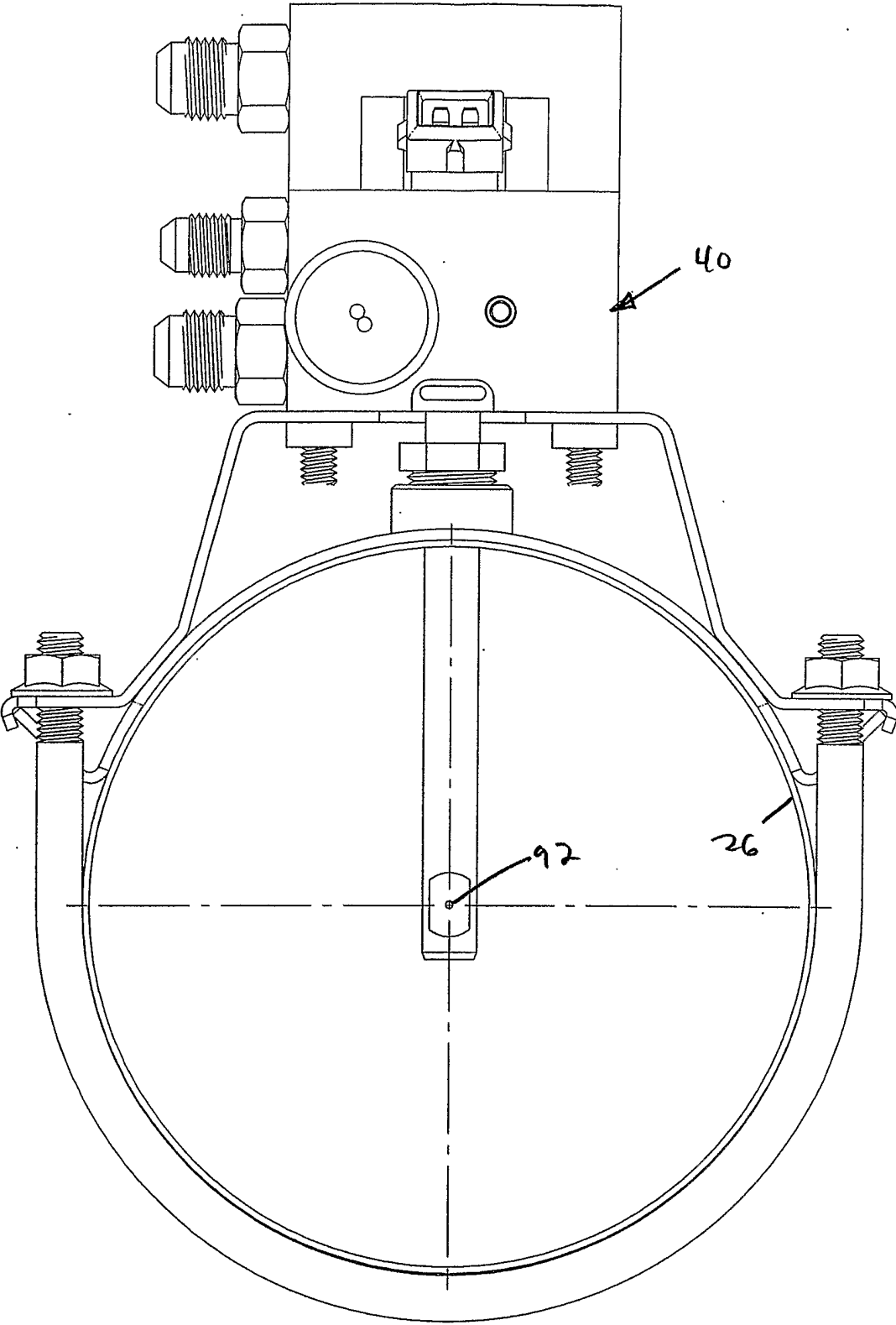


FIG. 2D



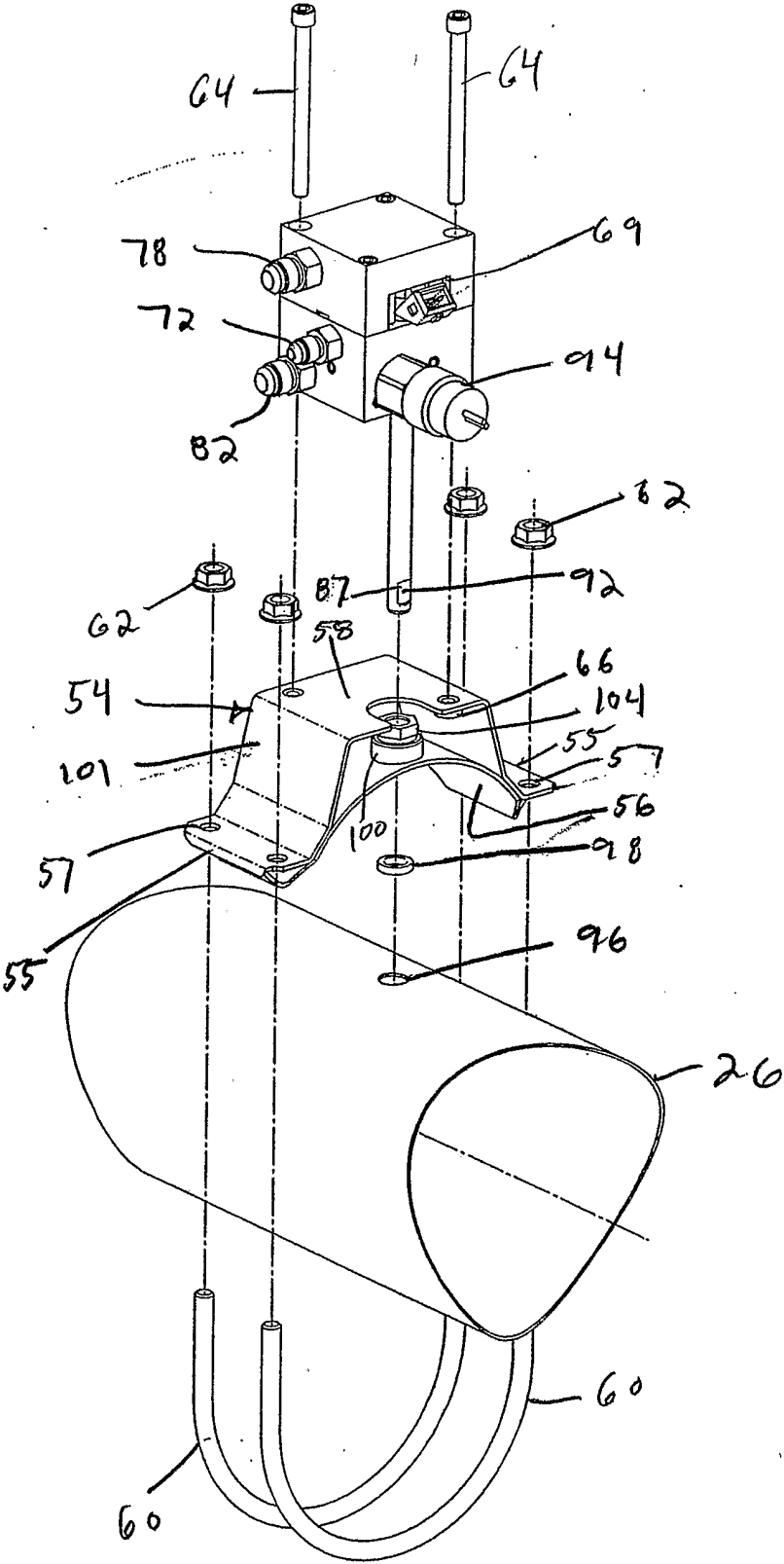


FIG. 4

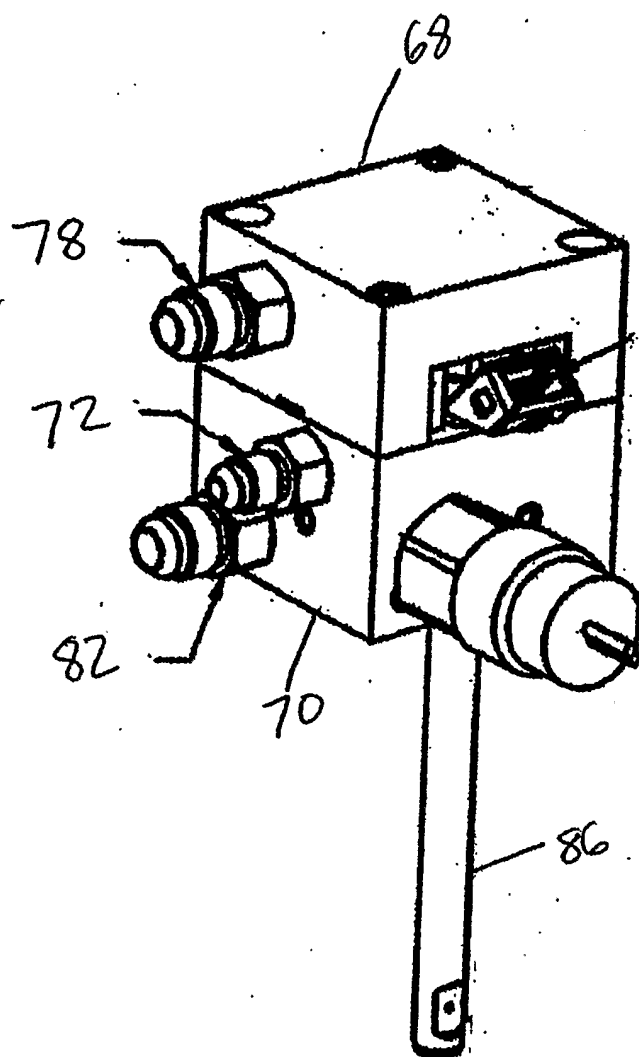


FIG. 5

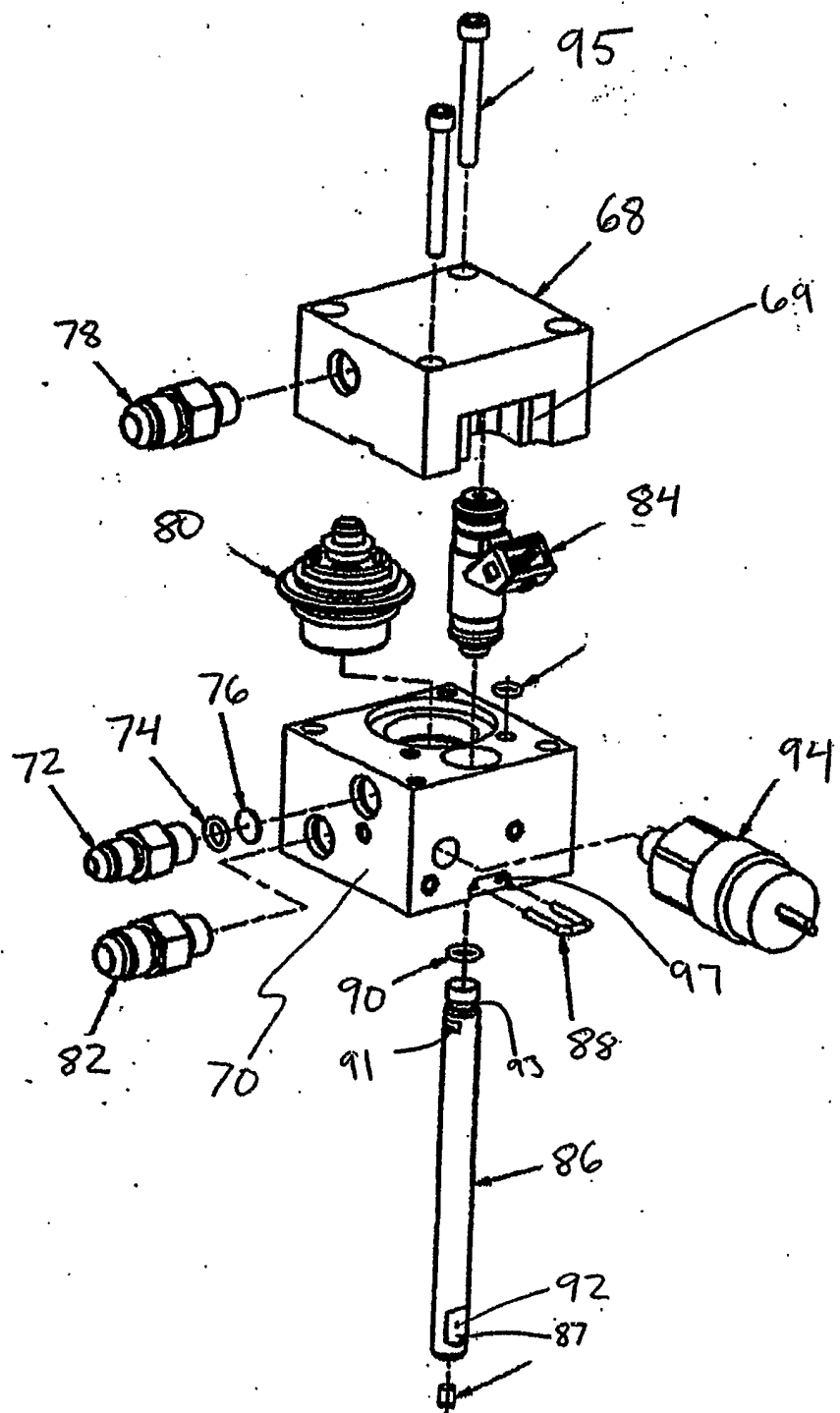
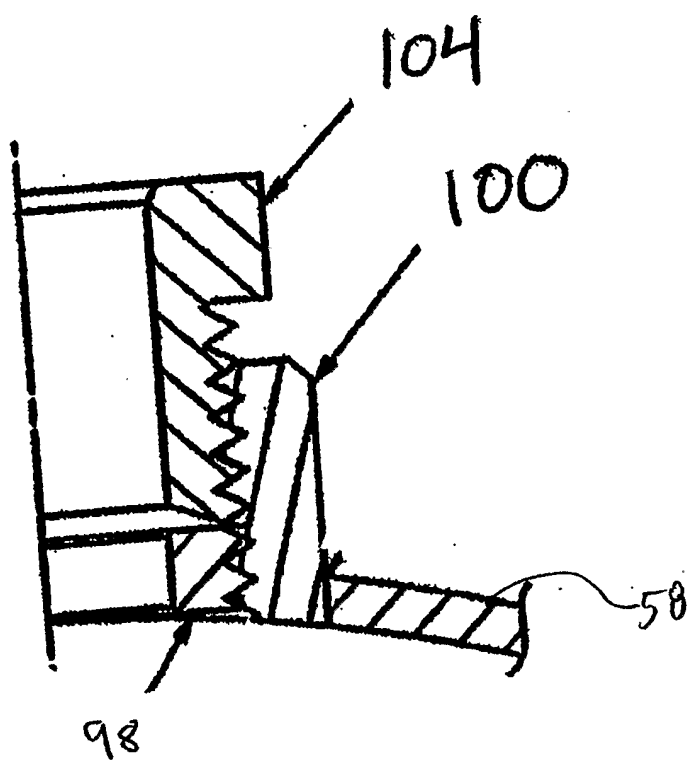
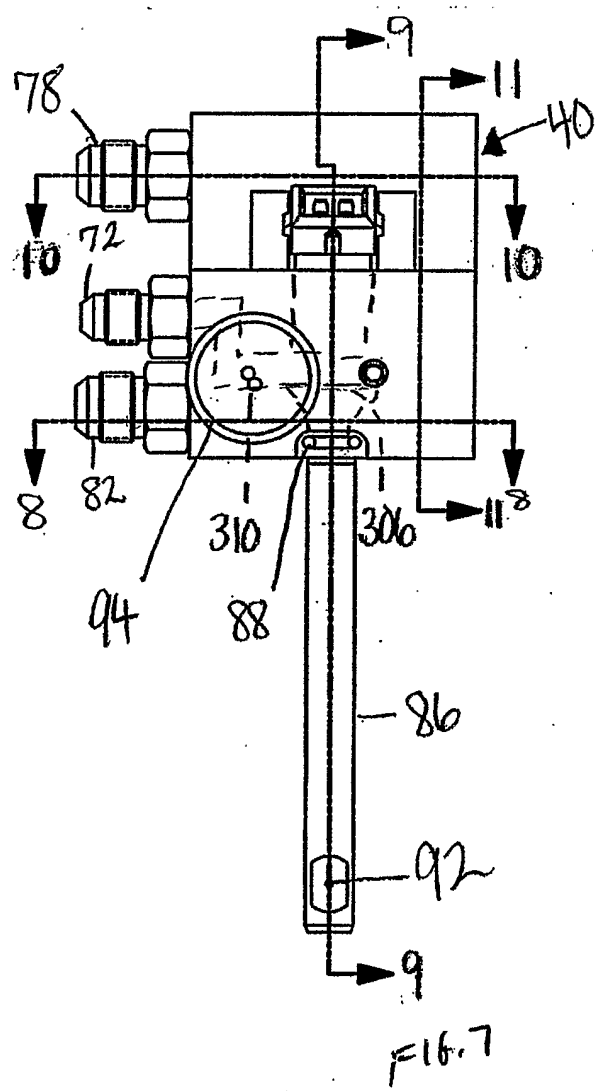
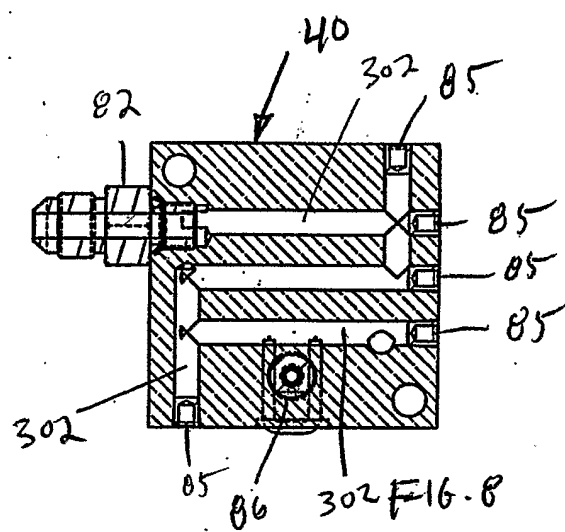
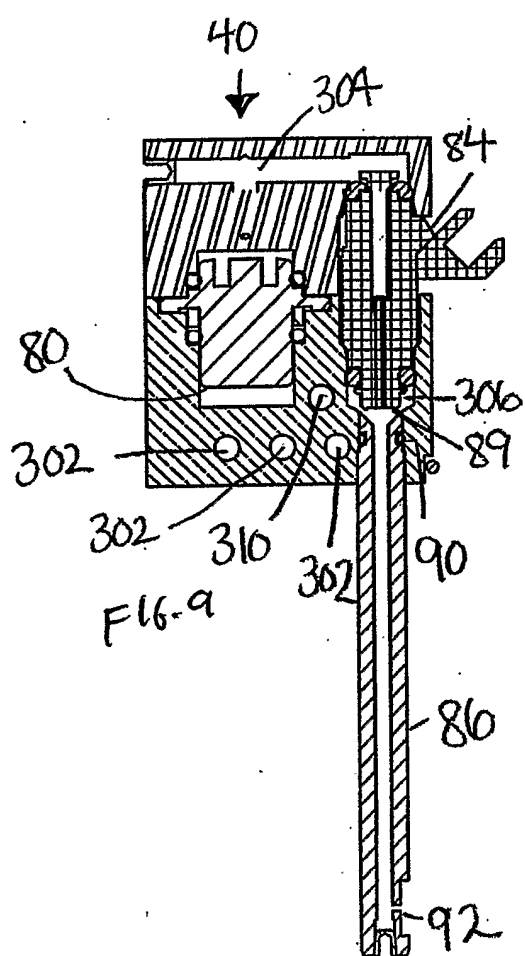


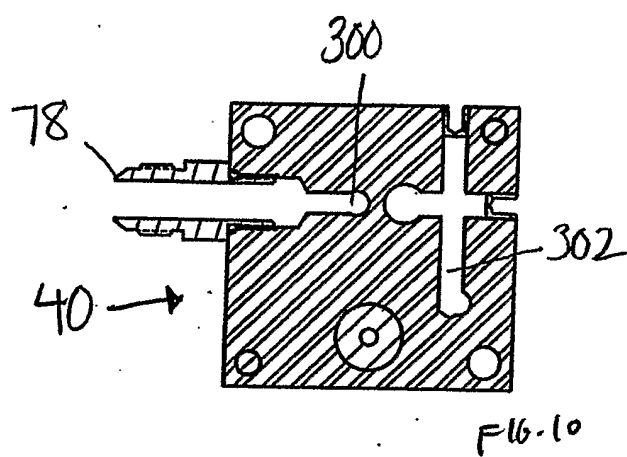
FIG. 6











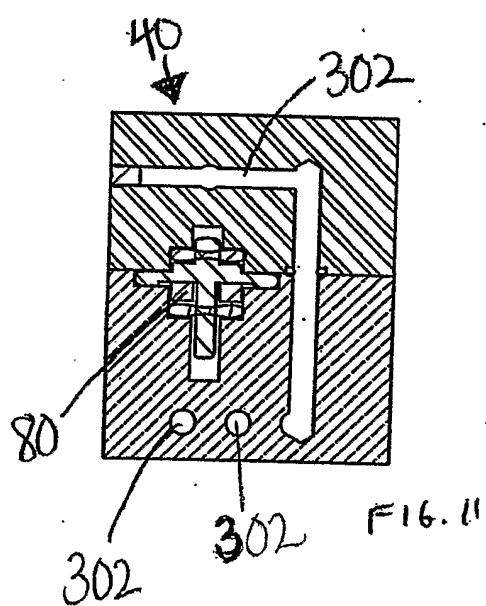


FIG. 12

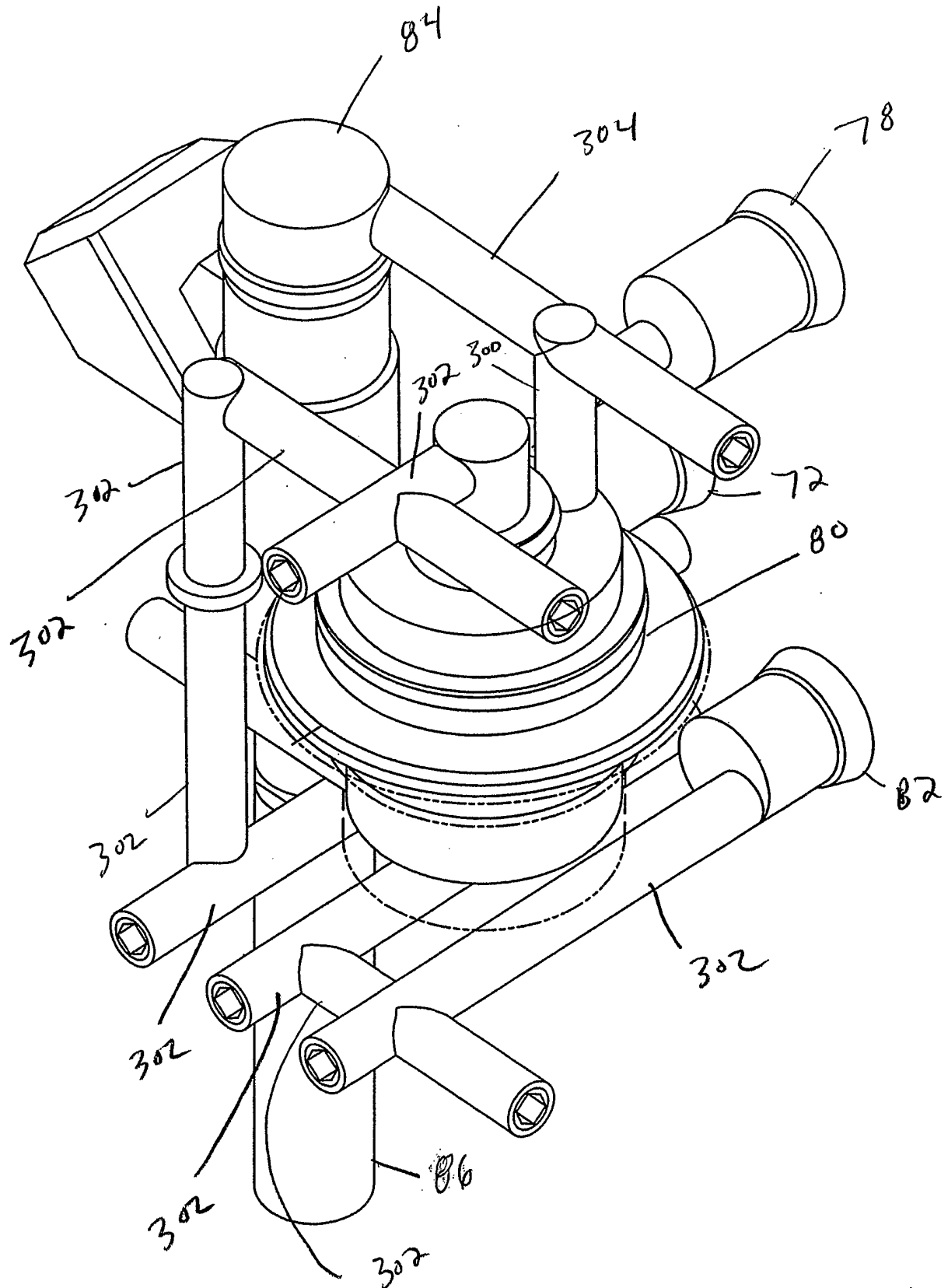


FIG. 13

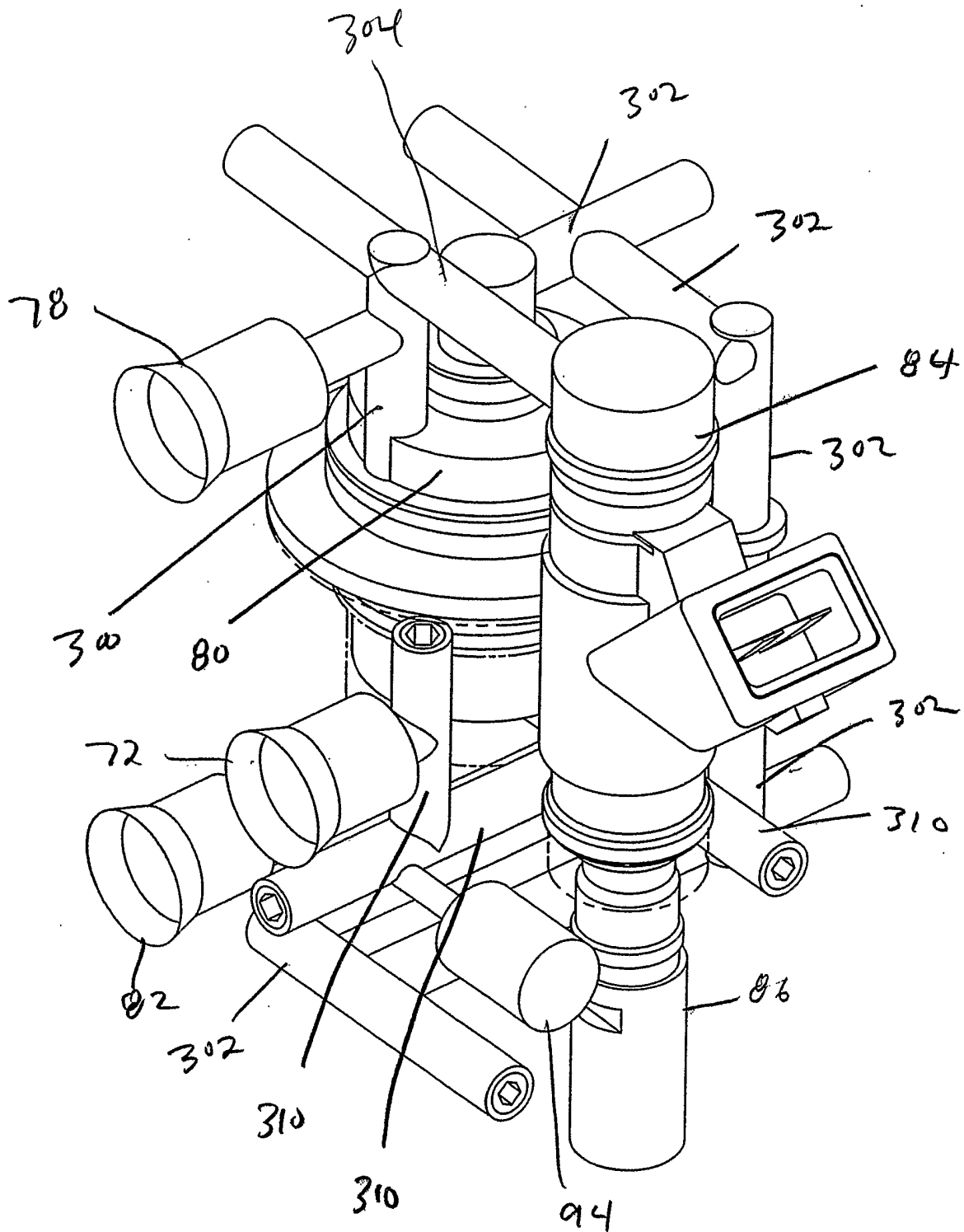


FIG. 14

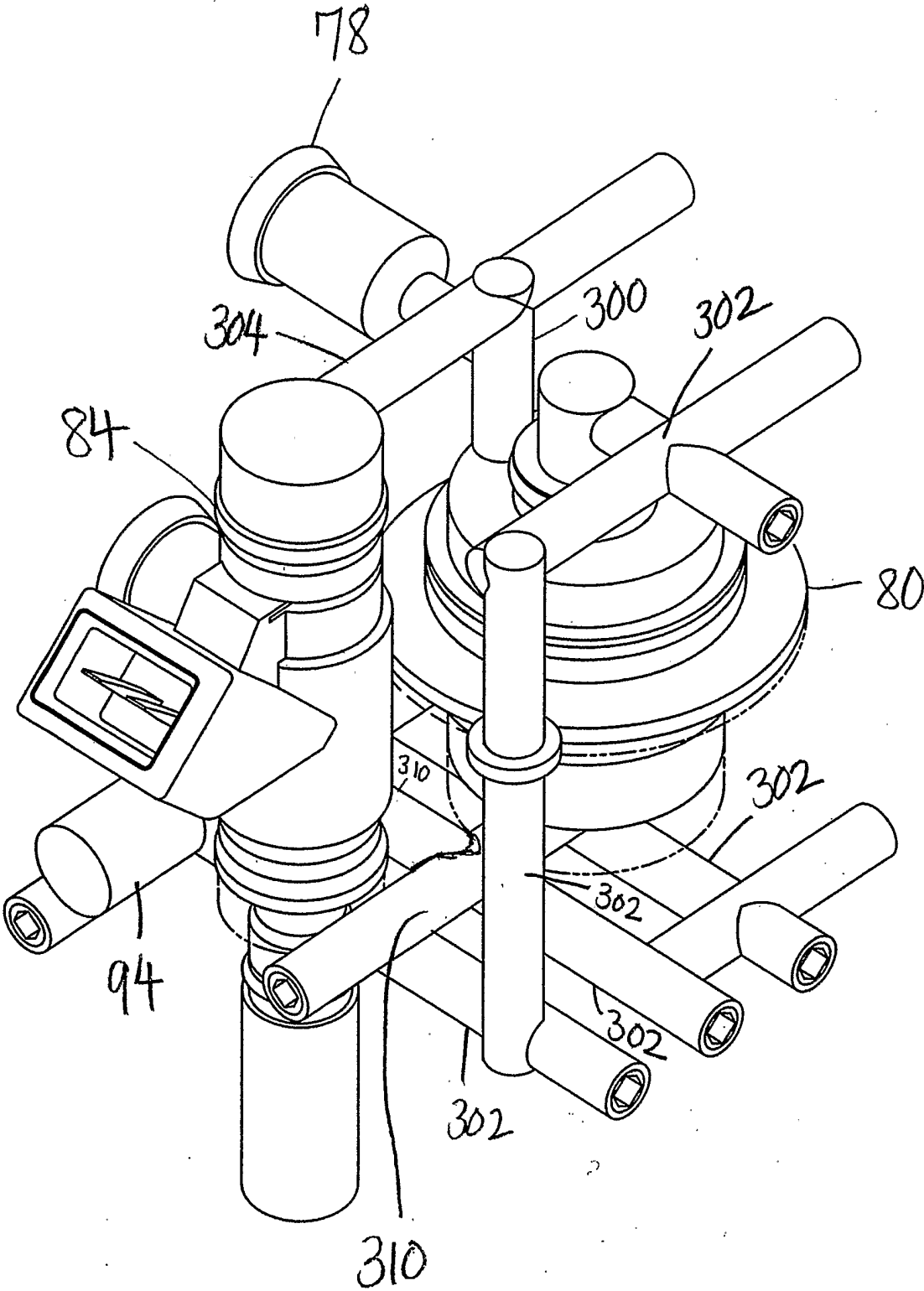


FIG. 15

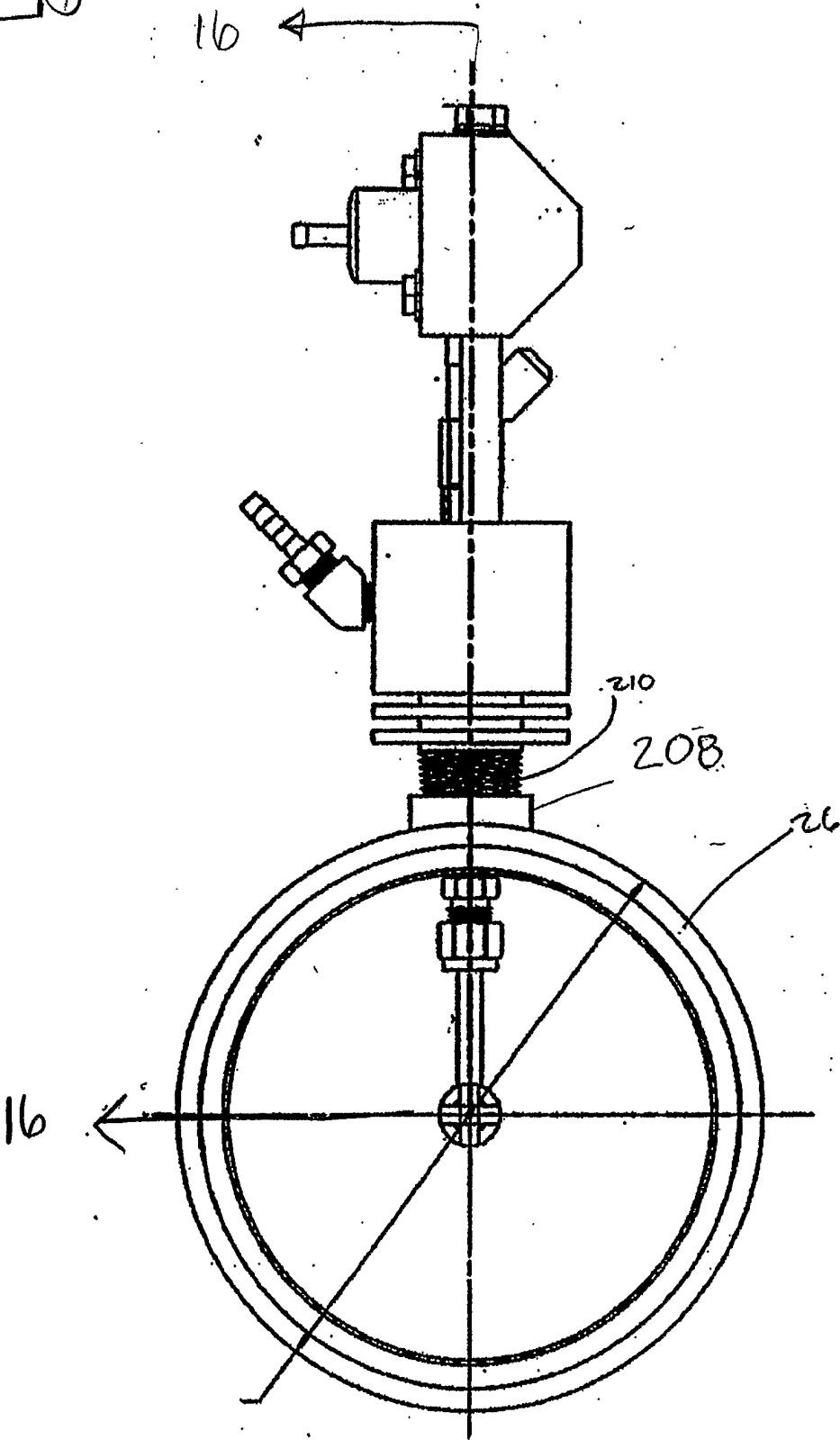


Fig. 16

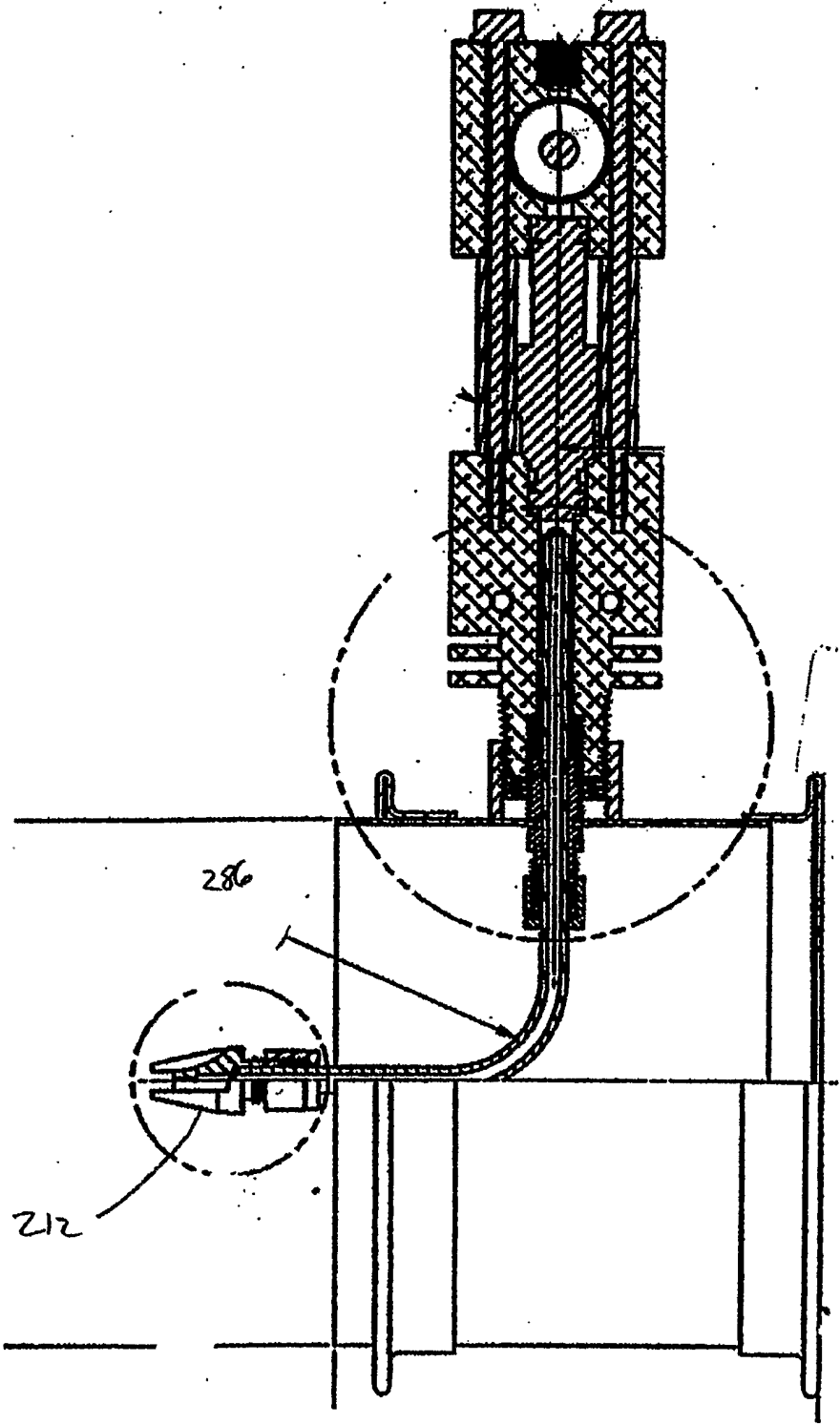


FIG. 17

