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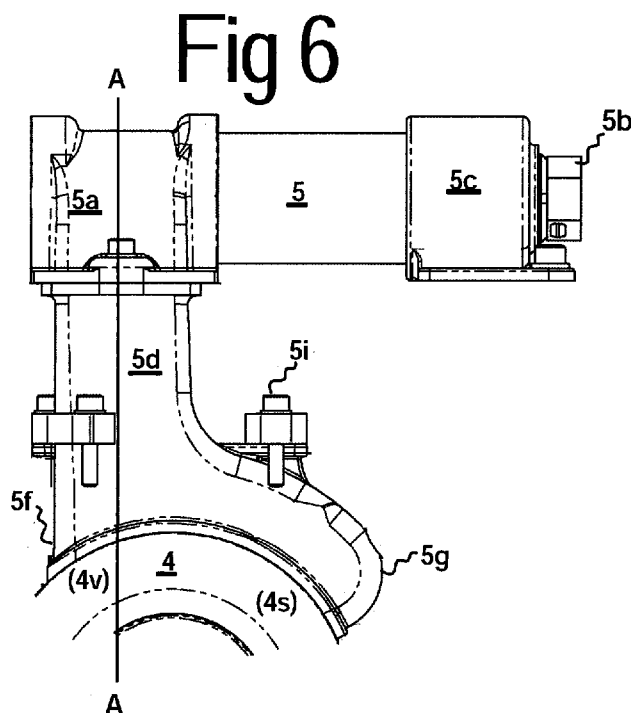
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(54) Title: A FUEL PUMP MODULE FOR FUEL DISPENSERS

(57) Abstract: This standardised fuel pumping module is
used within a forecourt fuel dispenser. Improved fluid
flow paths include a shaped conduit between an output of
a rotary fuel pump and a vortex air separator. Internal di-
mensions are optimized. A swash pump cartridge option
with a variable speed drive provides up to at least 140 air-
free l/min from the dispenser. Torque and motor speed
signals allow comparisons with fuel meter revolution rate
to indicate fraud or faults during delivery of fuel without
extra transducers. Means to shut down the dispenser and
raise an alarm are provided.





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TITLE:**A FUEL PUMP MODULE FOR FUEL DISPENSERS****FIELD**

The invention relates to improvements for fuel pumping and fuel processing means to be used within
5 a fuel dispenser as used in a gasoline station forecourt; more particularly to selection of a pump, liquid and gas flow paths, and selection of a load-sensitive motor for the pump capable of detecting damage to, fault conditions within, or tampering with the fuel dispenser .

BACKGROUND

A forecourt fuel dispenser includes a GPU ("global pump unit") device comprising fuel pump, gas
10 separation means, and pressure control means, as inter-connected components assembled as a solid block having industry-standardised dimensions and connection sites. The GPU draws fuel from a reservoir which is usually an underground tank, filters the fuel, removes any entrained air from the fuel, and delivers the fuel to a fuel meter under a controlled pressure. Should there be proprietary rights in the name "GPU" the device of the present invention shall be referred to herein as a "Fuel
15 Pump System" or FPS. The prime mover is typically a 0.75 KW (1 Hp) AC induction motor driving the fuel pump via a belt at more than a sufficient rate, and a large proportion of the pump output is returned to the input.

See the diagram Fig 1 from Zanzoni, US 3,715,863 (filed 1971) showing the prior-art components inside a FPS block, 1. Zanzoni described the GPU as a "pump with air separator apparatus". Fuel
20 drawn from a storage tank 2 through pipe 3 is mixed with bypass fuel flow and scavenging fuel flow before entering an inlet port of a pump 4. All the outflow from the pump 4 passes through a duct (see later) to the air separator 5. An axial flow out of the air separator, including some fuel and all the air, goes into a closed "atmospheric chamber" 8 located beneath a replaceable lid. The air bubbles rise and burst in the chamber, and are released. The separated liquid fuel is returned past a float valve
25 9 and back to the pump inlet as scavenging flow. The air-free fuel derived from the outer region of the air separator 5 is either returned to the pump inlet through the pressure relief valve 7 or passes through control valve 6 and to a pipe leading through a fuel meter and on to the fuel pump delivery nozzle. The physical size and location of ports and the position of the pump pulley on the GPU have

become standardised, to assist field installation and maintenance of the GPU. A diecast block having
30 internal channels and cavities minimises the space occupied by the GPU within the dispenser and
minimises the number of external, pressurised sealing surfaces, all of which can be sealed using
gaskets or the like; well known in the art. Removal of entrained air from the GPU output before
passing through a volume-responsive fuel meter is required by law, since the customer must not be
charged incorrectly. Mass-responsive (e.g. Coriolis) fuel meters are not yet widely used.

35 Shunta (US 4222751, filed 1978) described a re-dimensioned GPU for which a ten-fold
improvement in air separation effectiveness was claimed, by dimensional changes and an improved
connection from the rotary pump to the cyclone separator. The present inventors note that Shunta
includes an unidentified and unreferenced tapered insert part (see shaded taper below part 73 in Fig 2
of Shunta) between the pump and the cyclone, to better form the vortex within. That part seems to
40 be essential for effective operation of that cyclone separator.

The vane type rotary pump used in any standard GPU provides a 90 litres per minute (l/min) output
or delivery rate suitable for automobiles. Extra flow serves to maintain the vortex of the air
separator. As far as the present inventors are aware, the only GPU capable of providing 140 l/min
suitable for trucks is provided within a block about 20% larger in all dimensions, including a larger
45 vane pump. It cannot be used as a direct replacement for the 90 l/min GPU in an existing fuel
dispenser, so a new dispenser must be installed on the forecourt if the higher flow rate is required.
Suppliers and maintenance firms must carry stocks of the two sizes.

Apart from a need to raise the efficiency of a forecourt fuel dispenser and reduce the noise level,
safety and anti-fraud requirements have become very important. Since petrol/gasoline or diesel has a
50 substantial amount of easily liberated chemical energy, safe handling of such fuels is extremely
important in relation to fire and explosion - also to reduce pollution and toxicity hazards. Any real-
time discrepancy of fuel quantity between the meter indication and any other measure of fuel delivery
may be taken as a sign of a dangerous leak, or of theft.

The rising price of fuel and trends toward social inequality tend to increase the risk of theft.
55 Miscreants may divert some or all of the fuel from within a dispenser by tapping into the pipes
between the fuel pump and the metering means. This practice is believed to be sufficiently
widespread to justify provision of detection means according to the invention. There is an increasing
possibility that the staff at the forecourt may be involved, or, as a result of implied or actual threats

by miscreants, be unwilling or unable to prevent the theft of fuel.

60 For detecting fraud of a type where the meter is perhaps inadvertently made to run fast, so that the customer is overcharged for his purchase by a forecourt operator; i.e. where the reported amount sold exceeds the amount actually sold, Dickson in US 7076330 teaches various independent tests, such as vapour recovery parameters or time measurements to make a delivery of a known quantity. These are only indirectly linked to the measurement of volume and data from any one dispenser and
65 may need to be compared to data from similar dispensers in order to spot an anomaly. See also Dickson US 6745104, which compares particular deliveries with a generalised expectation. Other publications in the general field assume the presence of a sophisticated computer link between dispensers and a central controller that may be disrupted; for example US 6470223 Johnson.

The present applicants have already filed patent applications for a swash pump for liquids. See
70 PCT/NZ2010/00081. Such a pump is exploited in the present application. Note that while a swash pump is driven by a rotating drive, its internal movements are of a nutatory nature.

OBJECT

An object of the present application is to provide a fuel pump and associated electric drive for use within a fuel dispenser, capable of effectively providing a greater flow rate with greater efficiency
75 and a desired range of delivered flow rates of from about zero up to at least 140 l/min within a housing conforming to a GPU supplying the existing standard 90 l/min flow. Another object of the present application is to provide a fuel dispenser including an inherent monitoring means capable of detecting at least some types of abnormal operation, whether originating in criminal acts or in faulty operation. A further object of this invention is to provide a FPS capable of incorporating more than
80 one alternative type of rotary fuel pump, such as either a vane pump or a swash pump, within a case outwardly dimensioned according to existing standards, and a final object is to provide the public with a useful choice.

SUMMARY OF INVENTION

In a first broad aspect the invention provides a liquid fuel pumping module intended for direct
85 replacement of an existing module within a forecourt fuel dispenser and providing (a) fuel withdrawal from a supply through a fuel inlet by means of an internal rotary fuel pump, (b)

separation of the fuel from air or other included gases, and (c) delivery of the separated fuel under a controlled pressure into an existing fuel meter; wherein the module 1 has substantially identical dimensions and connection points to those of a standard module, and includes an internally smoothly curved conduit 5d located in between an output port of the rotary or nutatory fuel pump 4 and an inlet 5a of a vortex air separator 5 which conduit provides, when in use, improved operating conditions for air separation at a delivery rate in the range up to at least 140 litres per minute.

Preferably the direct replacement is a field replacement.

In an alternative aspect, the invention provides a fuel pumping module 1 containing a fuel pump 4 and fuel processing means 5, 8 herein called a Fuel Pump System or FPS inside a shaped block for use within a dispenser of liquid fuel; the fuel being selected from a range including petrol/gasoline, kerosene, aviation fuel, jet fuel, diesel fuel, ethanol, or combinations thereof, wherein the FPS includes at least one of the following alterations:

(a) moving the cavities within the FPS for holding the bleed and outlet valves upward, then using the space so created to provide a space for a larger diameter inlet valve, so that when in use a flow of fuel to the inlet port of an incorporated fuel pump is less obstructed resulting in a delivered flow of fuel having a reduced pulsatile pressure component, and so that a lower power consumption is required,

(b) providing a space for a novel shaped conduit 5d used to couple the outlet port of the fuel pump to an inlet of the air separator as a conduit having minimised internal obstructions, thereby reliably forming a vortex within the cyclone air separator, without use of an additional shaped insert,

(c) providing a shorter yet effective tubular cyclone air separation means, effective over a desired range of from about zero up to at least 140 litres per minute of delivered flow and

(d) providing a less restricted outlet for air and fuel from the axis of the vortex, yet

(e) the external dimensions of the FPS are substantially identical to those of existing FPS or GPU units.

In a first related aspect, an area of the fuel inlet 2b is increased by at least 2.5 times thereby providing, when in use, less restriction to incoming flow of fuel and reduction of a pulsatile pressure component of fuel flow out of the fuel pump 4, thereby providing improved metering conditions and reduced power consumption.

In a second related aspect, an outlet means for air from an end of a vortex air separation means is provided in between the separation means and an atmospheric chamber; the outlet means having at least twice as large a side exit aperture as that of prior-art outlet means.

120 Preferably a swash pump cartridge 4 inherently having, when in use, an inherently low pulsatile pressure component of fuel flow is provided for the fuel pumping module 1, thereby providing improved air separation conditions and reduced power consumption.

In a third related aspect, the fuel pump 4 is rotated, when in use, by an electric motor provided with electric power at a controlled turning rate from a variable-speed motor power supply 108 capable of sensing a torque delivered by the motor connected to the supply, and of providing a torque signal
125 111a for use in at least one task selected from the range of: (a) regulating motor speed, (b) sensing pump pressure, (c) regulating pump pressure (d) sensing flow, (e) detecting fault or unusual conditions, or (f) detecting deliberate tampering.

Preferably the fuel pumping module 1 is provided with computational means 109 capable of receiving as inputs one or more of: a signal 111 describing motor revolution rate, a signal 110
130 describing fuel meter revolution rate, and a signal 111a describing the torque delivered by the motor connected to the supply; said computational means being capable during use of providing an electrical output 115 in the event of a fuel flow discrepancy arising as a result of either a fault, or of tampering with the forecourt fuel dispenser.

In one option, the torque signal is sensed by means independent of the motor drive power supply.

135 Preferably the electrical output 115 from the computational means is coupled to electric power supply interruption means 117 capable when activated of immediately halting any fuel pumping activity.

Further, the electrical output 115 from the computational means is coupled to an alarm capable of calling the attention of a person.

140 Preferably said computational means is capable of being calibrated in the field for a particular combination of motor revolution rate and a corresponding fuel meter measurement rate.

Optionally the field calibration means takes into account a proportion of pumped fuel used to maintain an air separation means.

In a second broad aspect the invention provides a method for controlling a fuel pumping module as

145 claimed in any previous claim; the method including the steps of receiving at least one signal selected
from a range including: a signal 111 describing motor revolution rate , a signal 110 describing fuel
meter revolution rate, and a signal 111a describing the torque delivered by the motor connected to
the supply; the step of evaluating said at least one signal within computational means, and the step of
providing an alarm signal indication a fuel flow discrepancy arising as a result of either a fault, or of
150 tampering with the forecourt fuel dispenser.

Preferably the drive for the fuel pumping module is operated at variable operating speed just
sufficient to produce a desired output, when required, from the fuel dispenser.

In one option, a transmission means coupling the driving means and the rotary fuel pump is changed
so that the rotary pump may be turned at a different speed.

155 In a preferred option, the driving means used to turn the rotary fuel pump and the rotary fuel pump is
caused by the associated controller to turn at a different speed.

DETAILED DESCRIPTION OF THE INVENTION

The description of the invention to be provided herein is given purely by way of example and is not
to be taken in any way as limiting the scope or extent of the invention. Throughout this specification
160 unless the text requires otherwise, the word "comprise" and variations such as "comprising" or
"comprises" will be understood to imply the inclusion of a stated integer or step or group of integers
or steps but not the exclusion of any other integer or step or group of integers or steps. Each
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known in New Zealand or any other country.

DRAWINGS

Fig.1: A prior-art schematic diagram of interconnections within a GPU. Zanzoni, US 3,715,863.

170 Fig 2: An external view of the FPS of the invention, containing a fuel pump and fuel handling
means, showing planes of sections used in Figs 3 and 4.

Fig 2a: A perspective view of an outlet valve 5b for the vortex separator.

Fig 3: Sectioned view of the FPS of the invention along A-A in Fig 3.

Fig 4: Sectioned view of the FPS of the invention along B-B in Fig 3.

175 Fig 5: Top view of the FPS of the invention with the cover removed.

Fig 6: Front view of the FPS of the invention, exposing the shaped conduit.

Fig 7: Section of the shaped conduit and the air separator inlet port along A-A in Fig 6.

Fig 8a: Graph of pressure pulse amplitude, over a range of flow rates, in the fuel discharge from combinations under test, for diesel.

180 Fig 8a: Graph of pressure pulse amplitude, over a range of flow rates, in the fuel discharge from combinations under test, for petrol / gasoline.

Fig 9a: Graph of the effectiveness of air separation, as a deviation, over a range of flow rates in the fuel discharge from combinations under test, for diesel.

185 Fig 9b: Graph of the effectiveness of air separation, as a deviation, over a range of flow rates in the fuel discharge from combinations under test, for petrol / gasoline.

Fig 10a: Graph of the electric motor drive power consumption over a range of flow rates when driving some combinations of pumps and FPS units under test, for diesel.

Fig 10b: Graph of the electric motor drive power consumption over a range of flow rates when driving some combinations of pumps and FPS units under test, for petrol.

190 Fig 11: is a block diagram of a fuel dispenser showing means for the comparison of two measures of flow volume.

Fig 12: is a tracing of the torque during use of a swash pump as a fuel delivery pump, showing three instances of an open-nozzle valve state (lower centre of trace). Diesel was the fuel used in this test.

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Example Improvements: Improvements over a prior-art GPU like that of Shunta include an FPS having:

- 1) Same external dimensions and fittings, hence a direct replacement for a 70 litres per minute (l/min) GPU, yet capable of a greater output of at least 140l/min.
- 200 2) Larger inlet valve 2. (Inlet area 2.7 times greater) (2 in Fig 4)
- 3) Revised outlet valve 5b for the vortex separator. (Fig 2a)

- 4) Improved vortex separator. (Figs 6 and 7)
- 5) Novel duct 5 into vortex separator (Figs 6 and 7) allowing fuel pump alternatives below.
- 6) Capable of internally using a prior-art vane pump cartridge, or, .
- 205 7) Capable of internally using a swash pump cartridge of the type described by the applicants in PCT/NZ2010/00081.
- 8) Capability, assuming the swash pump cartridge is installed, of supplying 140 l/min, a rate particularly applicable to dispensing diesel fuel for trucks, from a FPS having a standard 90 l/min housing. (Fig 9a))
- 210 9) With the swash pump cartridge, outflow is less pulsatile (Figs 8a, 8b) and a shorter vortex is feasible.
- 10) Preferably using the swash pump, a torque-responsive motor controller and variable-speed drive allows (a) selection of a flow rate, (b) a more efficient drive at a rate just enough to maintain air separation while supplying fuel (Figs 9a, 9b), and (c) means to sense anomalies
- 215 indicating either faults or fraud and cause a shutdown if required. (Fig 12)

Improvement 1: The "Fuel Pumping System" or FPS (1 in Fig 2) includes a fuel pump, control valves, and air elimination means for use within a fuel dispenser and emulates a "Global Pumping Unit" or GPU. The same external dimensions, placement of fuel pipes, and motive power

220 connections have been retained, for compatibility and easy field replacement purposes. The FPS is shown from an external elevation view in Fig 2. 4 refers to a largely concealed fuel pump cartridge (see Fig 4) mounted behind the driven "V-belt" type pulley 4a. The control valve 6 and bypass valve 7 are mounted from the front inside bored holes reaching to an internal manifold. The housing covering the atmospheric chamber is shown at 8. The outlet 8A is referred to later. A vortex type air

225 separator 5 is retained.

Some improvements within the FPS are shown in Figs 3 and 4. Fig 3 is a cross section along the lines A-A in Fig 2, including the central axis of the longitudinally sectioned bypass valve 7 and that of the control valve 6. The outflow manifold 5e carries de-aerated fuel from the air separator 5 to the inlets of both the bypass valve 7 and the control valve 6. Fig 3 shows that the control valve 6 has

230 been moved to a higher position inside the FPS, but still in line with the manifold 5e. As in prior-art GPUs, control valve 6 both provides a minimum back-pressure of from 10 to 15 psi for the air

separator 5 and includes an axial over-pressure bleed valve to dissipate over-pressure conditions that may arise in the outlet pipe, such as if the delivery hose, while full of petrol/gasoline is heated by sunlight or is driven over while lying on the ground. Fig 3 also shows that the bypass valve 7 is moved to a higher position, still in line with the manifold 5e. Fig 3 shows a glimpse of the inlet port 4b of the swash pump (an option) behind and slightly below the outflow side of the bypass valve 7, keeping the bleed circuit short. Valves 6 and 7 were moved to allow use of a larger diameter inlet valve 2.

Fig 4 is a cross section along the lines B-B in Fig 2. It includes the centre of the longitudinally sectioned inlet valve 2 which is a non-return valve. The inlet valve is located inside a hole made from the rear of the FPS, giving access to the inlet port of the pump 4 at 4b. Note the deliberately large size of the inlet valve. Ducts leading recirculated fuel from the float valve 9 inside the atmospheric chamber 8, and from the bypass valve 7 also merge near the inlet port of the pump at 4b.

Improvement 2: One aspect of the invention is to reduce obstructions to incoming flow. A larger flow is intended. A pump is typically required to apply a suction corresponding to an about 4 metres head of the fuel in use. The inventors note that pressure fluctuations in the output are reduced when the inlet flow is unobstructed. The inventors have confirmed that reduced restriction to flow preceding the inlet port 4b of the fuel pump 4 results in a less pulsatile flow of fuel from the outlet of the pump (see Fig 8a, 8b and discussion, below), and reduces a tendency to draw in air bubbles. A larger inlet 2b surrounds spring-loaded sliding shaft 2a of non-return valve 2.

In the prior-art GPU, the internal diameter of the inlet valve is 31.3 mm but the area taken up by a spider for holding an internal spring-loaded sliding shaft which supports the valve itself, leaves a remaining open area of about 455 mm². In the present prototype, the total inlet diameter is 1450 mm² but 114 mm² must be subtracted for the spider and central spring (2) and valve support shaft, leaving 1235 mm open area. Assuming that the respective inlet valves are sufficiently widely open under a test environment to not impede flow, the relative increase in valve area provided by the present invention is 2.7 times over that of a prior-art inlet valve.

With reference to Fig 1, an inlet filter is usually placed in the line 3. A clogged filter may cause obstruction and its diameter should be maximised. An inlet filter is not shown to the right side or below inlet valve at or near 2, because there are at least two different preferred sites.

Improvement 3: The vortex air separation device in the current GPU discharges an axial sample of

the fuel spiralling along the vortex and containing any air that has been separated into the atmospheric chamber 8 of the GPU through a hexagonal or circular cap (5b on figure 6). This includes a spring-loaded cylinder fitting into the hollow centre at 5k. The prior-art cap has two side channels cut into it pass the fluid and the air into the atmospheric chamber for settling. When diesel is pumped through a prior-art GPU and large volumes of entrained air are expelled from the air separation device, high velocities in these channels may cause the diesel to form foam, which may overflow from the top of the GPU through outlet 8 on figure 2 into the petrol dispenser. Experiments have shown that increasing the number and apertures of these channels by 200 % (shown here as apertures 5j) and positioning the discharge as close as possible to the liquid surface in the top chamber such as by setting the float valve substantially reduces the amount of foam generated in the top chamber.

Improvement 4: Fig 5 is a plan view of the chamber of the FPS. Liquid entering the cylindrical vortex or cyclone air separator module 5 at the inlet 5a is caused to run to the right (in regard to the drawing) in a spiral flow pattern to the outlet port 5c of the separator module, thereby separating air from the incoming flow by centripetal forces and air in manifold 5e is fit for passing to a volume-responsive meter. Air in the central axis of the flow is captured within an axial vortex finder tube placed at the inlet to the bleed valve 5b on the module cap, at the right hand side. The proportion of air-rich fuel transmitted into the atmospheric chamber of the FPS and then scavenged, versus the air-free fuel "for sale" which is discharged into the manifold leading to valves 6 and 7 (see Figs 2 and 3) may be controlled by valve pressures in relation to pump output. As a result of inflow improvements and preferably use of the swash pump, this vortex cylinder is shorter than the original vortex air separator; providing more space for the atmospheric chamber 8. The internal dimensions of an example air separator are: length 147 mm, internal diameter 35 mm. The axial air bleed valve extends into the last 35 mm of the central vortex, with a tube about 14 mm in diameter. The shorter separator allows the reservoir 8 and float valve to be enlarged.

Improvement 5: Fig 6 is an elevation view showing the novel shaped conduit 5d in face view, connecting either type of rotary pump 4, only part of which is shown, to the air separator 5a - 5 - 5c. One purpose of conduit 5d is to seal the outlet port of either type (vane or swash) of pump cartridge 4 used within the FPS, and another is to carry the output with minimal turbulence to the inlet 5a of the separator, entering at one side as shown in Fig 7 such that flow is directed along a tangential line produced from the periphery of the vortex separator. The shaped conduit 5d has a wide inlet capable

of covering an outlet port of either selected type of pump so that a field replacement of pump cartridges can be done with minimal difficulty. Fig 7 shows a vertical section of the shaped conduit perpendicular to lines A-A in Fig 6. Bolts such as 5h fix and press the shaped conduit in place upon the casing of the rotary pump and, with preferred sealing means such as gaskets, seal the interior of the shaped conduit around the outlet port of the pump. This shaped conduit is physically produced around a part-circular profile so that the outlet port of either pump will when in use expel fuel under pressure into the open base of the shaped conduit.

The outlet of the shaped conduit 5d is both tapered and curved as shown in Fig 7 to provide least impediment to a flow of a carried liquid at the coupling to inlet 5a of the air separator. In face view the outlet is a rectangle. Preferably the coupling made from the shaped conduit 5d to the air separator 5 especially at the junction between parts 5a and 5d directs the flow of fuel into the air separator approximately along a tangential line produced from the periphery of the air separator, and is smoothly curved, with minimised internal obstructions in order to ensure that a vortex will reliably be started and maintained within the cyclone air separator. Surface finishing around the junction between the parts 5a (an inlet part for the air separator) and 5d (the shaped conduit) may be required in order to eliminate discontinuities that appear after assembly, that are likely to cause turbulence, downstream eddies or the like when the FPS is used, especially at a high flow rate. The shaped conduit 5d at least in its present embodiment is preferably made as a separate part, not as part of the casting of the FPS. The prototype shaped conduits have been made as a pair of flat parts each having a complementary raised edge along their side, welded together to form a flattened hollow shaped conduit. Other manufacturing processes such as injection moulding techniques are known to those skilled in the relevant arts. The FPS can deliver air-free fuel at an outlet port of the FPS at any fuel delivery rate up to the current limit of about 140 litres per minute. (see below).

With such a configuration, the inventors have found that the air separator 5 will function well at all delivery rates especially if (**Improvement 9**) a swash pump cartridge is used, since that pump has a less pulsatile output.

Improvements 6 and 7: A prior-art vane pump may be used in the FPS of the present invention.

The outlet port of this type of pump is inherently positioned at about the position marked 4v, under the left lower part 5f of the shaped conduit. It is noted that a vane pump of the size that fits into a 90 l/min GPU does not reliably support a 140 l/min if turned 1.56 times faster. Yet an objective is to

provide 140 l/min fuel delivery. The inventors prefer to replace the vane pump with a physically compatible swash pump cartridge. A swash pump, the redesigned FPS and a replacement constant-speed 1.25 kW AC induction motor (or a variable speed drive) can deliver 140 litres per minute at the nozzle of the dispenser, with flow to spare for operating the vortex air separation means. The preferred swash pump is volumetric. Its inherent resistance to turning (such as is caused by friction at seals or at rubbing surfaces) is sufficiently low in comparison to the work done on the liquid being pumped that it is possible to sense the liquid flow if torque or power measurement means is included.

Improvement 10 (see below) illustrates uses to which this sensing capability may be put.

Improvement 8: The preferred swash pump can reliably maintain a nozzle delivery rate of 140 litres per minute simply by being turned faster, assuming a motor drive which is not a fixed-speed AC induction motor - or if it is, assuming replacement of pulleys with a set that provides the higher pump speed. On the other hand, the vane pump cartridge presently used in a 90 l/min GPU cannot sustain a 140 l/min output by being turned faster. The outlet port of this type of pump is inherently positioned at about the position marked 4s under the right lower part 5g of the shaped conduit as shown in Fig 6, at an angular position which differs from that of industry-standard vane pumps.

Improvement 10: This improvement assumes that a torque-sensitive and preferably variable-speed pump motor drive is employed in conjunction with the FPS previously described in this section. In the prototype example this comprises a brushless DC motor with a compatible controller 109 such as are manufactured by Wellington Drives (Auckland, New Zealand), or an equivalent. Since existing GPUs use a 1 horsepower (0.75 KW) induction motor, the direct drive controller should have a similar capacity. Such controllers are responsive to torque and can be operated in a constant-torque more or, especially if run at a constant speed, can provide a "torque being used" or "power being consumed" signal. Even with a constant-speed AC induction motor, those skilled in the art know ways to derive the instantaneous torque generated, such as using a strain gauge on the motor mounting, or a phase difference along an elastic shaft carrying a torque. Furthermore, delivered-volume information can be derived from use of a substantially volumetric pump for which each revolution delivers a known amount of fuel, and comparing the pump revolutions with the raw output of a fuel meter including a rotating measurement part. We have tested both vane and swash type pumps and found that the pump output is directly related to the rate of turning for each type, within limits, although the swash pump has wider limits. Also, especially with a torque-controlled drive, it is not difficult to ensure that a fixed proportion of pump output is dedicated to the air

355 extraction device so that fuel flow can be monitored at least approximately on the basis of pump revolutions alone. Fig 12, discussed more fully below, shows test results illustrating that a signal representing torque can easily represent the load seen by the pump, and shows a contrast between nozzle open, when pump output is easily taken out through the hose and nozzle, and nozzle closed, when the internal pressure rises and the pump outflow is recycled through a valve within the FPS.

360 It is believed that an about 5% mismatch in the predetermined ratios can be tolerated, although this value of mismatch may be lowered or raised once practical performance over time is known. 5 per cent is nominated as reflecting the inventors' present expectations of possible back-flow within the swash pump over time. It is not likely that a thief will steal that small a fraction of the potential flow rate available from a dispenser since it will take too long to get a useful amount; however this assumption remains to be tested.

365 For improvement 10, improvements 1-9 are preferred requisites. Improvement 7 is preferred over improvement 6 since a swash pump has less inherent friction than a vane pump and it becomes much easier to detect anomalies in flow as reflected through the load on the prime mover used to drive the pump. Improved - that is - with fewer obstructions to flow - fluid pathways in the FPS assist in differentiating any anomalies. In order to retain compatibility with existing GPU installations the motor is driven through a transmission linkage, hitherto a rubber V-belt drive. Either a pair of pinion
370 gears, or a chain drive may be used as a type of transmission having lower inherent losses. If for some reason the FPS was no longer required to match the physical dimensions of a prior-art GPU and serving as a field replacement, a preferred direct drive brushless DC motor may be used in line with the axis of the pump itself.

375 See the diagram of Fig 11, which shows details of a fuel dispenser 100 according to Improvement 10. This Example shows no vortex air separation device and assumes that the over-pressure relief channel 114 is normally sealed by a form of safety valve 113 that will open only in the event of failure of the intended pressure control arrangement (see below). This bypass may also be opened momentarily by a solenoid acting to open valve 113 at the end of a fuel delivery cycle, after pump
380 106 has ceased to turn, either in order to remove any remaining pressure from the fuel delivery pipes between pump 106 and nozzle valve 105A, or to avoid over-pressure incidents such as the delivery valve being heated by sunlight or being driven over. If a vortex or like device is included, then allowance for a fraction of diverted fuel from the pump output is made. Air separation is not needed if meter 104 is a mass-sensitive type. Block 108 in this Example is a brushless DC motor with a

385 compatible torque-sensing controller 109 The controller will produce a signal indicating that one
revolution (or part of one) has actually been completed. Both the pump and the usual volume-
sensitive meter will provide pulses at consistent rates in direct proportion to the volume passed
through. The motor revolutions signal may be brought to the exterior along line 111 or used within
internal added means capable of performing a ratio comparison against an output indicating meter
390 revolutions 110 from the fuel meter 104. It follows that the fuel pump with controller unit has
several functions - (a) providing a volumetric flow, (b) providing a torque as an indication of
generated pressure - to be interpreted within the controller as an actual pressure so that the fuel
emerging from the pump is at a reasonably constant pressure, and (c) providing a turning rate signal.
In this mode, the revolution rate of the pump may vary from near zero to perhaps 1200-1500 rpm.

395 Preferred direct drive controllers typically including a microprocessor may be modified using spare
computational capacity, or a separate module for ratio comparison, the construction of which is
apparent to one skilled in the art, may be used. The actual "normal ratio" for any particular fuel
dispenser may be set up during field calibration and stored in memory device 112.

Block 109 or an equivalent internal to the motor controller is arranged to compare the ratios and
400 provide an "error present" signal at point 115 which may be used inside the fuel dispenser, for
example by tripping a power supply relay (for example, an existing residual current detector or
RCD) and stopping the pump so that no fuel can be brought up from the storage tank 101 by the
pump 106 through pipe 102. By way of a non-limiting example, an existing residual current detector
(RCD) 117 is shown between the incoming AC power line (phase) 118 and the power supply 119 to
405 supplied parts within the dispenser 119, and also between the incoming neutral line 120 and the
neutral supply 121 to supplied parts within the dispenser. The RCD is made to interrupt the
electricity supply by first closing an attached relay or other switching means 122 (shown with
normally-open contacts above it) which connect a series resistor 123 between the AC mains phase
wire, after the RCD, and electrical ground at point 124, so that the inward and outward currents
410 through the RCD are no longer balanced and the RCD will trip. Resistor 123 should be of perhaps
10,000 to 20,000 ohms, to cause a tripping current of perhaps 1 to 10 milliamperes at 117 or 230 V
AC (rms) as required for setting off the RCD. Preferably the RCD is reset by a responsible forecourt
operator, in order that the dispenser can operate again. A situation may arise in which the operator
responsible for the dispenser is under duress by one or more miscreants and cannot refuse them. The
415 status of terminal 115 may be carried to an indicator panel under supervision of a forecourt

attendant, where the actual delivery rate data may be shown. The status of terminal 115 may also be transmitted directly to a remote supervising site such as an owner's premises, a security firm, local police station, or the like. Nevertheless, local action as described in Option 1 means that the dispenser is protected regardless of the status of forecourt communications.

420 Note that for a vortex air separation device an about 5-10% greater volume of fuel is pumped through the fuel pump than is delivered. Some goes through the atmospheric chamber, carrying separated air and is used to maintain operation of the vortex/cyclone gas or air separation device (not shown in Fig 11) of the dispenser and returned to the pump inlet 107 as scavenged fuel.

425 Following is a list of some possible problems and their solutions, with reference to the invention as described in relation to Fig 11.

Problem 1: Fuel is lost from fuel line B because of either a leak, or tampering, while the FPS 100 is pumping and providing pressure in line B.

430 Solution: The pump will be turning so as to provide a torque, but the fuel meter may not be operating. On detecting a mis-matched ratio, the comparison device 109 causes the RCD 117 to open and delivery stops until an operator comes to the dispenser. Fig 12 shows the ease with which the torque signal shows a difference between the delivery nozzle being closed (high torque, 201) and the delivery nozzle feeding fuel into a tank (at 202, 203 and 204).

435 Optional Solution: A pressure transducer 116 placed at (B), either before (as shown), or preferably after the control valve 113A, should reveal a drop in pressure if fuel is leaving the pressurised space (B). If the pressure should drop while the pump and motor are operating but the meter is not turning, there is a probability of a leak of fuel from (B) as a result of theft or a mechanical break. The pressure transducer 116 may be installed as a modification of the GPU itself. Link 116a carries information to the comparison device 109.

440 Optional Solution: The pressure transducer 116 is replaced by sensing the position of the pressure-sensitive relief valve 113, which is closed during normal delivery, for instance by a suitably placed physical displacement transducer sensing valve movement (such as a magnet attached to the valve and a suitably located Hall-effect sensor). The electrical output of the fuel meter 104 as transmitted through line 110 can be compared in module 109 with the status of the pressure relief valve. This is not shown in Fig 11.

445 **Problem 2:** Fuel is lost from fuel line C; delivery nozzle valve 105A has not been opened.

Solution: The pump will be turned according to the predetermined torque, but the fuel meter will not be operating. The comparison device 109 detects output of an additional transducer means (not shown) giving an electrical signal indicating that the nozzle valve 105A is not open, although the pump and meter are turning in accordance with a predetermined ratio, and causes the RCD 117 to
450 open and delivery stops until an operator comes to the dispenser.

Problem 3: Meter 104 becomes inaccurate for any reason. A significant mismatch between the meter 104 and the volumetric pump 106 output arises. Meter 104 may be deliberately miscalibrated - such as to indicate more flow than actually exists, so that the public is charged at a higher rate for the fuel it buys (the actual volume delivered being less than indicated), and the forecourt operator,
455 who has bought fuel by volume from a supplier, profits from each sale. That sort of modification may allow the forecourt operator to offer an attractively lower apparent price per unit volume than those of his competitors.

Solution: The comparison device 109 detects the situation that the predetermined correct ratio between the meter and the pump is not evident during delivery, and causes the RCD 117 to open and
460 delivery stops until an operator comes to the dispenser. Proper field calibration of the predetermined correct ratio requires that the actual delivered volume be proved using a calibrated container, in case the meter is already mis-adjusted.

Problem 4: Large amounts of air are drawn into the fuel pump, such as by a leak admitting air into a negative pressure section of the inlet pipe 102 or a coupling 103, or tank 101 is empty.

465 Solution: The turning rate of the pump rises beyond usual limits in order to reach a predetermined torque, since extra air is inside the pump. Controller 109 detects this rate and causes the RCD 117 to open and delivery stops until an operator comes to the dispenser.

Improvement 10 Variant. A Coriolis or equivalent mass-sensitive meter is an as yet not widely used alternative fuel meter. It is not influenced by unknown amounts of essentially mass-free air
470 mixed with the fuel, so that an air or gas separation device forming part of the FPS as previously described in this section may be deleted. In this variant, the volume passing through the fuel pump 106, when operating, is continuously compared with the mass passing through the mass-sensitive fuel meter at 104. If no air separation or cyclone device is used within a fuel dispenser, the volume

passed through the fuel pump 106 is more nearly comparable to the mass passed through the fuel meter, since none of the fuel pump flow is used to create an air vortex.

TEST RESULTS, in relation to Improvements 1-9.

We have carried out some tests with a prior-art GPU body and rotary vane pump (trace 1 in Figs 8a and b, 9a and b and 10a and b), and the modified FPS body with either a vane pump (trace 2), or a swash pump (trace 3). Tests with petrol / gasoline were limited to about 80 l/min since there is no requirement to pump petrol at 140 l/min in forecourt dispensers for land vehicles.

Fig 8a: (diesel fuel) Graph of pressure pulse amplitude against flow rate, in the fuel discharge from combinations under test. The pulses are caused by the turning vanes within the vane pump, or by the peristalsis-like squeezing motion imposed by the swash pump on the fuel. Pulses were measured with a high-speed pressure transducer between the output of the FPS and the flow meter, using diesel fuel at ambient temperature, with a 4 meters vertical suction lift. The pressure pulse amplitude ought to be minimized so that the fuel meter can operate more accurately. Comparison of traces 1 versus either 2 or 3 shows that the improved FPS has a lower pulse amplitude for either a vane or a swash pump. One contributing cause is the larger diameter inlet valve. The swash pump inherently produces a lower pulse amplitude, even at a high delivery rate.

Fig 8b: (petrol, alias gasoline fuel) Graph of pressure pulse amplitude against flow rate, in the fuel discharge from combinations under test. As for Fig 8a, the vane pump produces the largest pulsation effect, less so when mounted in a FPS block. The swash pump which has been tested in the FPS block only, produced the smallest fluctuations. Lower fluctuations mean more accurate metering and better air separation.

Fig 9a: (diesel fuel) Graph of the effectiveness of air separation, as a deviation, against flow rate in the fuel discharge from combinations under test. Measurements used diesel fuel at ambient temperature, with a 4 meters vertical suction lift and an artificial air injection rate of 40 litres per minute. The meter reading was noted and compared with a volume collected in a calibrated container over a fixed period of time. The vertical axis shows the percentage deviation of accuracy of the fuel meter under test conditions. Note that an original GPU in trace 1 shows an inflexion in the trace between 80 and 90 litres per minute. The modified FPS does not show any change of deviation between 80 and 114 litres per minute when using a vane pump. The modified FPS, according to the

invention, does not show any change of deviation between 0 and 148 litres per minute when a swash pump is used. This straight-line trace has 6 test points.

505 The difference between trace 1 and trace 2 reflects the improved shaped conduit 5d and vortex air separator 5 design in particular. Even with a vane pump, the present invention would meet the requirements of present legislation or ordinances intended to prevent air being metered as if it was fuel within in the volume of fuel sold. It is desirable that the spiral flow pattern is established as soon as the fuel pump 4 starts to turn, and is maintained regardless of delivered flow rate during delivery
510 of fuel, so that air is expelled from the fuel sent to the fuel meter.

Fig 9b: (petrol or gasoline fuel) Graph of the effectiveness of air separation, as a deviation, against flow rate in the fuel discharge from two combinations under test. Measurements used petrol fuel at ambient temperature, with a 4 meters vertical suction lift and an air injection rate of 40 litres per minute. At 70 l/min the included air is 1 part in 1000 by volume, for a swash pump in a FPS block..

515 **Fig 10 a: (diesel fuel)** Graph of the brushless DC motor drive power consumption over a range of flow rates for the combinations of pumps and FPS units under test. It can be seen that the improved FPS (including the novel shaped conduit) especially when used with a swash pump requires significantly less energy to pump fuel. If the trace 2 is extrapolated to 140 litres per minute then it appears that an at least 1.8 kW (2.5 Hp) motor would be required to drive a vane pump of these
520 limited dimensions in order to supply about 140 litres per minute. The lower power consumption may be a result of (a) reduced obstructions to flow at and preceding the inlet valve, (b) improvements in the air separation means, (c) larger channels within the FPS, and, as shown by the displacement of trace 3 to the right, (d) use of a more efficient swash pump having an intrinsically higher capacity for increased flow.

525 **Fig 10 b: (petrol or gasoline fuel)** Graph of current for a three-phase AC induction motor, at 415 volts 50 Hz, versus delivered flow, for the three combinations. The current drawn is independent of flow rate, but is markedly higher at around 1.9A for the vane pump/GPU block than for the vane pump/FPS block at around 1.6A and only 1.1A for the swash pump/FPS block. This constant-speed type of motor would not be a good choice for electrical detection of torque by current drawn, but
530 torque might be sensed by other means known to those skilled in the relevant art.

TEST RESULT, in relation to Improvement 10.

Fig 12 is a graph showing swash pump torque over time as a percentage value, obtained from a torque test point in a brushless DC motor controller as previously described, while driving a swash pump within a GPU. The test liquid was diesel, at ambient temperature, and a 4 m lift load was imposed throughout. This trace shows that the raw torque signal as shown clearly reflects 3 instances of the opening of the delivery nozzle valve 105A at 202, 204 and 204. The higher torque seen when fuel is not being delivered through the hose (as 201) is presumed to reflect the raised pressure in the manifold. During periods when the trace of torque over time is at the higher level, the pump output is forced through overpressure relief valve 113 of Fig 11, but when the nozzle valve 105A is open, valve 113 is partly or completely closed. Clearly, this signal provides a good descriptor of fuel dispenser operation under normal circumstances or during either fault conditions or during theft. Apart from the technological means for extracting a torque signal, the use of a swash pump providing consistent flow and low torque, and to some extent the clean flow paths and maximised apertures provided throughout the FPS block as previously described in this specification assist in distinguishing the recycling state from the flow delivery state by means of their torque signals. In practice the torque signal may be combined with either or both of pump revolution rate and fuel meter revolution rate. This approach has the advantage that no added sensors are used. The sensing means is a self-contained part of the apparatus integral with the drive to the fuel pump so it cannot be interfered with. If the fuel pump cannot operate, there is no fuel available under pressure for theft. Pressure sensors have a limited life. The torque signal 111a may be used for at least one task selected from the range of: (a) regulating motor speed, (b) sensing pump pressure, (c) regulating pump pressure, (d) sensing flow rate, (e) sensing flow path, (f) detecting fault or unusual conditions, or (g) detecting deliberate tampering by a fuel thief.

More sophisticated fraud sensing algorithms will also detect unusual opening or closing patterns in the transition from higher to lower torque and back again, but experiments to explore this option have not yet been done. The relatively sharp on-off torque profile caused by operation of the nozzle valve 105A as shown here is likely to be different to the profile of a bleed of fuel from the pipe (B) before the fuel enters the meter. Another factor that might be sensed is the mean height of the "floor" of the part of the trace during delivery. The normal nozzle will have a characteristic rate of delivery as shown by the torque trace having a particular height, while unauthorised taps may have other torque values; higher or lower than the normal delivery rate. If pipe B should become fractured, the torque would be lowest. A person skilled in the art can easily construct a logic diagram to determine

the state of the dispenser and likely outside activity, and take action. In a practical embodiment, the logic diagram can be converted into software or into hardware evaluation means and output means.

565 This apparatus will work for a vane type fuel pump as well, although the signal will be less clear on account of higher friction losses inside that pump.

VARIATIONS

Two meters and two delivery hoses from one dispenser holding one FPS unit. The line 110 in Fig 11 carrying rate pulses from each meter should be passed into a summing means, the output of which is supplied to the comparison device 109 for comparison with the rate of turning of the single fuel pump. A person skilled in the electronic arts will be able to substitute an appropriate circuit, even an analogue mixing circuit, if the comparison device uses analogue signals. The constant pressure control mode used will be able to cope with the different flow rates occurring whether none, or two nozzle valves 105A are open at any time. If two nozzles are used from the same FPS unit, the torque traces as shown in Fig 12 may have three or even four normal levels: neither nozzle, nozzle A, nozzle B, or A + B are in use. Field calibration should include those conditions.

One FPS unit providing either 90 or 140 l/min fuel. So far as the Applicants are aware, at this time there is no reliably operable vane pump capable of supplying fuel at a rate of at least 140 litres per minute and having outer dimensions compatible with a 90 l/min FPS. As previously mentioned a swash pump is easily capable of supplying fuel at either rate, with extra volume to maintain an air separation device, if required. A variable speed DC type motor such as a brushless DC motor plus controller, together having sufficient power rating (such as 1.25 to 2 kW) is coupled to the pump so that the pump is turned just fast enough to give a desired pumping rate. The variable speed motor can provide either a high or a low flow rate of fuel delivery from the same FPS, user-switchable from customer to customer, again subject of course to safety considerations. This method would have by far the best efficiency. The invention may be used with other types of fuel pump, perhaps with shape or mounting modifications to entrain the outlet flow emerging from a particular position.

INDUSTRIAL APPLICABILITY and ADVANTAGES

Commercial benefits are derived from:

- 590 1. Energy savings when the FPS is used alone; especially if combined with the swash pump and a torque-controlling mode of motor operation (see Fig 10), without additional physical sensors.
2. Metering accuracy is catered for even at the 140 litres per minute rate since the improved air separation function is shown to be effective up to at least that rate, and the pressure pulse is reduced (as shown in figs 8 and 9).
- 595 3. Ability to modify existing 90 l/min dispensers to deliver 140 l/min. The changes include (a) a 90 l/min GPU-compatible field replacement FPS including a swash pump, and (b) (if necessary) a replacement motor having a sufficient power output, plus transmission means and motor drive.
4. Service providers need to carry less stock since the same FPS can be used as a direct replacement for the 90 l/min FPS out of an existing dispenser, as well as a 140 l/min option from an
600 existing dispenser, and for diesel or petrol/gasoline fuel dispensers.
5. Unusual, illegal or dangerous conditions can be detected by data processing means attached to the preferred swash pump motor drive, pumping can be halted immediately, and an alarm can be raised. No known fuel dispensers provide relevant data as a matter of course..

Finally, it will be understood that the scope of this invention as described by way of example and/or
605 illustrated herein is not limited to the specified embodiments. Where in the foregoing description, reference has been made to specific components or integers of the invention having known equivalents, then such equivalents are included as if individually set forth. Those of skill will appreciate that various modifications, additions, equivalents, and substitutions are possible without departing from the scope and spirit of the invention as set forth in the following claims.

610 **We Claim:**

1. A liquid fuel pumping module intended for direct replacement of an existing 90 litres per minute delivery module within a forecourt fuel dispenser, providing (a) fuel withdrawal from a supply through a fuel inlet by means of an internal fuel pump, (b) separation of the fuel from air or other included gases, and (c) delivery of the separated fuel under a controlled pressure into an existing fuel meter; characterised in that the module 1 has substantially identical external dimensions and connection points to those of the existing module, and includes an internally smoothly curved conduit 5d located in between an output port of the internal fuel pump 4 and an inlet 5a of a vortex air separator 5 which conduit provides, when in use, improved operating conditions for air separation at a delivery rate in the range up to at least 140 litres per minute.
2. A fuel pumping module as claimed in claim 1, characterised in that the module 1 provides for inclusion therein of a fuel pump cartridge 4 selected from a range including a vane pump cartridge and a swash pump cartridge, and the internally smoothly curved conduit 5d is capable of sealing over an output port of either fuel pump 4.
3. A fuel pumping module as claimed in claim 2, characterised in that the swash pump cartridge option 4 provides, when in use, a higher maximum flow rate, a reduced power consumption and an inherently low pulsatile pressure component of fuel flow.
4. A fuel pumping module as claimed in claim 2, characterised in that a fuel inlet 2b is increased by at least 2.5 times in area thereby providing, when in use, less restriction to incoming flow of fuel and reduction of a pulsatile pressure component of fuel flow out of the fuel pump 4, providing improved fuel metering conditions and a reduced power consumption.
5. A fuel pumping module as claimed in claim 1, characterised in that an outlet means for air from an end of the vortex air separation means is provided in between the separation means and an atmospheric chamber; the outlet means having at least twice as large a side exit aperture area as that of prior-art outlet means.
6. A fuel pumping module as claimed in claim 2, characterised in that the fuel pump 4 is turned, when in use, by an electric motor provided with controlled electric power from a variable-

speed motor power supply 108 capable of sensing a torque delivered by the motor, and of providing a torque signal 111a for use by computational means 109 in performing at least one task selected from the range of: (a) regulating motor speed, (b) sensing pump pressure, (c) regulating pump pressure, (d) sensing flow rate, and (e) sensing flow path.

7. A fuel pumping module as claimed in claim 6, characterised in that the torque signal is sensed by means independent of the motor drive power supply.

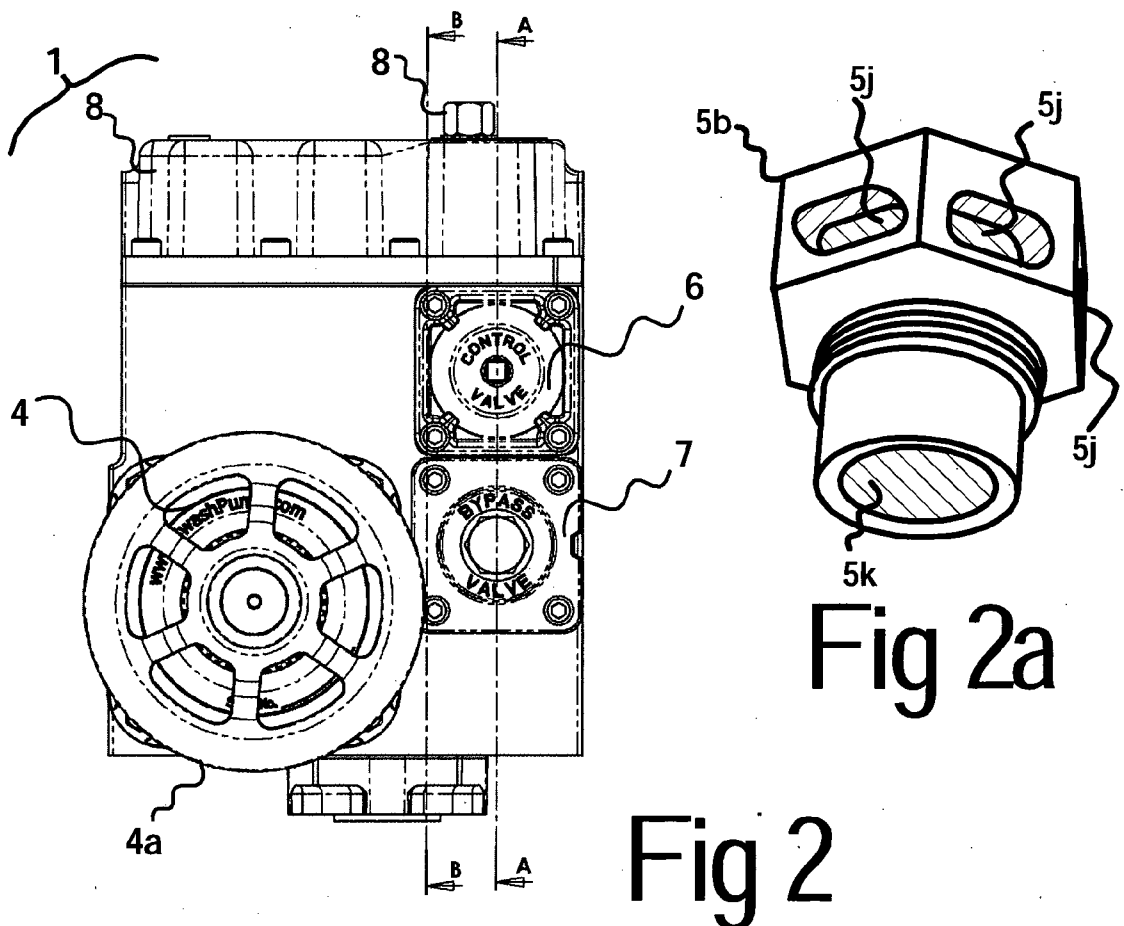
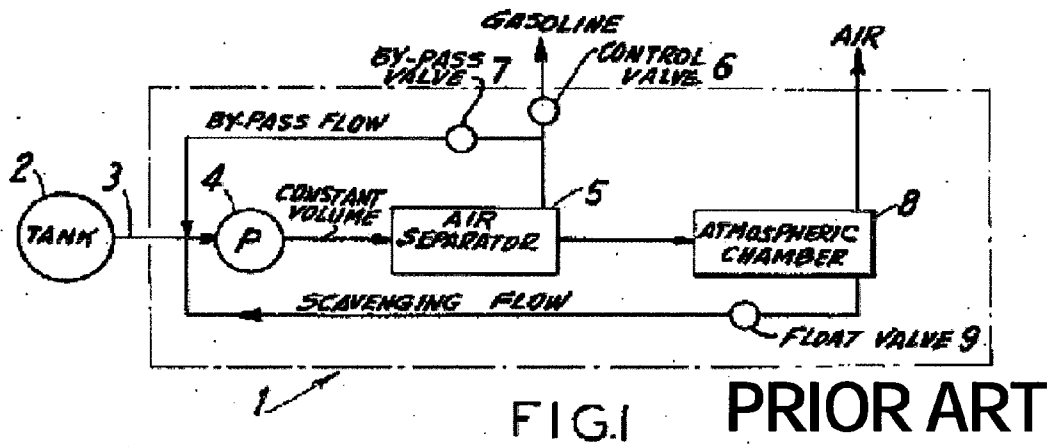
8. A fuel pumping module as claimed in claim 6, characterised in that the computational means 109 is further capable of processing one or more of: a signal 111 describing motor revolution rate, and a signal 110 describing fuel meter revolution rate.

9. A fuel pumping module as claimed in claim 6 or in claim 8, characterised in that the computational means is capable during use of detecting fault or unusual conditions, or detecting deliberate tampering by a fuel thief and of providing an electrical output 115 in the event of a fuel flow discrepancy.

10. A fuel pumping module as claimed in claim 9, characterised in that the electrical output 115 from the computational means is coupled to at least one of: an electric power supply interruption means 117 capable when activated of immediately halting any fuel pumping activity, and means for raising an alarm capable of calling the attention of a person.

11. A method for controlling a fuel pumping module as claimed in claim 6; the method including the steps of receiving into computational means at least one signal selected from a range including: a signal 111 describing motor revolution rate, a signal 110 describing fuel meter revolution rate, and a signal 111a describing the torque delivered by the motor connected to the supply; the step of evaluating said at least one signal within the computational means, and the step of providing an alarm signal indication a fuel flow discrepancy arising as a result of either a fault, or of tampering with the forecourt fuel dispenser.

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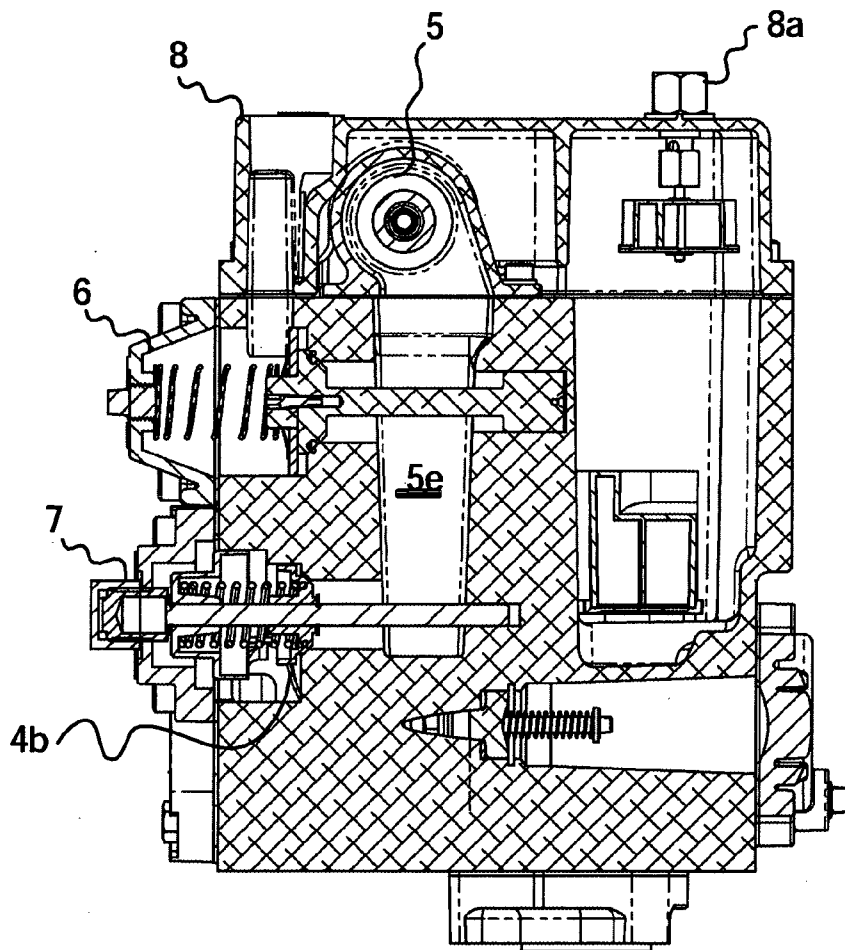


Fig 3

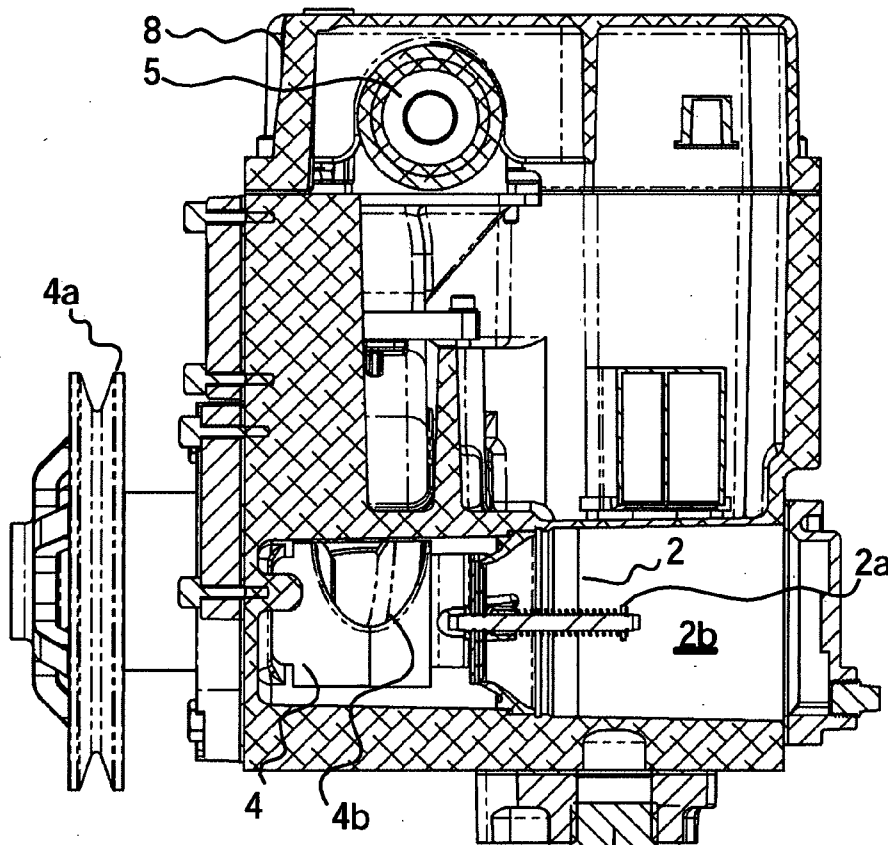


Fig 4

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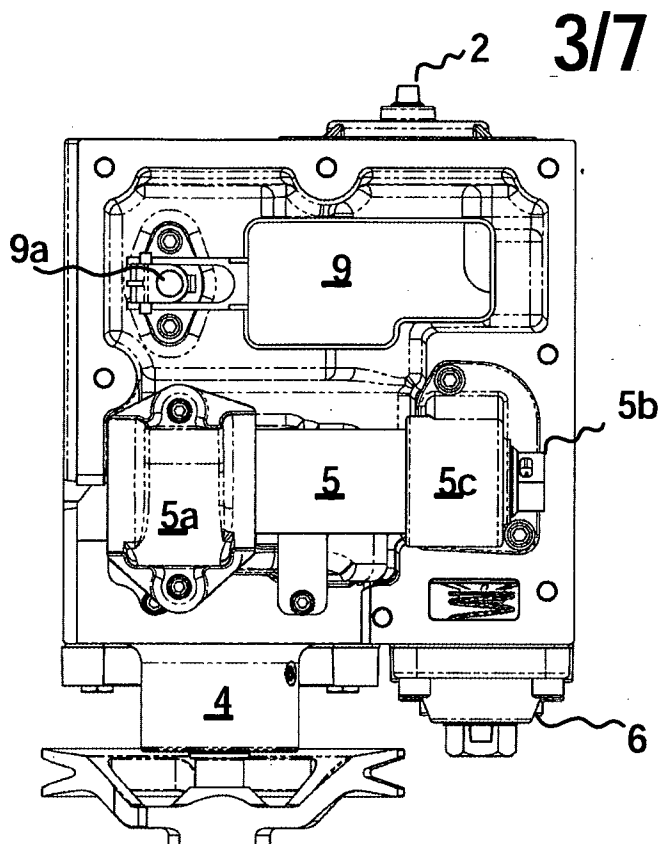


Fig 5

Fig 7

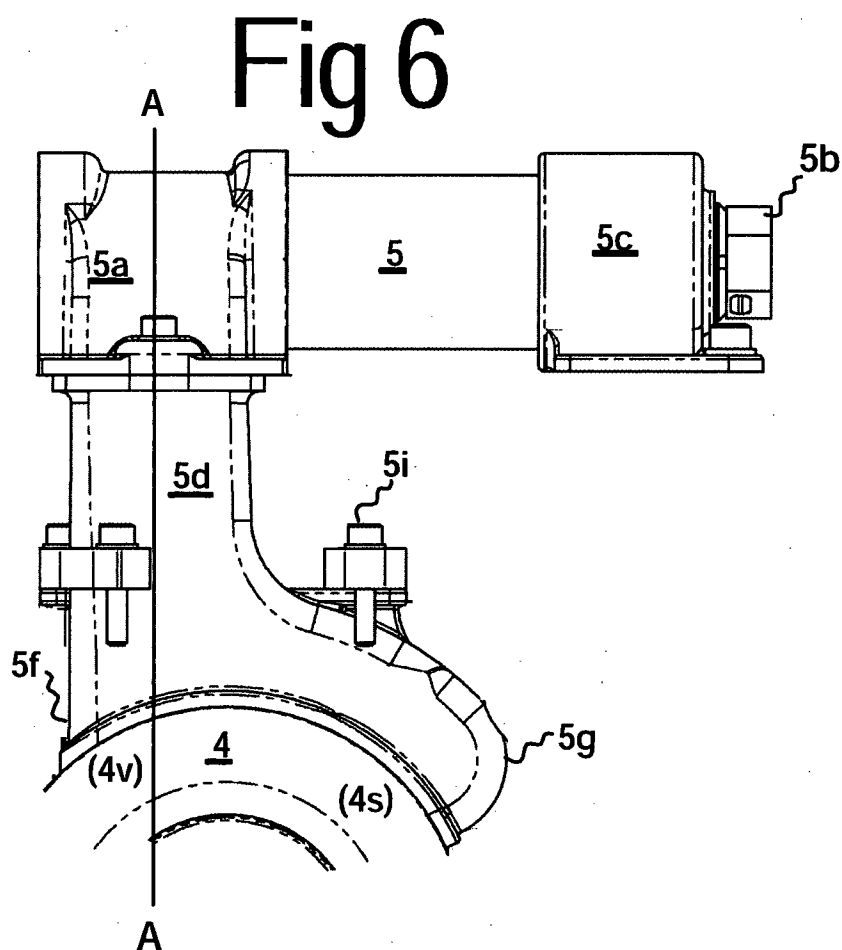
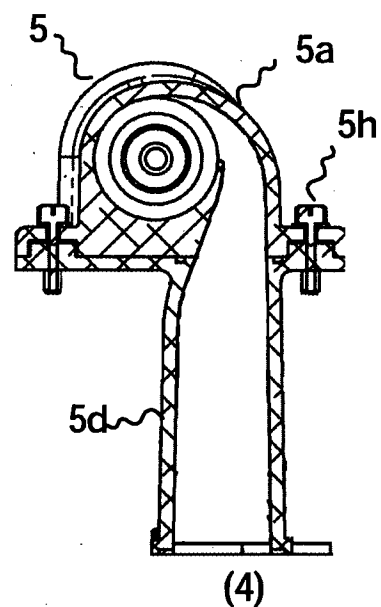


Fig 6



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Fig 8a

Flow v Discharge pressure pulse - diesel

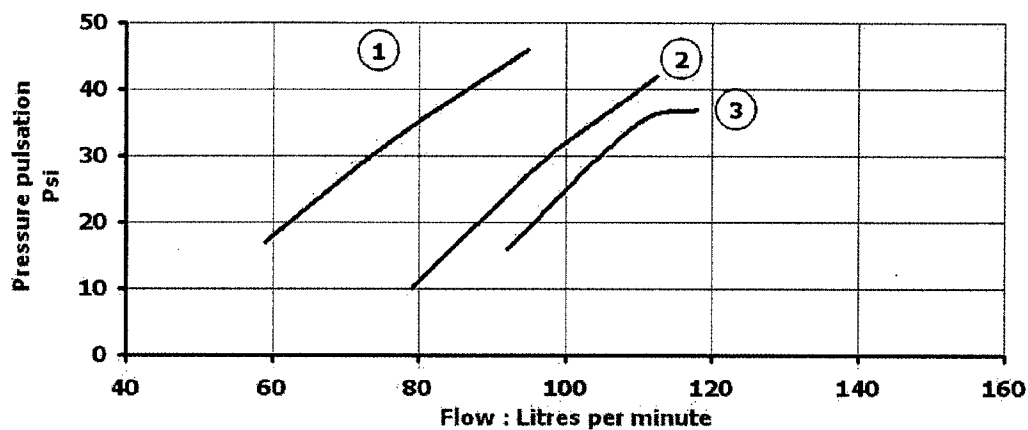


Fig 8b

Flow v Discharge pressure pulse - Petrol

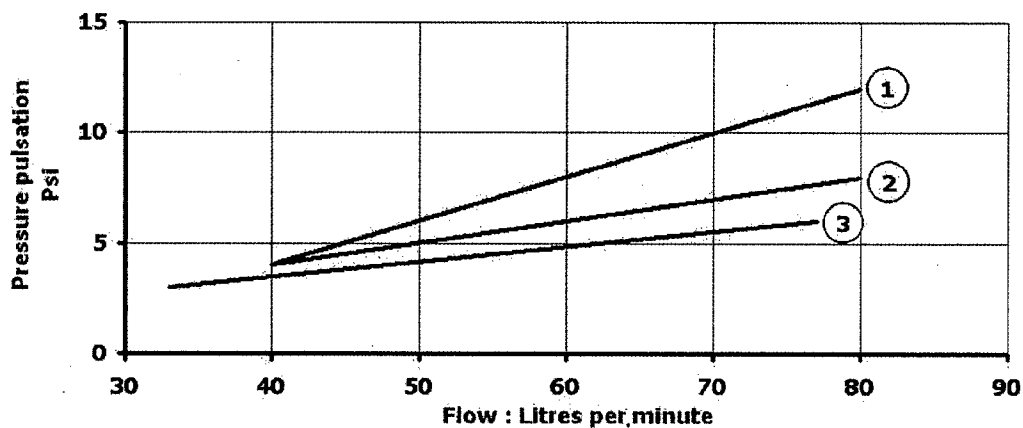
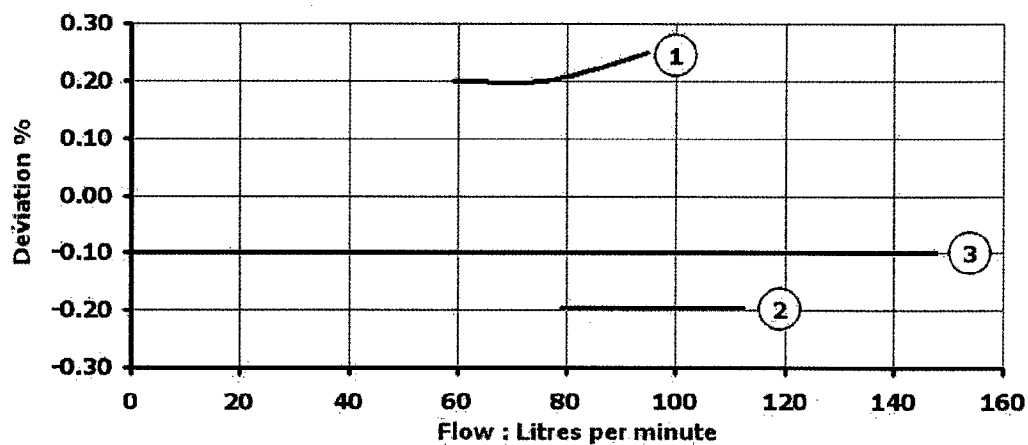


Fig 9a

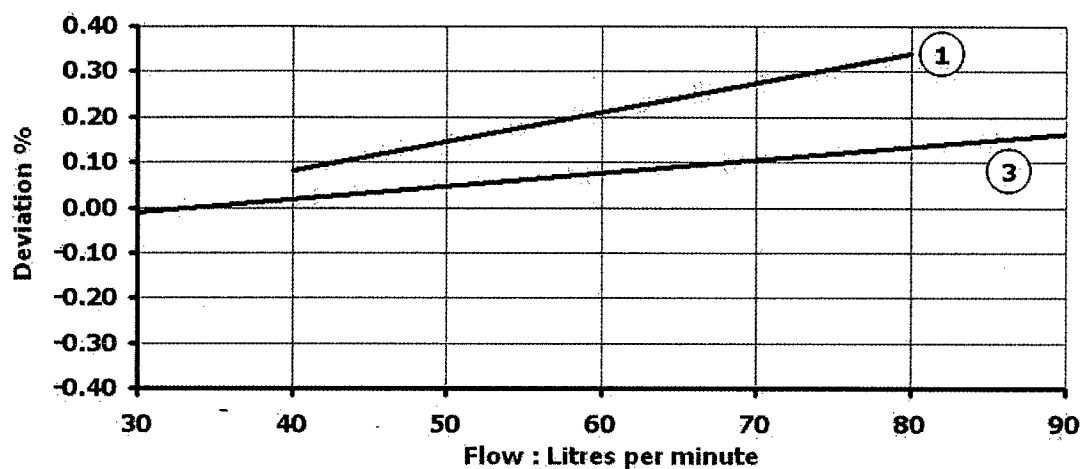
Air separation v Flow



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Fig 9b

Air separation v Flow petrol



Flow v Motor power

Fig 10a

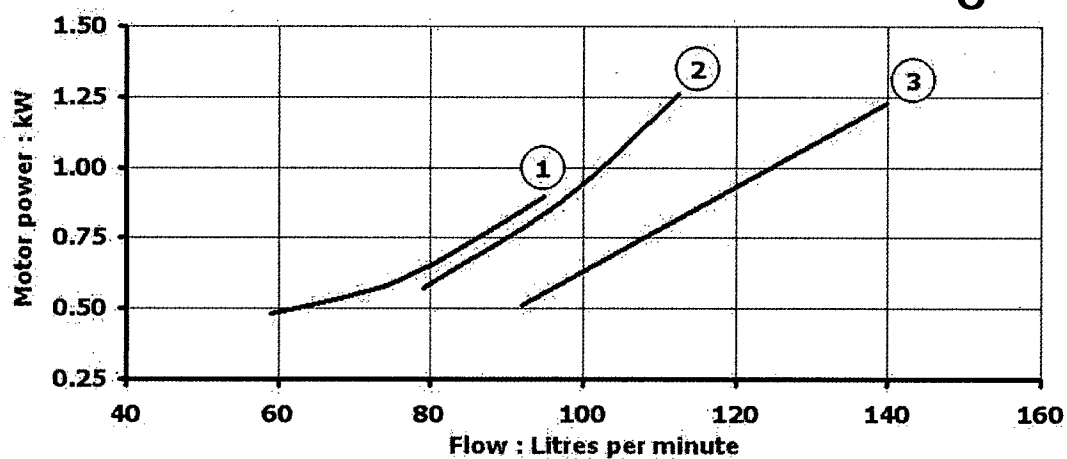
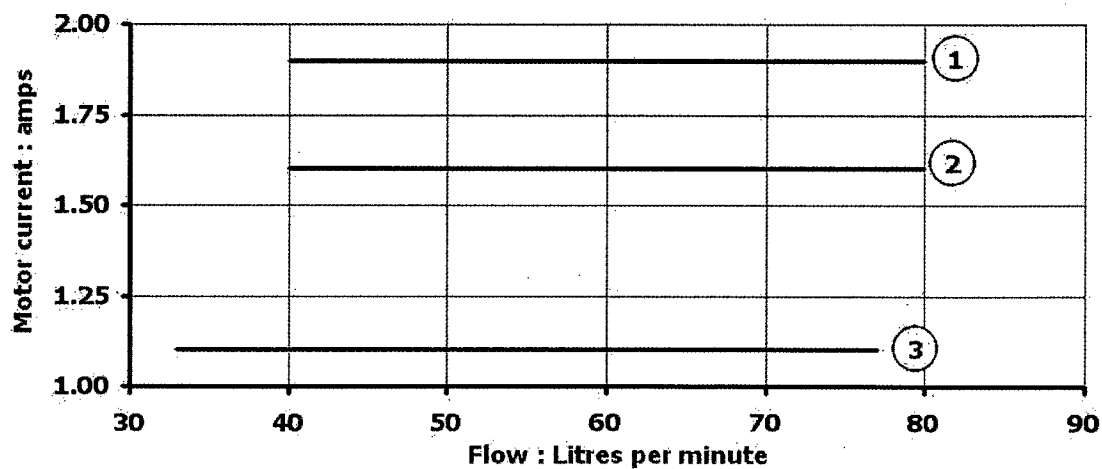


Fig 10b

Flow v Motor Current



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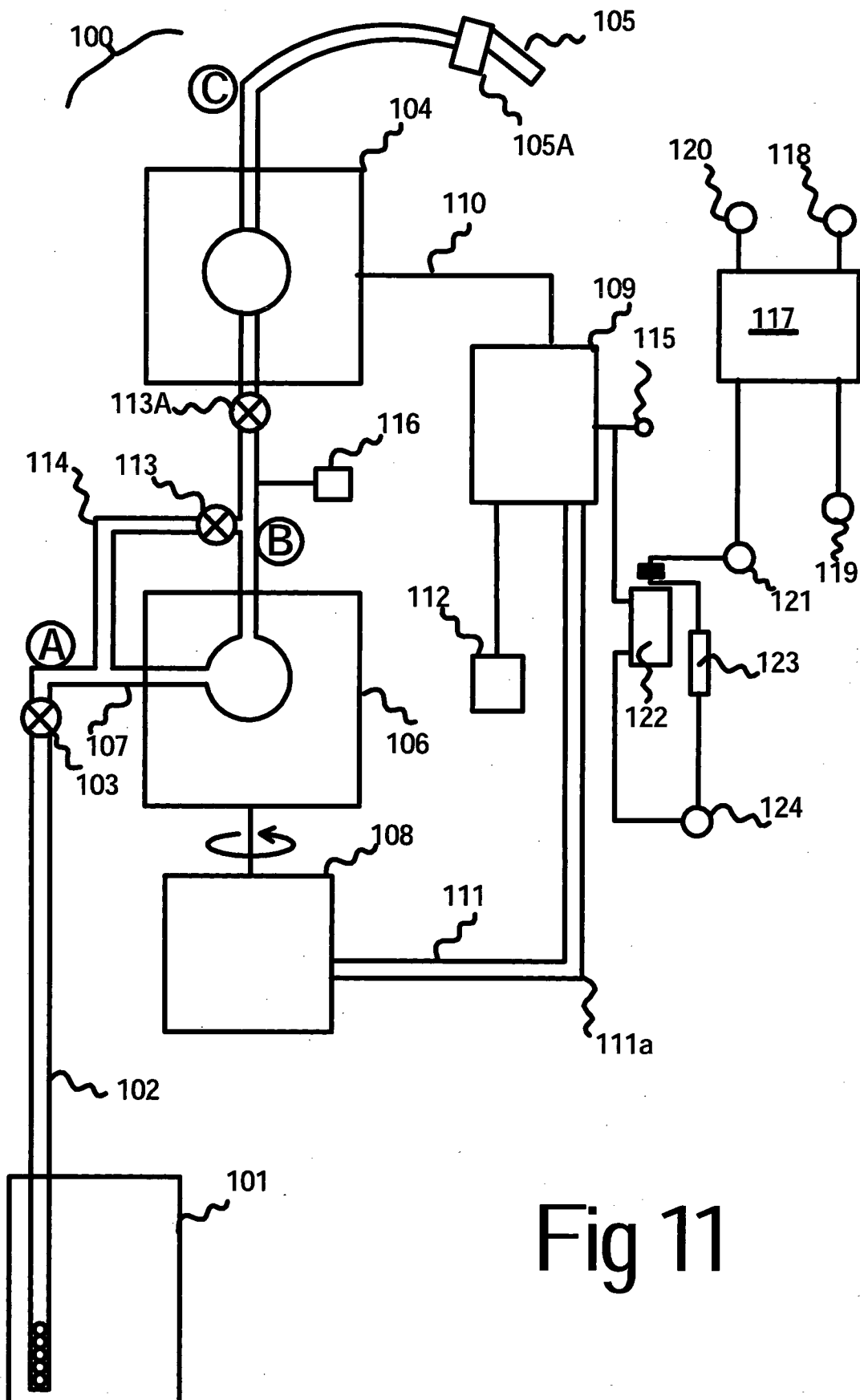


Fig 11

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Fig 12

