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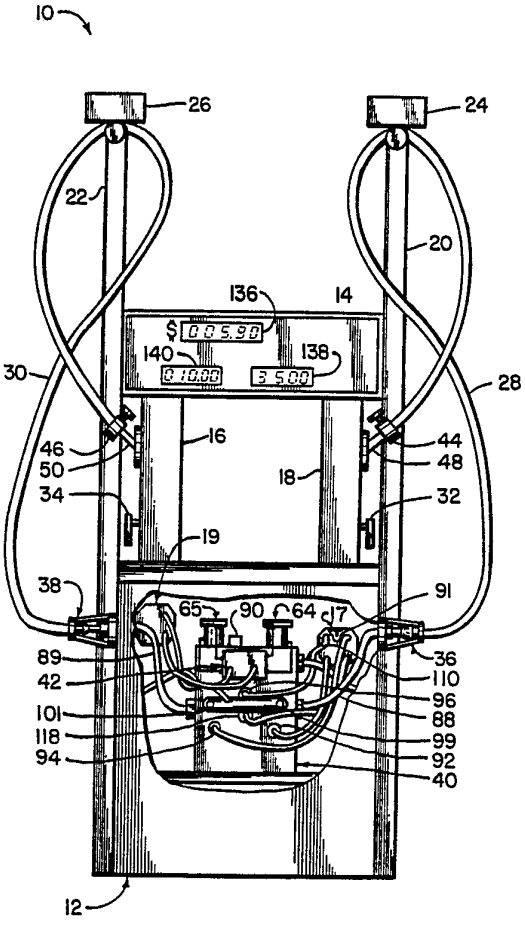
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**(54) Title:** IMPROVED METHOD AND APPARATUS FOR DISPENSING NATURAL GAS

**(57) Abstract**

A supply plenum and valve body assembly (40) connected to a source of compressed natural gas (CNG) selectively turns on the flow of CNG through either a first sonic nozzle (52) or a second sonic nozzle (54) and out through respective dispensing hose assemblies (28, 30). A pressure transducer (96), a supply plenum temperature transducer (118), and an ambient temperature transducer (91) measure the stagnation pressure and temperature of the CNG and the ambient temperature, respectively. A pressure transducer (92) fluidically connected to the vehicle tank via the dispensing hose assembly monitors the pressure of the CNG in the vehicle tank. An electronic control system (13) connected to the pressure and temperature transducers and to the supply plenum and control valve assembly (40) calculates a vehicle tank cut-off pressure based on the ambient temperature and on the pressure rating of the vehicle tank that has been pre-programmed into the electronic control system (13), calculates the volume of the vehicle tank and the additional mass of CNG required to increase the tank pressure to the cut-off pressure, and automatically turns off the CNG flow when the additional mass has been dispensed into the vehicle tank. The electronic control system (13) also determines the amount of CNG dispensed through the sonic nozzles (52, 54).



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# IMPROVED METHOD AND APPARATUS FOR DISPENSING NATURAL GAS

Technical Field:

This invention relates generally to methods and apparatus for measuring and controlling fluid flow rates and, more particularly, to a method and apparatus for dispensing natural gas.

Background Art:

Over the past few years, there has been a steadily increasing interest in developing alternative fuels for automobiles in an effort to reduce the harmful emissions produced by conventional gasoline and diesel powered vehicles. One such alternative fuel that has already been used with favorable results is compressed natural gas (CNG). Besides being much cleaner burning than gasoline or diesel fuel, most modern automobiles can be converted to operate on compressed natural gas (CNG). Typically, such a conversion may include various minor modifications to the engine and fuel delivery system and, of course, the installation of a natural gas fuel tank capable of storing a sufficient amount of CNG to provide the vehicle with range and endurance comparable to that of a conventionally fueled vehicle. In order to provide a reasonably sized storage tank, the CNG is usually stored under relatively high pressures, such as 3,000 to 4,000 pounds per square inch gauge (psig).

While the conversion process described above is relatively simple, the relatively high pressure under which the CNG is stored creates certain refueling problems that do not exist for conventional vehicles powered by liquid fuels, such as gasoline. Obviously, since the gas is transferred and stored under high pressure, special fittings, seals, and valves have to be used when the CNG is transferred into the CNG storage tank on the vehicle to prevent loss of CNG into the atmosphere. Also, special precautions must be taken to minimize the danger of fire or explosion that could result from the unwanted escape of the high pressure CNG. Accurate, yet convenient and easy to use measurement of the amount of CNG delivered into the vehicle's storage tank is also a problem. Consequently, most currently available natural gas refueling systems require that several relatively complex steps be performed during the refueling process to prevent leakage, minimize the risk of fire or explosion, and to measure the amount of fuel delivered. Unfortunately, because such processes tend to be relatively complex, they cannot be carried out very easily by most members of the general public or even by unskilled workers. Therefore, most CNG dispensing systems usually require trained personnel to perform the refueling process. As of date, providing trained operators to

perform the refueling operation has not yet posed a significant problem, because natural gas refueling stations are generally limited to fleet operators of vehicles who can afford to have trained personnel to perform the refueling operations and who either do not care to keep accurate measurements of each vehicle fill-up or who can afford complex flow measuring equipment to do it. However, because the interest in natural gas powered automobiles is increasing rapidly, and there is a growing need to develop a natural gas refueling system that is highly automated and has sufficient fail-safe systems to minimize the danger of fire or explosion, while at the same time being capable of accurate measurements and being used safely by the general public. Ideally, such a natural gas dispensing system should be as familiar to the customer and as easy to use as a conventional gasoline pump and refueling station.

As mentioned above, there are several natural gas dispensing "pumps" currently available. One such system is disclosed in the patent to Fisher *et al.*, U.S. Patent No. 4,527,600. While the dispensing system disclosed by Fisher *et al.*, is relatively easy to use, it requires certain relatively expensive components. For example, Fisher's dispensing system utilizes differential pressure transducers to determine the amount of CNG that is dispensed into the vehicle tank. Disadvantageously, however, such differential pressure transducers are expensive, and have a rather limited range of pressure ratios of about 3 to 1.

Another significant problem associated with the dispensing systems currently available, such as the system disclosed by Fisher, is that such systems cannot determine accurately when the natural gas storage tank in the vehicle is filled to rated capacity, yet not overfilled. That is, since natural gas storage tanks in vehicles have to be rated to safely contain CNG under a given pressure at a given temperature (e.g., 3000 psig at a temperature of 70° F, the "standard temperature"), it is important to determine the correct pressure to which the tank should be filled when the ambient temperature is not exactly 70° F. For example, if the ambient temperature is warmer than the standard temperature of 70° F, the tank can be filled safely to a pressure higher than the rated pressure. In fact, the tank will not be completely filled under such circumstances until it is at such a higher pressure. Conversely, if the ambient temperature is below standard temperature, the tank cannot be filled safely to the rated pressure, because as the CNG warms to the standard temperature, the pressure will exceed the rated pressure. In this situation, the tank is overfilled, and there is a significant danger of the safety relief valve on the tank venting the excess CNG to the atmosphere, thereby losing the CNG and possibly even creating an explosion hazard. Worse yet, the tank may actually rupture if the safety valve malfunctions.

Unfortunately, however, none of the currently available natural gas dispensing pumps compensate for changes in ambient temperature. Accordingly, these currently available dispensing systems are usually configured to turn off the flow of natural gas at pressures well below the rated pressure of the tank to avoid the dangerous overfilling and consequent over-pressurization the vehicle storage tank described above. Consequently, if the ambient temperature is higher than the standard temperature of 70° F, the tank will be substantially underfilled.

Another problem relates to accurately sensing the vehicle tank pressure while the vehicle tank is being filled. For example, it is impossible to sense the vehicle tank pressure with a remotely located pressure sensor if the CNG flow through the dispensing hose reaches sonic velocity (a choke point) at some point between the pressure sensor and the vehicle tank itself. Typically, such a choke point occurs in the safety check valve located in the vehicle tank coupler assembly. Accordingly, such dispensing pumps are usually designed to ensure that the flow of CNG between the remote pressure sensor for sensing the vehicle tank pressure and the vehicle tank itself remains subsonic at all times and under all flow conditions, which, of course, limits the maximum delivery rate of the pump. Unfortunately, even if the dispensing pump is designed to ensure that a sonic choke point does not occur between the pressure sensor and the tank, it is still necessary to compensate for pressure errors due to the pressure drop in the hose and coupler/check valve assembly, which is difficult, since the pressure drop in the vehicle check valve may vary depending on the characteristics of particular valve.

Therefore, there is a need for a natural gas dispensing system that provides the desired degree of safety for dispensing natural gas under high pressures that is preferably as easy to use a conventional gasoline pump. Such a dispensing system should be relatively simple and reliable and ideally would not require expensive and complex differential pressure transducers. Most importantly, such a dispensing system should be capable of automatically determining a temperature corrected cut-off pressure to ensure that the vehicle storage tank is completely filled regardless of the ambient temperature and regardless of whether the CNG flows through a sonic choke point in the dispensing hose or coupler/check valve assembly. Finally, it would be desirable for such a dispensing system to accommodate two or more dispensing hoses from a single supply plenum to reduce the number of pressure and temperature sensors to a minimum, thus providing better overall system reliability and lower cost.

Disclosure of the Invention:

Accordingly, it is a general object of this invention to provide a pressurized fluid dispensing system that can automatically compensate for non-standard ambient gas temperature to promote complete filling of a pressurized storage tank.

It is a further general object of this invention to provide a pressurized fluid dispensing system that can accurately fill a pressurized storage tank to its rated capacity even though the flow of CNG through the dispensing hose passes through a sonic choke point.

It is another general object of this invention to provide a pressurized fluid dispensing system that can accurately measure the amount of fluid transferred into a pressurized storage tank without the need to resort to expensive and performance limiting differential pressure transducers and regardless of whether the CNG in the dispensing hose flows through a sonic choke point.

It is another object of this invention to provide a pressurized fluid dispensing system that uses sonic nozzles to measure the amount of fluid dispensed.

It is a more specific object of this invention to provide a natural gas dispensing system that is highly automated and simple to use while providing a high degree of safety.

It is yet another more specific object of this invention to provide a natural gas dispensing system that can easily support multiple dispensing hoses from a single supply plenum.

Additional objects, advantages, and novel features of the invention shall be set forth in part in the description that follows, and in part will become apparent to those skilled in the art upon examination of the foregoing or may be learned by the practice of this invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and in combinations particularly pointed out in the appended claims.

To achieve the foregoing and other objects, and in accordance with the purpose of the present invention, as embodied and broadly described herein, the natural gas dispensing system according to this invention may comprise a supply plenum connected to a CNG source and a control valve assembly for selectively turning on the flow of CNG through a sonic nozzle and out through a dispensing hose assembly. Pressure and temperature transducers connected to the supply plenum measure the stagnation pressure and temperature of the CNG and a pressure transducer fluidically connected to the vehicle tank via the dispensing hose assembly is used to determine the discharge pressure. A second temperature transducer is used to measure the ambient temperature. An electronic control system connected to the pressure and temperature transducers and to the control valve assembly calculates a vehicle

tank cut-off pressure based on the ambient temperature and on the pressure rating of the vehicle tank that has been pre-programmed into the electronic control system, calculates the volume of the vehicle tank and the additional mass of CNG required to increase the tank pressure to the cut-off pressure, and automatically turns off the CNG flow when the additional mass has been dispensed into the vehicle tank. The electronic control system also determines the amount of CNG dispensed through the sonic nozzle based on the upstream stagnation temperature and pressure of the CNG and the length of time the CNG was flowing through the sonic nozzle.

The method of this invention includes the steps of connecting a CNG supply tank and the vehicle tank with a pressure tight dispensing hose, sensing the ambient temperature before initiating the dispensing cycle, and calculating a cut-off pressure for the vehicle tank based on the ambient temperature and based on the pressure rating for the vehicle tank. The dispensing cycle is then initiated by briefly cycling the valve to pop open the vehicle tank check valve and equalize the pressure in the dispensing hose and the vehicle tank and sensing the initial vehicle tank pressure. Next, a predetermined mass of CNG is dispensed into the vehicle storage tank to increase the tank pressure to an intermediate pressure. The initial and intermediate tank pressures are then used to determine the volume of the vehicle tank. Well-known gas relations are then used to calculate the mass of CNG required to fill the vehicle tank to the temperature compensated cut-off pressure and the dispenser then fills the tank with the calculated mass of CNG.

Brief Description of the Drawings:

The accompanying drawings, which are incorporated herein and form a part of this specification, illustrate the preferred embodiment of the present invention, and together with the description, serve to explain the principles of the invention. In the drawings:

Figure 1 is a front view in elevation of the natural gas dispensing system according to the present invention with the front panel of the lower housing broken away to show the details of the natural gas supply plenum and valve body assembly, and with the front cover of an electrical junction box broken away to show the location of the ambient temperature sensor;

Figure 2 is a perspective view of the supply plenum and valve body assembly shown in Figure 1 with the supply plenum cover removed and with a corner section broken away to reveal the details of the sonic nozzle, the control valve assembly, and the pneumatic air reservoir;

Figure 3 is a plan view of the supply plenum and valve body assembly of the present invention showing the plenum chamber cover in position, the various inlet and outlet connections, and the various pressure and temperature transducers used to sense the pressures and temperatures of the CNG at various points in the plenum and valve body assembly;

Figure 4 is a sectional view in elevation of the supply plenum and valve body assembly taken along the line 4-4 of Figure 3 more clearly showing the details of the plenum chamber cover, the supply plenum, one of the sonic nozzles, the corresponding control valve assembly, and the positioning of the various pressure and temperature transducers;

Figure 5 is a schematic view of the pneumatic system of the present invention showing the pneumatic connections to the control valve assemblies, the locations of the various pressure and temperature transducers, and the path of the natural gas from the supply plenum through the sonic nozzles and ultimately through the hose connections;

Figure 6 is a block diagram of the electronic control system used to control the function and operation of the natural gas dispensing system according to the present invention;

Figure 7 is a graph of vehicle tank pressure vs. mass of CNG;

Figure 8 is a flow chart showing the steps executed by the electronic control system of the present invention;

Figure 9 is a flow chart showing the detailed steps of the Start Sequence shown in Figure 8;

Figure 10(a) is a flow chart showing the detailed steps of the Fill Sequence of Figure 8;

Figure 10(b) is a continuation of Figure 10(a);

Figure 11 is a detailed flow chart showing the steps of the End Sequence of Figure 8; and

Figure 12 is a flow chart showing an alternative Fill Sequence process that could be substituted for the Fill Sequence process shown in Figures 10(a) and 10(b).

Best Mode for Carrying Out the Invention:

The major components of the natural gas dispensing system 10 according to the present invention are best seen in Figure 1 and comprise a lower housing 12 which houses the supply plenum and valve body assembly 40, along with numerous associated components, as will be described in detail below. The electrical wires from the various pressure and temperature transducers 92, 94, 96, and 58 as well as from the solenoid valve assembly 42 are routed to two sealed electrical junction boxes 17 and 19, respectively, via pressure-tight

conduit to reduce the chances of fire or explosion. Electrical wires from these two junction boxes 17, 19 are then routed in pressure-tight conduit to an elevated and pressurized penthouse 14 which houses the electronic control system 13 (not shown in Figure 1, but shown in Figure 6) and various display windows 136, 138, and 140. Penthouse 14 is mounted to the lower housing 12 by left and right penthouse support members 16, 18. Two vertical hose supports 20, 22 are attached to either side of lower housing 12 and penthouse 14 and support the two retrieving cable assemblies 24, 26, as well as a first dispensing hose 28 and a second dispensing hose 30, respectively. These first and second dispensing hoses 28, 30 are connected to the supply plenum and valve body assembly 40 via two breakaway connectors 36, 38 and two natural gas output lines 88 and 89. Finally, each dispensing hose 28, 30 terminates in respective three-way valve assemblies 44, 46 and pressure-tight hose couplers 48, 50. Each pressure-tight hose coupler is adapted to connect its respective dispensing hose to the natural gas storage tank coupler on the vehicle being refueled (not shown).

The high degree of automation of the dispensing system 10 allows it to be easily and safely used on a "self serve" basis, much like conventional gasoline pumps, although the system could also be operated by a full-time attendant. In order to dispense the CNG into the vehicle tank, a dispensing hose, such as dispensing hose 28, is connected to the vehicle tank being refueled via pressure-tight coupler 48, which is adapted to fit with the standardized connecter on the vehicle. The customer or attendant would then move the three-way valve 44 to the "fill" position and move the transaction switch 32 to the "on" position. The natural gas dispensing pump 10 then begins dispensing CNG into the vehicle tank, continuously indicating the amount of natural gas being dispensed on display 140, the price on display 136, and the pressure in the vehicle tank on display 138 (after a finite delay and under no flow conditions), much like a conventional gasoline pump. After the vehicle tank has been filled to the proper pressure, as determined by the ambient temperature sensed by temperature transducer 91 located within junction box 17, the dispensing system 10 automatically shuts off the flow of CNG into the vehicle, as will be described in detail below. The customer or attendant would then move transaction switch 32 to the "off" position, and turn the three-way valve to the "vent" position to vent the natural gas trapped in the space between the hose coupler 48 and the vehicle coupler (not shown) into a vent recovery system (not shown), where it is re-compressed and pumped back into the CNG storage tank (also not shown).

The supply plenum and valve body assembly 40, along with the electronic control system (not shown in Figure 1, but shown in Figure 6 and fully described below) forms the

heart of the natural gas dispensing system 10 and includes sonic nozzles, digital control valves, and various pressure and temperature transducers to automatically dispense the exact amount of natural gas required to completely fill the vehicle storage tank as well as to automatically calculate and display the total amount of natural gas dispensed into the storage tank. Since the CNG dispensed by the system 10 is under considerable pressure (about 4,000 psig), the dispensing system 10 also includes a number of fail-safe and emergency shut-off features to minimize or eliminate any chance of fire or explosion, as will be described below.

A significant advantage of the natural gas dispensing system 10 is that it does not require performance limiting and complex differential pressure transducers to determine the amount of CNG dispensed into the vehicle storage tank. Advantageously, the present invention can accurately measure the amount of CNG dispensed using relatively inexpensive and simple gauge pressure transducers, as will be discussed below.

Yet another advantage of the natural gas dispensing system 10 is that a plurality of sonic nozzles can be connected to a single input or supply plenum, each of which may be operated independently of the others without adversely affecting the metering accuracy or performance of the other nozzles. Accordingly, the preferred embodiment utilizes two sonic nozzles and two control valve assemblies, so that two dispensing hoses can be easily used in conjunction with the single supply plenum and valve body assembly 40, thereby increasing utility and reducing cost. Furthermore, because more than one sonic nozzle can be connected to the single supply plenum, only a single set of pressure and temperature transducers are required to sense the stagnation pressure and stagnation temperature of the CNG contained within the supply plenum, even though two or more hoses or "channels" are connected to the single plenum, thereby further reducing the cost and complexity of the dispensing system 10.

Perhaps the most significant feature of the present invention is that the CNG dispensing system 10 is temperature compensated to automatically fill the vehicle natural gas tank to the correct pressure regardless of whether the ambient temperature is at the "standard" temperature of 70° F. For example, if the ambient temperature is above standard, say 100° F, the vehicle tank will be automatically filled to a pressure greater than its rated pressure at standard temperature, since, when the CNG in the tank cools to the standard temperature, the pressure will decrease to the rated pressure of the tank. The dispensing system 10 automatically determines the proper cut-off pressure for the ambient temperature and automatically terminates the refueling process when the calculated cut-off pressure is reached. Such automatic temperature compensation, therefore, ensures that the vehicle storage tank is filled to capacity regardless of the ambient temperature.

Another significant feature of the present invention is that it does not rely on a pressure sensor to determine the pressure of the vehicle tank during the filling process. Instead, the CNG pump according to the present invention first determines the volume of the vehicle storage tank and then computes the mass of CNG required to fill the vehicle tank to the previously determined, temperature compensated cut-off pressure. Therefore, the present invention eliminates the need for continuously sensing the vehicle tank pressure, avoids the problems associated with pressure losses in the dispensing hose and coupler/check valve assembly, and is accurate even if a sonic choke point exists in the interconnecting dispensing hose or coupler assembly.

The details of the supply plenum and valve body assembly 40 are best seen and understood by referring to Figures 2, 3 and 4 simultaneously. As described above, the preferred embodiment includes two separate and independent nozzle, valve, and hose assemblies, which may be referred to hereinafter as channels. However, to simplify the description, only the first channel i.e., the channel for hose 28 will be described in complete detail. The components utilized by the second channel (hose 30) are identical in every respect, and, therefore, will not be described in detail.

In the preferred embodiment, the supply plenum and valve body assembly 40 is machined from a single block of aluminum, although other materials could be used just as easily. Supply plenum and valve body assembly 40 defines, in combination with the plenum chamber cover 112, a supply plenum 56, (see Figures 3 and 4) and a pneumatic reservoir 86, and also houses the two sonic nozzles 52, 54 and the corresponding control valve assemblies 64, 65. Various pressure transducers 92, 94, and 96 and temperature transducer 118, as well as the solenoid valve assembly 42 (shown in Figure 1, but not shown in Figures 2, 3, and 4 for clarity), are also mounted to the supply plenum and valve body assembly 40, as will be described below.

As mentioned above, the natural gas dispensing system 10 of the present invention utilizes sonic nozzles to accurately meter the flow of CNG through each dispensing hose. Such sonic nozzles have been used for decades as flow regulators because the mass flow rate of a gas flowing through such a nozzle is independent of the back pressure at the nozzle exit, so long as the gas is flowing at sonic velocity in the throat section of the nozzle. Put in other words, the metering accuracy is not affected by variations in the vehicle tank pressure. Therefore, sonic nozzles eliminate the need to measure both the upstream and downstream pressures of the gas in order to determine the gas flow rate.

Briefly, a sonic nozzle, such as sonic nozzle 52, comprises a converging section 442 and a diverging section 444 separated by a throat section 446, which represents that portion of the nozzle having the smallest cross-sectional area, see Figures 2 and 4. Gas entering the converging or inlet section 442 of sonic nozzle 52 is accelerated until it is flowing at the speed of sound in the throat, provided there is a sufficiently high pressure ratio between the "upstream" pressure (i.e., the pressure of the CNG in the supply plenum 56) and the "downstream" pressure (i.e., the pressure in the intermediate chamber 62). If the diverging section 444 is properly designed in accordance with well-known principles, the gas will decelerate in the diverging section 444 until nearly all of the velocity pressure has been converted back into static pressure before the gas enters the downstream or intermediate chamber 62. A significant feature of the sonic nozzle is that for a given set of stagnation pressures and temperatures of the fluid upstream of the nozzle, there is a maximum flow which can be forced through the nozzle that is governed by the throat area. No matter what happens downstream from the throat in the way of decreasing the pressure or increasing the flow area, the flow rate will remain the same, so long as sonic conditions are maintained at the throat. Accordingly, the mass flow rate through a sonic nozzle is governed by the following equation:

$$\dot{m}=C_d\frac{kAp_1}{\sqrt{T_1}} \qquad (1)$$

where m is the mass flow rate of the fluid flowing through the nozzle; $C_d$ is the nozzle discharge coefficient for the particular nozzle being used; k is a constant depending on the ratio of specific heats and the gas constant of the fluid; $p_1$ is the stagnation pressure of the fluid in the supply plenum 56; A is the nozzle throat area; and $T_1$ is the absolute temperature of the fluid in the supply plenum 56. See the text, *The Dynamics and Thermodynamics of Compressible Fluid Flow*, by Ascher H. Shapiro, Volume 1, page 85, equation (4.17), the Ronald Press Co., New York, 1953, for the exact relationship between k, the ratio of specific heats, and the gas constant. The flow rate through a sonic nozzle is, therefore, proportional to the stagnation pressure $p_1$ in the supply plenum 56 divided by the square root of the stagnation temperature $T_1$ in supply plenum 56 times the effective throat area of the sonic nozzle. It follows that the fluid flow rate determinative parameter is the stagnation pressure $p_1$ divided by the square root of the stagnation temperature $T_1$. This linear relationship is maintained so long as the fluid flowing through the nozzle remains sonic at the throat, which eliminates any dependence of flow rate upon the pressure in the downstream or intermediate

chamber 62 (see Figure 2). Further, proper design of such a sonic nozzle will allow the velocity in the throat to reach sonic velocity or "choke" at reasonably small pressure ratios of about 1.05 or 1.1. That is, the pressure of the fluid in the supply plenum 56 need only be about 5 to 10 percent higher than the pressure in the intermediate or downstream chamber 62 to achieve and maintain sonic velocity in the throat section 446.

If the pressure ratio between the stagnation pressure $p_1$ in supply plenum 56 and the stagnation pressure $p_2$ in the intermediate (i.e. discharge) chamber 62, is not sufficient to sustain sonic velocity through the throat of the nozzle, then the flow rate through the nozzle is dependent on the upstream stagnation temperature and pressure ($T_1$ and $p_1$) as well as the downstream stagnation pressure $p_2$, and the equation listed above becomes a function of the downstream stagnation pressure, thus:

$$\dot{m}=C_d\frac{kAp_1}{\sqrt{T_1}}f(\frac{p_1-p_2}{p_1}) \qquad (2)$$

where m is the mass flow rate of the fluid passing through the nozzle; $C_d$ is the nozzle discharge coefficient for the particular nozzle being used; k is a constant depending on the ratio of specific heats and the gas constant of the fluid; $p_1$ is the stagnation pressure of the fluid in the supply plenum 56; A is the nozzle throat area; $T_1$ is the absolute temperature of the fluid in the supply plenum 56; and $p_2$ is the stagnation discharge pressure.

Referring back to Figures 2, 3, and 4, simultaneously, the flow of natural gas through the sonic nozzle 52 is controlled by a "digital" valve assembly 64 for the first dispensing hose 28 as shown in Figure 1. The valve assembly 64 is referred to as a digital valve because it has only two positions: on and off. There are no intermediate positions typically associated with analog-type valves. As mentioned above, there is an identical sonic nozzle 54 and digital valve assembly 65 for the second channel, i.e., hose 30, as shown in Figure 1.

The digital valve assembly 64 for the first channel is oriented at right angles to the sonic nozzle 52 so that an intermediate or downstream chamber 62 is defined in the area between the downstream section of the nozzle and the valve body assembly 64. A vertical condensate leg 82 extends downward from the intermediate or downstream chamber 62 to collect any condensate from the CNG as it flows through sonic nozzle 52. A suitable plug 84 or, optionally, a valve assembly (not shown), can be attached to the bottom of the condensate leg 82 to allow the leg 82 to be drained at periodic intervals. The provision of a suitable valve assembly (not shown) would be obvious to persons having ordinary skill in this art and therefore, is not shown or described in further detail.

The digital valve assembly 64 comprises a pneumatically operated valve actuator assembly 69 that is secured to the supply plenum and valve body assembly 40 via a plurality of bolts 70. The pneumatically operated valve actuator assembly 69 includes a piston 68 disposed within a cylinder 66 and suitable pneumatic ports 120 and 122. Air pressure applied to one side of the piston 68 via one such port 120 or 122 while the other side is vented by the other port allows the piston 68 to move in the preferred direction, as is well-known. Therefore, valve actuator assembly 69 controls the position of the pressure balanced piston 76 within sleeve 72 via piston rod 78 to selectively turn on or shut off the flow of natural gas from the intermediate chamber 62 through the outlet port 88. Note that pressure balanced piston 76 includes a plurality of passageways 80 to equalize the pressure on both sides of the piston 76. This pressure equalization is necessary because the natural gas in the intermediate chamber 62 is under relatively high pressure of about 4,000 psig, whereas the compressed air used to actuate the valve actuator assembly 69 is in the range of about 100 psig. If the pressure were not equalized on both sides of piston 76, the high pressure of the natural gas acting on the surface of piston 76 would force the piston and piston rod assembly 78 upward, and the relatively low pneumatic pressure acting on the actuator piston 68 would be unable to move the piston 68 back downward against the high pressure of the natural gas. As a result, the valve assembly comprising piston 76 and sleeve 72 could never be closed. Note also that sleeve 72 has a recessed area 73 extending circumferentially around the sleeve 72 in the area of outlet port 88 to allow natural gas flowing through several radial vent ports 74 in the sleeve 72 to exit through outlet port 88. The pneumatic reservoir 86 contained within the supply plenum and valve body assembly 40 provides a reserve of pneumatic pressure in the event of failure of the pneumatic supply pressure to the valve actuator 69, as will be described in detail below.

The supply plenum and valve body assembly 40 also houses the various pressure and temperature transducers required by the natural gas dispensing system 10 of the present invention. Essentially, the supply plenum 56 is fluidically coupled to a supply stagnation pressure transducer 96 via supply stagnation pressure port 60 (see Figures 2 and 4), which senses the supply stagnation pressure $p_1$. Similarly, a temperature probe 58 from a stagnation temperature transducer 118 extends into the natural gas supply plenum 56 to measure the stagnation temperature $T_1$ of the CNG. The stagnation pressure $p_2$ of the CNG in the intermediate chamber 62 is measured by pressure transducer 92 via port 132 (Figure 4). Finally, a vent pipe 98 and pressure relief valve assembly 99 fluidically coupled to the outlet port 88 via passageway 134 vents natural gas contained within the dispensing hose 28 in the

event the pressure in the hose 28 exceeds a predetermined pressure. In the preferred embodiment, the pressure relief valve assembly 99 is set to about 3600 psig. Note also that a second vent pipe 100 and corresponding pressure relief valve assembly 101 are connected to the intermediate chamber of the second channel.

The details of the pneumatic system used to control the operation of the valve assemblies 64, 65, as well as the flow of the natural gas through the system and through the hose assemblies 28 and 30 are best understood by referring to Figure 5. As was briefly described above, the natural gas control valve assemblies 64 and 65 are controlled by a conventional pneumatic system operating with instrument-quality pneumatic air under about 100 psig pressure supplied by a conventional compressor and regulator system (not shown). This pneumatic supply air enters the system through check valve 124 and passes through inlet 110 into pneumatic reservoir 86. See also Figure 3. A small amount of air is taken off this line 110 and passes through a check valve and purge regulator assembly 130 to maintain the penthouse 14 under a small positive pressure, as will be described below. The pressurized air next passes into storage reservoir 86 out through outlet 90 (Figure 2) and into the solenoid valve assembly 42, as seen in Figure 1. Essentially, solenoid valve assembly 42 comprises two conventional electrically operated solenoid valves 41, 43, one for each channel or hose and which solenoid valves are controlled by the electronic control system, as will be described in detail below. Each solenoid valve 41, 43 in solenoid valve assembly 42 operates in a conventional manner. For example, a first solenoid valve 41 in valve assembly 42 is used to selectively reverse the flow to a valve body assembly 64 via inlet lines 120 and 122, therefore selectively opening or closing the digital valve assembly 64. An identical solenoid valve 43 in solenoid valve assembly 42 connected to valve assembly 65 operates the second "channel" i.e., hose 30 of the natural gas dispensing system 10.

As was briefly mentioned above, a purge regulator and check valve assembly 130 is used to supply air under very low pressure, i.e., about one to five inches of water, to the pressure-tight penthouse 14 to ensure that a positive pressure is maintained in the penthouse compartment 14 (which houses all the electronics used by the natural gas dispensing system 10) to eliminate any possibility of natural gas accumulation in the penthouse chamber, possibly leading to an explosion or fire hazard. Also in the preferred embodiment is a pressure relief valve 131, to vent excess pressure from the penthouse in the event of a malfunction of the regulator and check valve assembly 130.

In operation, the supply of CNG connected to the supply plenum and valve assembly 40 enters the supply plenum 56 via input line 114 and inlet filter 116, and the stagnation

pressure $p_1$ and the stagnation temperature $T_1$ are sensed by pressure transducer 96 and temperature transducer 118. See also Figure 4. During the idle loop process 212, described below, the system may be programmed to eliminate the accumulated drift between the supply stagnation pressure transducer 96 and pressure transducer 92. Essentially, the accumulated drift may be eliminated by moving the three way valve 44 to the "vent" position and opening valve 64 to equalize the pressure between pressure transducers 96 and 92. The electronic control system then re-calibrates transducer 92 to eliminate any systematic errors that would otherwise occur.

After the vehicle tank is coupled to the dispenser, the three-way valve 44 located at the end of the hose assembly 28 is moved to the "fill" position and the electronic control system then actuates solenoid valve 41, which opens valve 64, to dispense a small amount of CNG into the vehicle tank to open the check valve in the vehicle and to ensure that the pressure in the hose 28 is equal to the pressure in the vehicle tank. This initial vehicle tank pressure $p_{v0}$ is sensed by pressure transducer 92 and stored for later use. The control system next opens the valve 64 and dispenses an initial known mass ($m_1$) of CNG into the vehicle tank and determines the intermediate pressure $p_{v1}$ of the vehicle tank after valve 64 is again closed. The change in pressure i.e., $p_{v1} - p_{v0}$, is then used to determine the volume of the vehicle tank V, according to the well-known state equation: $pV = (m/M)RT$, or, when solved for tank volume V:

$$V = \frac{m_1 Z_1 R T_{amb}}{M\left(p_{v1} - p_{v0}\frac{Z_1}{Z_0}\frac{T_1}{T_0}\right)} \qquad (3)$$

where:

$m_1$ = the initial known mass of the gas;

$Z_i$ = the gas compressibility factor at a point i;

R = the universal gas constant;

$T_{amb}$ = the ambient temperature;

M = the molecular weight of the gas;

$p_{vi}$ = the pressure at a point i; and

$T_i$ = gas temperature at a point i.

After the volume of the vehicle storage tank is determined, the control system then calculates the additional mass required ($m_2$) to fill the tank to the previously calculated cutoff pressure

$p_{v\,cutoff}$ using the state equation solved for mass, thus:

$$m_2 = \frac{VM}{RT_{amb}}\left(\frac{p_{vcutoff}}{Z_{cutoff}} - \frac{p_{v1}}{Z_1}\right) \qquad (4)$$

The system then again opens valve 64 until an amount $m_2$ has been dispensed into the vehicle tank, which will fill the tank to the cut-off pressure. After this filling process is complete, the operator then moves the three-way valve 44 to the "vent" position to allow the natural gas contained in the section between the coupler 48 on the end of hose assembly 28 and the coupler attached to the vehicle tank to be evacuated from the system through check valve 126 and into the vent recovery system (not shown), where it is re-compressed and pumped back into the CNG supply tank. If this pressurized natural gas is not evacuated from the section between coupler 48 and the vehicle coupler, it would be impossible for the user to disconnect the hose 28 from his vehicle, because the extremely high pressure in the hose would prevent the couplers from disconnecting, which is a characteristic of the type of couplers used in this industry.

The electronic control system used to control the operation of the solenoid valve assembly 42, monitor and determine the pressures and temperature measured by the various transducers as described above, as well as to perform the necessary computations, is shown in Figure 6. Essentially, the output signals from the various pressure transducers 92, 94, and 96, ambient pressure transducer 91 (Fig. 1) and stagnation temperature transducer 118 are received by analog multiplexer 136, which multiplexes the signals and sends them to an analog to digital (A/D) converter 138. The analog to digital converter 138 converts the analog signals from the various transducers into digital signals suitable for use by the micro-controller or microprocessor 140. In the preferred embodiment, microprocessor 140 is a MC68HC11 manufactured by the Motorola Corporation, although other microprocessors could be used with equal effectiveness. Random access memory (RAM) 142 and read only memory (ROM) 144 are also connected to the microprocessor 140 to allow the microprocessor 140 to execute the desired routines at the desired times, as is well-known.

Microprocessor 140 also has inputs for receiving signals from the transaction switches 32 and 34 (see also Figure 1) for each respective dispensing hose assembly 28, 30. Optionally, a number of authorization switches, such as switches 31, 33, 35, and 37 could be connected in series with switches 32 and 34 to provide additional authorization devices, such as a credit card readers, which must be activated before natural gas will be dispensed,

or to provide an emergency shut-off feature by means of a switch (such as 31, 33, 35, or 37) remotely located in the station building.

A series of communication ports 146, 148, 150, and 152 are also connected to microprocessor to 140 for the purposes of transmitting and receiving data, which data may comprise new program information to modify the operation of the dispensing system 10 or may comprise specific authorization and coding data that could be fed to a master control computer remotely located from the dispensing system 10. Since the details associated with such communication ports 146, 148, 150, and 152 are well-known to persons having ordinary skill in the art, and since such persons could easily provide such communications ports depending on the desired configuration and after becoming familiar with the details of this invention, these communications ports 146, 148, 150, and 152 will not be described in further detail. Similarly, two relay outputs 164, 166 are used to send pulse data to optionally connected card readers (also not shown), as is also well-known.

A relay output latch 154 is also connected to the microprocessor 140 and multiplexes signals to relay outputs 156 and 158 which control the solenoid valves 41 and 43 for hose assemblies 28 and 30, respectively. Two spare relays 160 and 162 are also connected to relay output latch 154 and may be used to control other various functions not shown and described herein. Finally, in the preferred embodiment eight (8) rotary switches 145 are also connected to microprocessor 140 to allow the user to configure the microprocessor 140 to his particular requirements. Again, since such configuration-selectable features may vary depending on the particular use desired and microprocessor, and since it is well-known to provide for such user selectable features, the details of the rotary switches 145 will not be described in further detail.

The details processes executed by the microprocessor 140 during operation of the dispensing system 10 are best seen by referring to the flow diagrams shown in Figures 8, 9, 10(a), 10(b), and 11. However, processes executed by the microprocessor 140 will be understood more easily by first describing the overall theory and operation of the mass-based filling process used by the present invention.

As best seen in Figure 7, the stagnation pressure in the vehicle tank is linearly related to the mass of gas in the tank (neglecting compressibility and at constant temperature). As discussed above, many factors, such as frictional effects or sonic choke points, may make it difficult, if not impossible, to use a remotely located sensor upstream of the dispensing hose to accurately measure the pressure of the vehicle tank while it is being filled. To solve these problems the present invention first determines the volume V of the vehicle tank and then

calculates the additional mass of CNG that is required to increase the pressure of the tank to the previously calculated cut-off pressure $p_{v\ cutoff}$. The system then simply dispenses the additional mass of CNG into the vehicle tank, thus insuring that the tank is always filled to the cut-off pressure regardless of the pressure drop in the dispensing hose and regardless of whether a sonic choke point exists in the dispensing hose or coupler assembly between the vehicle tank and the pressure transducer 92.

Briefly, the fill method of the present invention first quickly cycles valve 64 to pop open the safety check valve and equalize the pressure in the dispensing hose and vehicle tank. After valve 64 has closed, the initial vehicle tank pressure $p_{v0}$ can be accurately sensed by transducer 92, since there is no CNG flow through the dispensing hose. The initial tank pressure $p_{v0}$ corresponds to an initial mass $m_0$ of CNG already in the tank, as seen in Figure 7. The system then adds an initial known mass ($m_1$) of gas to the tank, thus increasing the tank pressure to an initial pressure of $p_{v1}$. Equation (3) above can now be used to determine the volume of the vehicle tank V. Once the tank volume has been determined, Equation (4) is used to determine the additional mass ($m_2$) required to increase the pressure in the tank to the previously calculated cut-off pressure $p_{v\ cutoff}$.

Unfortunately, there will always be a certain amount of uncertainty in the measured values of $p_{v0}$ and $p_{v1}$, as represented by the error boxes 183 and 185 (Figure 7), which will result in an error 187 in achieving the desired cut-off pressure $p_{v\ cutoff}$ by the addition of mass $m_2$ of CNG. Therefore, the present invention also includes suitable safeguards to ensure that the pressure error will never exceed $p_{v\ max}$ or fall below $p_{v\ min}$. More specifically, while the size of the error band 187 can be reduced by using precision pressure transducers to determine the pressure, even the best transducers will have some uncertainty. Therefore, the method of the present invention limits the maximum extrapolation permitted in calculating the additional mass ($m_2$) required to reach the cut-off pressure. If the pressure of the vehicle storage tank is less than 1/4 of the final pressure, i.e., if $p_{v1} / p_{v\ cutoff} \geq 0.25$, then the method of the present invention will reduce the calculated value of the additional mass $m_2$ to 75% of its original value to avoid overshooting the cut-off pressure. Then, after the reduced mass $m_2$ is added, the valve 64 is closed and a new tank pressure is determined. The new tank pressure is then used to recompute the additional mass required to fill the tank to the cut-off pressure.

Referring now to Figure 8, the steps performed by the microprocessor 140 are as follows. When power is initially applied to the natural gas dispensing system 10, the microprocessor 140 executes an initialization procedure 210, which serves to clear all fault

flags, blank out and turn on the displays, and perform various diagnostic tests on the microprocessor 140, the random access memory 142, and the read only memory 144. Since such initialization and diagnostic test procedures 210 are well-known in the art and are usually dependent on the particular hardware configuration being used, the precise details of these initialization and diagnostic procedures will not be explained in further detail.

After the initialization procedure 210 has been completed, the program flow continues to the idle loop and wait for start command process 212. Essentially, this process 212 places the dispensing system 10 in idle state, whereby the microprocessor 140 awaits input from one of the transaction switches 32 or 34 to signal that the operator wishes to begin dispensing natural gas. If the microprocessor 140 receives a signal from one of the transaction switches 32 or 34, the microprocessor 140 will proceed to the start sequence procedure 214. In this start sequence procedure 214, the microprocessor 140 executes a number of predetermined steps to measure and calibrate the pressures and temperatures received from the various pressure and temperature transducers connected to the supply plenum and valve assembly 140. The start sequence procedure 214 also calculates the vehicle tank cut-off pressure, $p_{v\ cutoff}$, based on the ambient temperature $T_{amb}$, and data stored in the ROM relating to the rated pressure of the vehicle tank, as will be described below. After the start sequence procedure 214 is complete, the microprocessor proceeds to the fill sequence process 216. The fill sequence 216 performs all of the necessary steps to completely fill the natural gas storage tank in the vehicle including the steps of initially cycling the valve to pressurize the dispensing hose, measuring the initial tank pressure, calculating the volume of the tank and the mass of CNG required to fill the tank to the cut-off pressure, and, of course, automatically shutting off the flow of natural gas when the vehicle tank has been filled to the previously calculated cut-off pressure. After the fill process is complete, the microprocessor will next execute the end sequence process 218 to complete the transaction process and return the system 10 to the idle state 212.

The details of the start sequence 214 are best seen in Figure 9. The process begins by executing 220 to clear all channel-specific fault flags and wait for an authorization code from a host computer system, if one is provided. The process next proceeds to 222 which begins by clearing any transaction totals from a previous filling operation and turns on the display segments to indicate to the user that the electronic control system is active and proceeding with the filling process. Also during the step 222, the computer measures and stores values for $p_1$ and $p_2$ as sensed by transducer 96 and transducer 92, respectively. Since the valve 64 is not yet open, the pressures sensed by transducers 92 and 96 are identical, as

mentioned above. The ambient temperature $T_{amb}$ sensed by transducer 91 is also measured and stored at this time. Step 222 next calculates a cut-off pressure limit $p_{v\ cutoff}$ as a function of the previously measured $T_{amb}$ and the predetermined tank pressure limit that was previously programmed into the microprocessor 140. Finally, the process 222 resets a state timer to zero seconds. Next, the microprocessor 140 executes processes 224, 226 and 228. Essentially, these processes measure and store the values detected for $p_1$ and $p_2$ three (3) additional times, with at least a one second interval between measuring periods to insure that the pressures have stabilized and to compensate for the fact that the A/D converter 138 cannot convert the signals from the pressure transducers on a real time basis. Of course, if a real time A/D converter were used, then it would not be necessary to wait one second between readings. In step 228, the pressure transducer 92 ($p_2$) is calibrated by summing the earlier measurements for $p_1$ and subtracting the sum of the measurements from $p_2$ and dividing by 4. This value is then stored by the microprocessor 140, which adds it to all subsequent pressure readings from transducer 92 to eliminate systematic errors. Finally, this process 228 sets a fault flag if the calibrated value for $p_2$ (i.e., transducer 92) exceeds a predetermined limit, indicating a fault in the system or a defective transducer.

Start sequence step 214 next executes process 230 which re-checks the position of the transaction switch. If the transaction switch has been opened, the process will go back to the idle loop step 212. If the transaction switch is still closed, the microprocessor 140 will open the natural gas valve and set the transaction time to equal to the open valve response time. The reason that the transaction time is set to the open valve response time (in the preferred embodiment the open valve response time is about .1 second) is because in the preferred embodiment it takes about .1 second before sonic flow is established in the sonic nozzle 52. Note that this open valve response time is dependent on the particular nozzle and valve configuration employed and is determined for a particular set-up on an experimental basis, and the amount of natural gas that flows through the nozzle during this time will be added to the total amount of CNG dispensed. Finally, the start sequence process 214 executes step 232 which updates the transaction time and determines whether the transaction time is greater than the predetermined stabilization time. In the preferred embodiment, the stabilization time is approximately 1 second and is used because the analog to digital converter 138 connected to the microprocessor 140 does not operate on a real time basis, i.e., the A/D converter 138 is relatively slow and is only capable of updating the data received from the various transducers about every 0.3 to 0.4 seconds. Therefore, the microprocessor 140 will wait until

the transaction time has exceeded the stabilization time before proceeding with the fill sequence process 216.

Referring now to Figures 10(a) and 10(b), fill sequence 216 begins with step 240 which briefly cycles the valve 64 to dispense a small amount of CNG into the vehicle tank and briefly pop open any check valves in the vehicle, thus equalizing the pressure in the dispensing hose with the pressure in the vehicle tank. Step 240 also determines the initial tank pressure $p_{v0}$ and estimates an initial fill mass $m_1$ based on the difference between the initial tank pressure $p_{v0}$ and the previously calculated cut-off pressure $p_{v\,cutoff}$ to ensure that the cut-off pressure will not be exceeded by adding the initial mass $m_1$.

Fill sequence 216 next executes step 241, which controls the exact process by which the vehicle tank is filled. For example, before the dispensing process is initiated, the user can input a total dollar amount of natural gas to be dispensed into his vehicle tank. Alternatively, the user can instruct the system to completely fill the vehicle tank. In any event, process 241 forms one step in a loop that continuously determines whether the total dollar amount equals the preprogrammed fill limit or whether the tank is to be filled to the previously calibrated cut-off pressure $p_{v\,cutoff}$ calculated in step 222 (see Figure 9). Finally, step 241 also continually checks to insure that the transaction switch is still closed and that the computer has not received any emergency shutdown commands from an outside host computer or a fault code generated within the microprocessor 140 itself. If none of these events occur, the process proceeds to step 242 which first updates the cycle time and then calculates the flow rate and total mass of CNG dispensed. Optionally, data output pulses may be sent to a card reader (not shown) and, in any event, the display will continually be updated with the total mass of CNG dispensed (or equivalent) and the total cost. Also during this process 242, the system continually monitors the time variation of the discharge pressure $dp_2/dt$. If $dp_2/dt$ exceeds a certain predetermined limit, indicating a sudden loss of outlet pressure, such as would result from a ruptured dispensing hose, the computer will automatically set a fault code and immediately turn off the flow of CNG. Finally, this process 242 continually checks the ratio of the discharge pressure $p_2$ against the supply pressure $p_1$. If this ratio exceeds the preprogrammed limit (0.82 in the preferred embodiment), the computer will also set a flag. The reason a flag is set in this case is that if the ratio of $p_2$ to $p_1$ exceeds a certain limit, sonic flow will no longer be maintained and the sonic nozzle 52 and the mass flow calculations will no longer be correct. In that case, the microprocessor will automatically calculate the mass flow rate for subsonic nozzle conditions, as explained above. Process 242 is repeated until one of the conditions in step 243 is

satisfied, in which case the process proceeds to step 244 which closes the valve, measures the initial pressure $p_{v1}$ and $T_{amb}$, calculates the actual amount of initial mass ($m_1$) dispensed, as well as the tank volume V and additional mass ($m_2$) required to fill the tank to the cut-off pressure, as determined by Equations (3) and (4), respectively.

Process 245 next determines whether the initial pressure $p_{v1}$ is within 100 psig of the previously determined cut-off pressure $p_{v\,cutoff}$. If so, the tank is full and the process executes the end sequence 218. If not, the process proceeds to step 246 which determines whether the tank is more than one quarter (1/4) full (on a pressure basis). If the tank is more than 1/4 full, the process proceeds to step 248. However, if the tank is less then 1/4 full, then $m_2$ is reduced to 75% of its original value before proceeding to step 248. As mentioned above, this process 246 minimizes the chances for tank overfilling due to uncertainties in the measured values for the tank pressure. Step 248 is identical to step 242 and, therefore, will not be described again. Process 248 is repeated until one of the conditions in step 249 is satisfied, in which case the process proceeds to step 251 which closes the valve, measures the tank pressure $p_{v2}$, $T_{amb}$, and calculates the actual amount of additional mass ($m_2$) dispensed into the tank. Finally, step 253 checks to see whether the tank pressure is within 100 psig of the calculated cut-off pressure. If it is, the tank is full and the process executes the end sequence process 218. If not, the tank is still not filled, a new mass ($m_3$) is calculated based on the tank pressure $p_{v2}$ and the process 248 is repeated again.

The detailed steps of the end sequence process 218 are shown in Figure 11. This process 218 begins by executing step 250 which sets the total cycle or transaction time to equal the actual measured cycle time plus the valve close response time, which, in the preferred embodiment is about 0.25 seconds. Here again, the valve close response time is added to the total cycle time because the A-D converter 138 cannot convert data on a real time basis. Next, the total amount of compressed natural gas dispensed is calculated based on the total cycle time and in accordance with the preprogrammed relation for mass flow through the sonic nozzle, both when the flow was choked and when it was not choked (i.e., subsonic), plus the small amount of natural gas that flows through the nozzle during the valve opening and closing times. Output pulses are again sent to a card reader (not shown) and the total volume dispensed and the total cost are displayed on displays 140 and 136. Optionally, the discharge pressure $p_2$ can be displayed on display 138. Process 250 then updates the grand total of the volume of compressed natural gas dispensed from the system for accounting purposes and the mass and volume flows are zeroed by the computer. If any fault flag was detected, the computer will set the specific channel in which the fault flag was detected to a

fault state. The process 218 next executes step 252 which continually monitors the condition of the transaction switch. If the switch is closed, the process will remain at this step until the user opens the switch indicating that the fill process is complete. Process 252 then sets the inter-transaction timer to zero seconds. Finally, the process 218 executes step 254 which waits until the inter-transaction time-out period has elapsed. Once the time-out period has elapsed, the process will return to the idle loop 212 and the dispensing process can be initiated again by a new customer.

While the preferred embodiment of the natural gas dispensing system 10 according to the present invention utilizes the Fill Sequence 216 illustrated in Figures 10(a) and 10(b) and described above, other fill sequences could be substituted as alternates, depending on the particular configuration of the vehicle storage tank and the desired level of accuracy for measuring the amount of CNG dispensed into the vehicle tank. For example, if a check valve is not installed in the vehicle, or if it is known that the flow of CNG will not pass through a sonic choke point between the pressure sensor 92 and the vehicle tank, the Fill Sequence 216 illustrated in Figures 10(a) and 10(b) may be replaced with a simpler Fill Sequence 1216 illustrated in Figure 12. Replacing the Fill Sequence 216 with Alternative Fill Sequence 1216 would be accomplished by simply reprogramming the microprocessor 140 to perform the steps shown in Figure 12. Essentially, Alternative Fill Sequence 1216 monitors the vehicle tank pressure, essentially $p_2$, via pressure transducer 92 until the pressure $p_2$ reaches the previously determined cut-off pressure $p_{2\,cutoff}$. When the tank pressure $p_2$ reaches the cut-off pressure, the Alternative Fill Sequence 1216 is complete, and the system would then proceed to the End Sequence step 218 as shown in Figure 8 and described in detail above.

The details of the Alternative Fill Sequence process 1216 are shown in Figure 12 and the process begins by executing decision step 1240. In this particular embodiment, the dispensing system 10 can be programmed to fill the vehicle natural gas tank according to a number of different options. For example, before the Alternative Fill Sequence process 1216 is initiated, the user could input a total dollar amount of natural gas to be dispensed into his vehicle tank. Alternatively, the system could be programmed to completely fill the vehicle tank, without setting any particular dollar maximum. In any event, process 1240 forms a loop to continually check and determine whether the total dollar amount equals the preprogrammed fill limit or whether the tank pressure $p_2$ is greater than the cut-off pressure $p_{2\,cutoff}$ determined in step 222 (see Figure 9). Finally, step 1240 also continually checks to ensure that the transaction switch is still closed and that the microprocessor 140 has not received any emergency shutdown commands from an outside host computer or a fault code

generated within the microprocessor 140 itself. If none of these events occur, the process 1216 proceeds to step 1242 which first updates the cycle time and then calculates the flow rate and total volume dispensed. Data output pulses will be sent to a card reader (not shown) and the display will be continually updated with the total volume of CNG dispensed, the total cost, as well as the discharge pressure $p_2$ as measured by pressure transducer 92. Also during this process 1242, the system continually monitors the time variation of the discharge pressure $dp_2/dt$. If $dp_2/dt$ exceeds a certain predetermined limit, indicating a sudden loss of outlet pressure, such as would result from a ruptured dispensing hose, the computer will automatically set a fault code and immediately turn off the flow of CNG. Finally, this process 1242 continually checks the ratio of the discharge $p_2$ against the supply pressure $p_1$. If that ratio exceeds the preprogrammed limit, the computer will also set a flag. The reason a flag is set in that case is that if the ratio of $p_2$ to $p_1$ exceeds a certain limit, sonic flow will no longer be present in the sonic nozzle 52, and the mass flow calculations will no longer be correct. In that case, the microprocessor 140 will automatically calculate the mass flow rate for subsonic nozzle conditions, as was described in detail above. Finally, as shown in Figure 12, the process 1216 is repeated until one of the conditions in step 1240 is satisfied, in which case the process executes step 1244, which closes the valve, updates the cycle time, and directs the program flow to execute the End Sequence process 218 shown in Figure 8 and described above.

This completes the detailed description of the preferred embodiments of the natural gas dispensing system 10 according to the present invention. While some of the obvious and numerous modifications and equivalents have been described herein, still other modifications and changes will readily occur to those having ordinary skill in the art. For example, none of the sealing devices required by this invention have been shown and described herein, as it is well-known to provide various types of seals, such as "O" ring type seals, to prevent the CNG from leaking, and persons having ordinary skill in this art could readily provide such seals after becoming familiar with the details of the present invention.

Further, while this invention has been shown and described to dispense compressed natural gas, other fluids could be used just as easily with a system according to the present invention with little or no modification. For instance, the dispensing system shown and described herein could also be used to dispense hydrogen or propane gas. Moreover, more than two sonic nozzles could be connected to the supply plenum to provide an increased number of dispensing hoses from a single dispenser body or plenum. Finally, numerous enhancements of the operating program are possible by reprogramming the microprocessor

to make the appropriate enhancements, as would be obvious to those persons having ordinary skill in the art.

The foregoing is considered as illustrative only of the principles of this invention. Further, since numerous modifications and changes will readily occur to those skilled in the art, it is not desired to limit the invention to the exact construction and operation shown and described, and accordingly, all suitable modifications and equivalents may be considered as falling within the scope of the invention as defined by the claims which follow.

Claims

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. Temperature compensated fluid dispensing apparatus for dispensing fluid from a fluid source to a fluid receiver at an ambient temperature, wherein the fluid in the fluid source has a stagnation temperature and wherein the fluid receiver has a receiver pressure rating at a predetermined pressure and temperature, comprising:

valve means interconnecting the fluid source and the fluid receiver for selectively closing off the interconnection between the source and the receiver; and

valve control means connected to said valve means for actuating said valve means to close off the interconnection between the fluid source and the fluid receiver when the fluid receiver has been filled to a pressure equivalent to the receiver pressure rating corrected for the ambient temperature.

2. The temperature compensated fluid dispensing apparatus of claim 1, wherein said valve control means includes:

means for sensing the ambient temperature and for generating an ambient temperature signal related thereto;

means for determining an initial stagnation pressure of the fluid in the fluid receiver and for generating an initial receiver stagnation pressure signal related thereto;

means for dispensing an initial mass of fluid into said fluid receiver;

means for determining an intermediate stagnation pressure of the fluid in the fluid receiver and for generating an intermediate receiver stagnation pressure signal related thereto;

calculation means responsive to said ambient temperature signal for determining a cut-off receiver stagnation pressure based on said ambient temperature and based on the receiver pressure rating, for determining a fluid receiver volume based on said initial receiver stagnation pressure and said intermediate receiver stagnation pressure, and for determining an additional mass of fluid to increase said receiver stagnation pressure to about the cut-off receiver stagnation pressure; and

valve actuation means connected to said valve means and to said calculation means for causing said valve means to close off the interconnection between the fluid

source and the fluid receiver when said additional mass has been dispensed into said fluid receiver.

3. The temperature compensated fluid dispensing apparatus of claim 2, further comprising a sonic nozzle connected between the fluid source and said valve means.

4. The temperature compensated fluid dispensing apparatus of claim 3, wherein both said means for determining an initial stagnation pressure and said means for determining an intermediate pressure comprise pressure sensing means for sensing the pressure of the fluid in said fluid receiver and for generating a pressure signal related thereto, and wherein said pressure sensing means is located between said sonic nozzle means and said valve means.

5. The temperature compensated fluid dispensing apparatus of claim 4, wherein said pressure sensing means is located between said valve means and the receiver.

6. The temperature compensated fluid dispensing apparatus of claim 3, including means for sensing the stagnation temperature of the fluid in the fluid source and for generating a source stagnation temperature signal related thereto, and wherein said means for sensing the stagnation pressure of the fluid in the fluid receiver is located between said sonic nozzle and said valve means.

7. The temperature compensated fluid dispensing apparatus of claim 6, further comprising flow rate calculation means responsive to said source stagnation temperature signal and to said source stagnation pressure signal for determining a mass flow rate of fluid flowing through said sonic nozzle when the fluid flow through said sonic nozzle is choked.

8. The temperature compensated fluid dispensing apparatus of claim 7, wherein said flow rate calculation means is also responsive to said receiver stagnation pressure signal for determining a subsonic mass flow rate of fluid flowing through said sonic nozzle when said receiver stagnation pressure is too high to allow the sonic nozzle to choke.

9. Temperature compensated fluid dispensing apparatus for independently dispensing fluid from a fluid source into first and second fluid receivers at an ambient temperature, wherein the fluid in the fluid source has a stagnation temperature and wherein each fluid receiver has a receiver pressure rating at a predetermined stagnation pressure and temperature, comprising:

a supply plenum connected to the fluid source;

first valve means interconnecting the fluid source and the first fluid receiver for selectively closing off the interconnection between the source and the first fluid receiver;

second valve means interconnecting the fluid source and the second fluid receiver for selectively closing off the interconnection between the source and the second fluid receiver; and

two channel valve control means connected to said first valve means and said second valve means for independently actuating said first and second valve means to close off the interconnection between the fluid source and the corresponding fluid receiver when the corresponding fluid receiver has been filled to a pressure equivalent to the receiver pressure rating corrected for the ambient temperature.

10. A fluid dispensing system for controlling an amount of fluid flowing from a fluid source to a fluid receiver, wherein the fluid in the fluid source has a stagnation temperature and wherein the fluid in the fluid receiver has a stagnation pressure, comprising:

valve means interconnecting the source and the receiver for selectively closing off the interconnection between the source and the receiver;

means for sensing the ambient temperature for generating an ambient temperature signal related thereto;

means responsive to said ambient temperature signal for determining a cut-off receiver stagnation pressure based on said ambient temperature and in accordance with predetermined receiver pressure parameters;

means for determining an additional mass of fluid to be added to said fluid receiver to increase the pressure in said receiver to about said cut-off receiver stagnation pressure; and

valve control means connected to said valve means and responsive to said means for determining an additional mass of fluid for actuating said valve means to close off the interconnection between the source and the receiver when said additional mass of fluid has been added to said fluid receiver.

11. A fluid metering and control system for measuring and controlling an amount of fluid flowing from a fluid source to a fluid receiver, wherein the fluid in the fluid source has a stagnation temperature and a stagnation pressure and wherein the fluid in the fluid receiver has a stagnation pressure, comprising:

a sonic nozzle interconnecting the source and the receiver;

valve means positioned between said sonic nozzle and the receiver for selectively closing off the interconnection between the source and the receiver;

means for sensing the ambient temperature and for generating an ambient temperature signal related thereto;

means for sensing the stagnation pressure of the fluid in the source and for generating a source stagnation pressure signal related thereto;

means for sensing the stagnation temperature of the fluid in the source and for generating a source stagnation temperature signal related thereto;

means responsive to said ambient pressure signal and responsive to said source stagnation temperature signal for determining a mass flow rate of fluid flowing through said sonic nozzle when the fluid flow through said sonic nozzle is choked;

means responsive to said ambient temperature signal for determining a cut-off receiver stagnation pressure based on said ambient temperature and in accordance with predetermined receiver pressure parameters;

means for determining an additional mass of fluid to be added to said fluid receiver to increase the pressure in said receiver to about said cut-off receiver stagnation pressure; and

valve control means connected to said valve means and responsive to said means for determining an additional mass of fluid to be added to said fluid receiver for actuating said valve means to close off the interconnection between the source and the receiver when said additional mass has been added to said fluid receiver.

12. The fluid metering and control system of claim 11, including means for sensing a downstream stagnation pressure downstream of said sonic nozzle and for generating a downstream stagnation pressure signal related thereto.

13. The fluid metering and control system of claim 12, wherein said means responsive to said source stagnation pressure signal and said source stagnation temperature signal is also responsive to said downstream stagnation pressure signal for determining a subsonic mass flow rate of fluid flowing through said sonic nozzle when said downstream stagnation pressure is too high to allow the sonic nozzle to become choked.

14. The fluid metering and control system of claim 13, including means for combining and integrating said mass flow rate flowing through said sonic nozzle when said sonic nozzle is choked with the subsonic mass flow rate of fluid flowing through said sonic nozzle when said sonic nozzle is not choked during the period when said valve means is not closed to produce a total mass of fluid that passed through said sonic nozzle into the receiver.

15. A method of dispensing compressed gas from a pressurized storage tank to a receiver under less pressure than the storage tank, comprising the steps of:

connecting said storage tank and said receiver with a pressure tight dispensing hose;

sensing an ambient temperature before initiating the dispensing cycle;

calculating a cut-off pressure for the receiver based on the ambient temperature tank and based on a predetermined rated pressure for the receiver;

sensing an initial pressure of said receiver;

adding a predetermined mass of gas to the receiver;

sensing an intermediate pressure of said receiver;

determining a volume of the receiver and an additional mass of fluid to increase said receiver stagnation pressure to about the cut-off pressure;

initiating the flow of gas through said dispensing hose from said supply tank to said receiver; and

terminating the flow of gas when the additional mass has been added to said receiver.

16. The method of claim 15, including the step of:

sensing the stagnation pressure and stagnation temperature of the gas within the storage tank and;

calculating the amount of gas dispensed from said storage tank into said receiver based on the stagnation temperature and pressure of the gas in the storage tank and flowing through a sonic nozzle.

17. The method of claim 15, wherein the step of determining a volume of the receiver and an additional mass of fluid includes the step of reducing the additional mass of the fluid by a predetermined amount if said receiver is less than about 1/4 full of gas on a pressure basis.

18. The temperature compensated fluid dispensing apparatus of claim 1, wherein said valve control means includes:

means for sensing the ambient temperature and for generating an ambient temperature signal related thereto;

means for determining a stagnation pressure of the fluid in the fluid receiver and for generating a receiver stagnation pressure signal related thereto;

calculation means responsive to said ambient temperature signal for determining a cut-off receiver stagnation pressure based on said ambient temperature and based on the receiver pressure rating; and

valve actuation means connected to said valve means and to said calculation means and responsive to said receiver stagnation pressure signal for causing said valve means to close off the interconnection between the fluid source and the fluid

receiver when said receiver stagnation pressure is about at said cut-off receiver stagnation pressure.

19. The temperature compensated fluid dispensing apparatus of claim 18, further comprising a sonic nozzle connected between the fluid source and said valve means.

20. The temperature compensated fluid dispensing apparatus of claim 19, wherein said means for determining a stagnation pressure includes:

pressure sensing means for sensing the pressure of the fluid and for generating a pressure signal related thereto, and wherein said pressure sensing means is located between said sonic nozzle means and said valve means; and

pressure drop correcting means responsive to said pressure signal for correcting the pressure of the fluid to account for frictional effects, so that the pressure of the fluid is substantially equal to the stagnation pressure of the fluid in the fluid receiver.

21. The temperature compensated fluid dispensing apparatus of claim 20, wherein said pressure sensing means is located between said valve means and the receiver.

22. The temperature compensated fluid dispensing apparatus of claim 19, including means for sensing the stagnation temperature of the fluid in the fluid source and for generating a source stagnation temperature signal related thereto, and wherein said means for sensing the stagnation pressure of the fluid in the fluid receiver is located between said sonic nozzle and said valve means.

23. The temperature compensated fluid dispensing apparatus of claim 22, further comprising flow rate calculation means responsive to said source stagnation temperature signal and to said source stagnation pressure signal for determining a mass flow rate of fluid flowing through said sonic nozzle when the fluid flow through said sonic nozzle is choked.

24. The temperature compensated fluid dispensing apparatus of claim 23, wherein said flow rate calculation means is also responsive to said receiver stagnation pressure signal for determining a subsonic mass flow rate of fluid flowing through said sonic nozzle when said receiver stagnation pressure is too high to allow the sonic nozzle to choke.

25. Temperature compensated fluid dispensing apparatus for independently dispensing fluid from a fluid source into first and second fluid receivers at an ambient temperature, wherein the fluid in the fluid source has a stagnation temperature and wherein each fluid receiver has a receiver pressure rating at a predetermined stagnation pressure and temperature, comprising:

a supply plenum connected to the fluid source;

first valve means interconnecting the fluid source and the first fluid receiver for selectively closing off the interconnection between the source and the first fluid receiver;

second valve means interconnecting the fluid source and the second fluid receiver for selectively closing off the interconnection between the source and the second fluid receiver; and

two channel valve control means connected to said first valve means and said second valve means for independently actuating said first and second valve means to close off the interconnection between the fluid source and the corresponding fluid receiver when the corresponding fluid receiver has been filled to a pressure equivalent to the receiver pressure rating corrected for the ambient temperature.

26. A fluid dispensing system for controlling an amount of fluid flowing from a fluid source to a fluid receiver, wherein the fluid in the fluid source has a stagnation temperature and wherein the fluid in the fluid receiver has a stagnation pressure, comprising:

valve means interconnecting the source and the receiver for selectively closing off the interconnection between the source and the receiver;

means for sensing the ambient temperature for generating an ambient temperature signal related thereto;

means for determining the stagnation pressure of the fluid in the receiver and for generating a receiver stagnation pressure signal related thereto;

means responsive to said ambient temperature signal for determining a cut-off receiver stagnation pressure based on said ambient temperature and in accordance with predetermined receiver pressure parameters; and

valve control means connected to said valve means and responsive to said receiver stagnation pressure signal for actuating said valve means to close off the interconnection between the source and the receiver when said receiver stagnation pressure equals said cut-off receiver stagnation pressure.

27. A fluid metering and control system for measuring and controlling an amount of fluid flowing from a fluid source to a fluid receiver, wherein the fluid in the fluid source has a stagnation temperature and a stagnation pressure and wherein the fluid in the fluid receiver has a stagnation pressure, comprising:

a sonic nozzle interconnecting the source and the receiver;

valve means positioned between said sonic nozzle and the receiver for selectively closing off the interconnection between the source and the receiver;

means for sensing the ambient temperature and for generating an ambient temperature signal related thereto;

means for sensing the stagnation pressure of the fluid in the source and for generating a source stagnation pressure signal related thereto;

means for sensing the stagnation temperature of the fluid in the source and for generating a source stagnation temperature signal related thereto;

means responsive to said ambient pressure signal and responsive to said source stagnation temperature signal for determining a mass flow rate of fluid flowing through said sonic nozzle when the fluid flow through said sonic nozzle is choked;

means for determining the stagnation pressure of the fluid in the receiver and for generating a receiver stagnation pressure signal related thereto;

means responsive to said ambient temperature signal for determining a cut-off receiver stagnation pressure based on said ambient temperature and in accordance with predetermined receiver pressure parameters; and

valve control means connected to said valve means and responsive to said receiver stagnation pressure signal for actuating said valve means to close off the interconnection between the source and the receiver when said receiver stagnation pressure equals said cut-off receiver stagnation pressure.

28. The fluid metering and control system of claim 27, wherein said means responsive to said source stagnation pressure signal and said source stagnation temperature signal is also responsive to said receiver stagnation pressure signal for determining a subsonic mass flow rate of fluid flowing through said sonic nozzle when said receiver stagnation pressure is too high to allow the sonic nozzle to become choked.

29. The fluid metering and control system of claim 28, including means for combining and integrating said mass flow rate flowing through said sonic nozzle when said sonic nozzle is choked with the subsonic mass flow rate of fluid flowing through said sonic nozzle when said sonic nozzle is not choked during the period when said valve means is not closed to produce a total mass of fluid that passed through said sonic nozzle into the receiver.

30. A method of dispensing compressed gas from a pressurized storage tank to a receiver under less pressure than the storage tank, comprising the steps of:

connecting said storage tank and said receiver with a pressure tight dispensing hose;

sensing the ambient temperature before initiating the dispensing cycle;

calculating a cut-off pressure for the receiver based on the ambient temperature tank and based on a predetermined rated pressure for the receiver;

initiating the flow of gas through said dispensing hose from said supply tank to said receiver;

determining the stagnation pressure of said receiver; and

terminating the flow of gas when the stagnation pressure of said receiver substantially equals said cut-off pressure.

31. The method of claim 30, including the step of:

sensing the stagnation pressure and stagnation temperature of the gas within the storage tank and;

calculating the amount of gas dispensed from said storage tank into said receiver based on the stagnation temperature and pressure of the gas in the storage tank and flowing through a sonic nozzle.

32. The method of claim 31, including the step of calibrating a pressure transducer used to sense the receiver pressure against a pressure transducer used to sense the storage tank pressure before the gas flow is initiated.

33. The method of claim 30, wherein the step of determining the stagnation pressure of said receiver includes the steps of:

sensing an intermediate pressure of the gas in said dispensing hose; and

correcting the intermediate pressure of the gas in said dispensing hose for a pressure drop in said dispensing hose, to determine the stagnation pressure of said receiver.

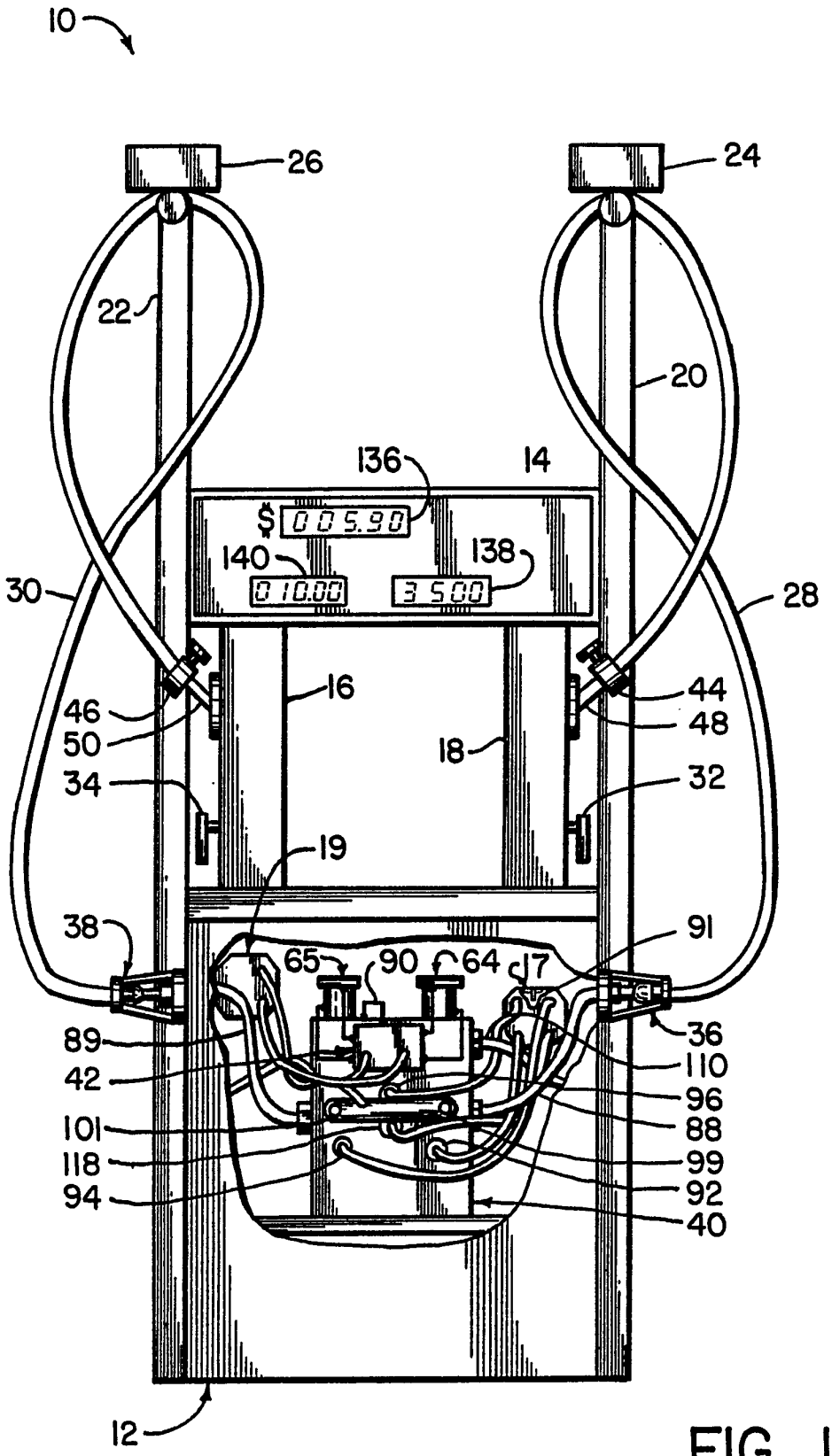

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FIG. 1

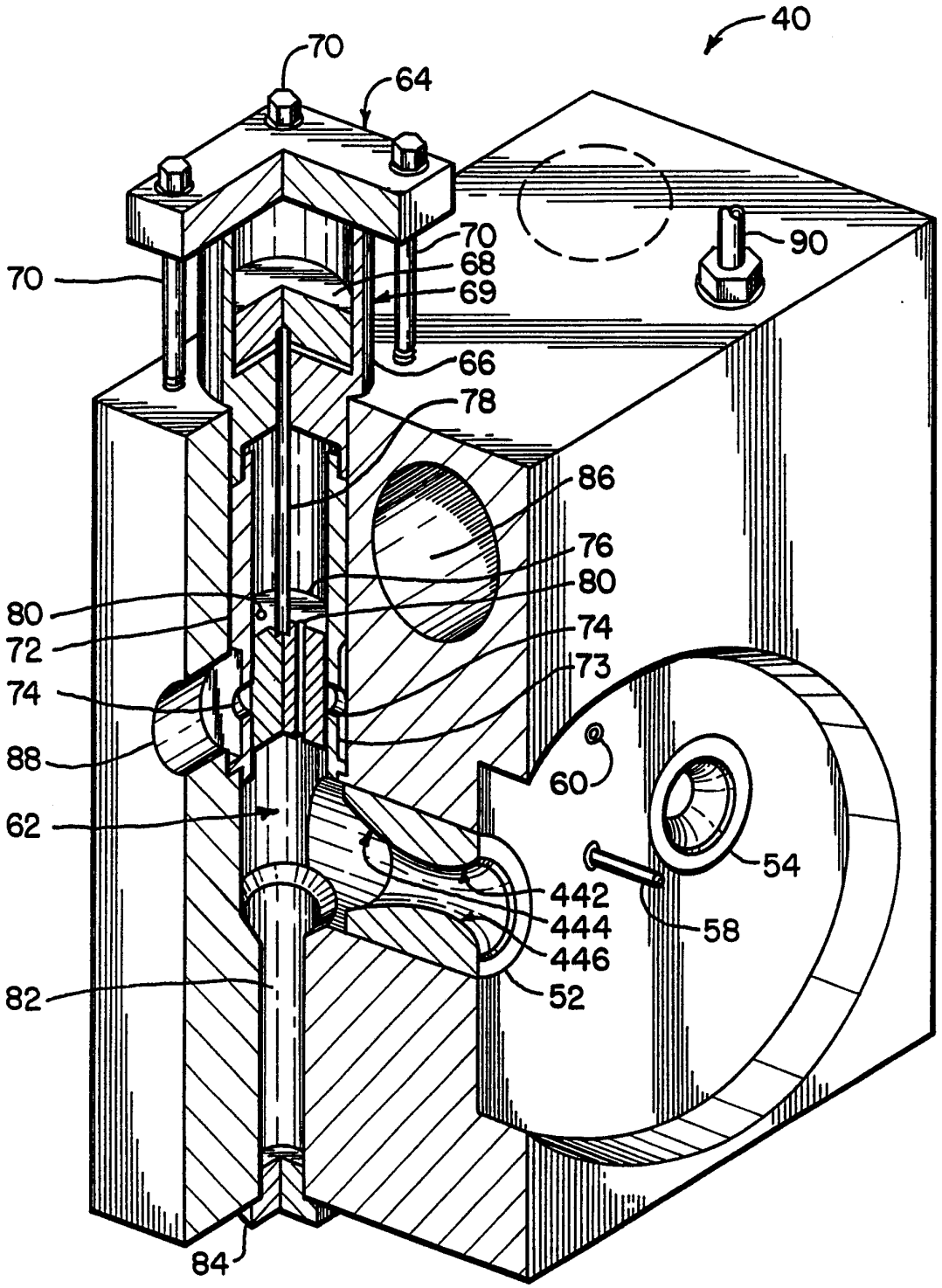

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FIG. 2

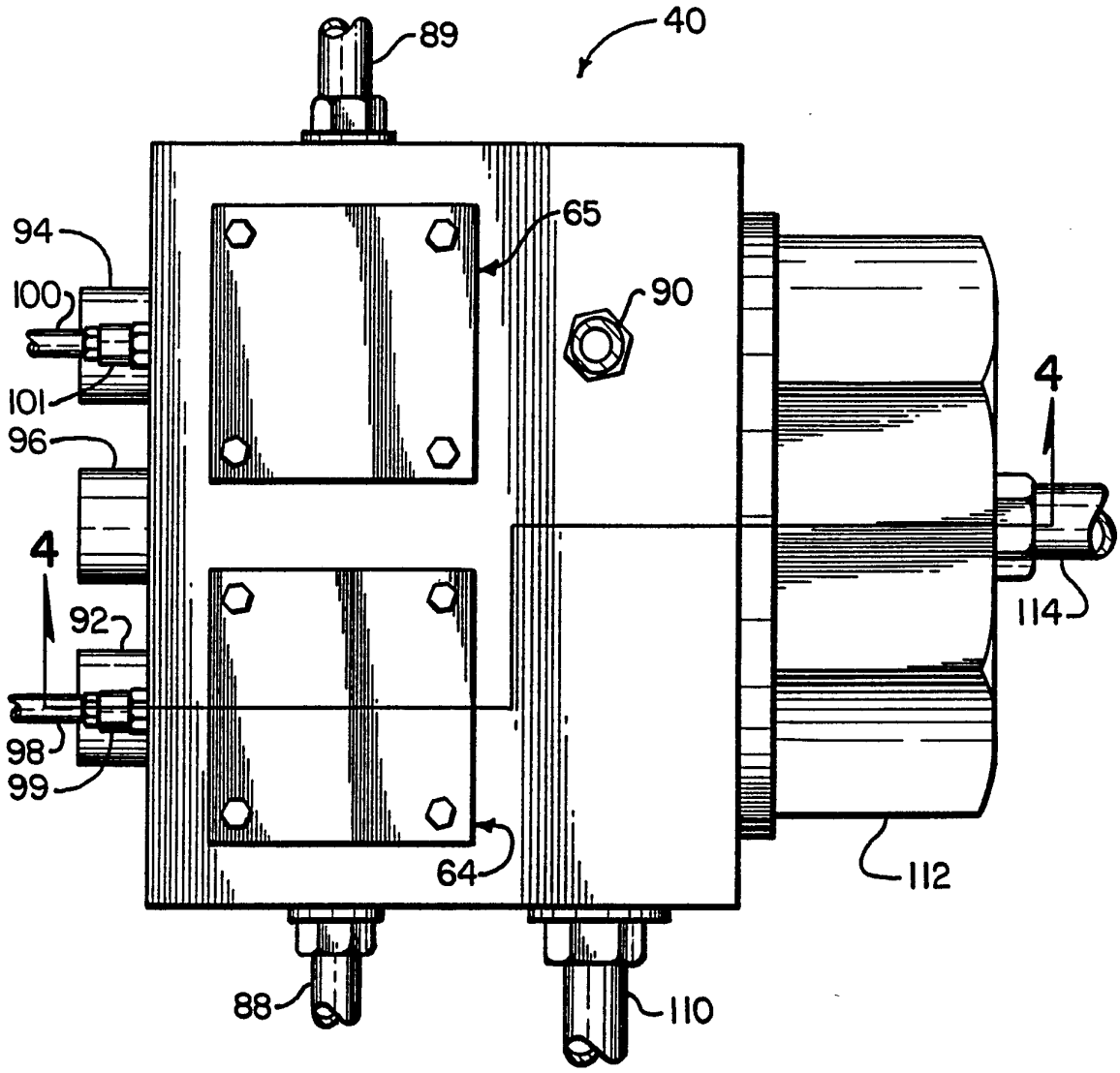



FIG. 3

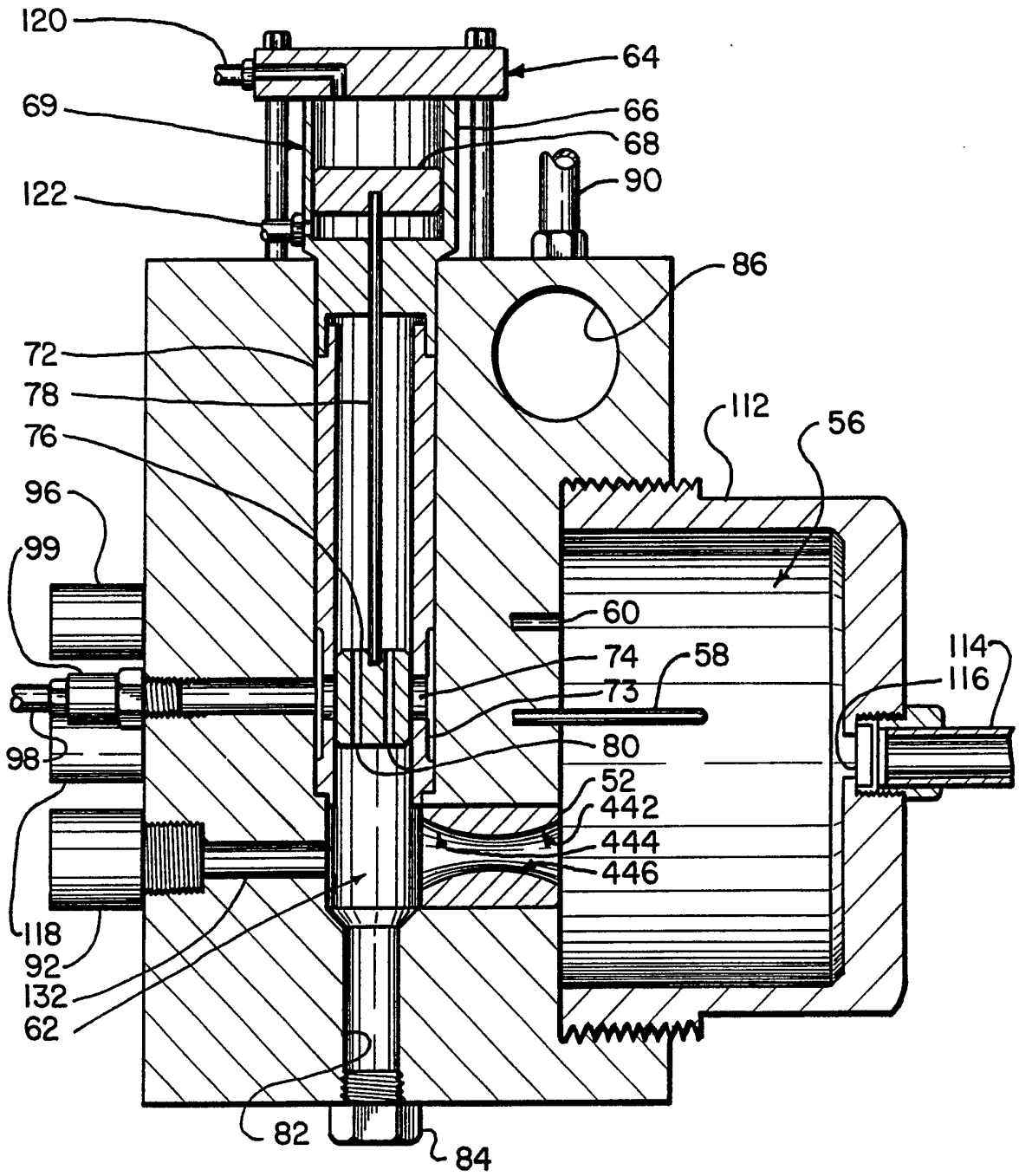

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FIG. 4

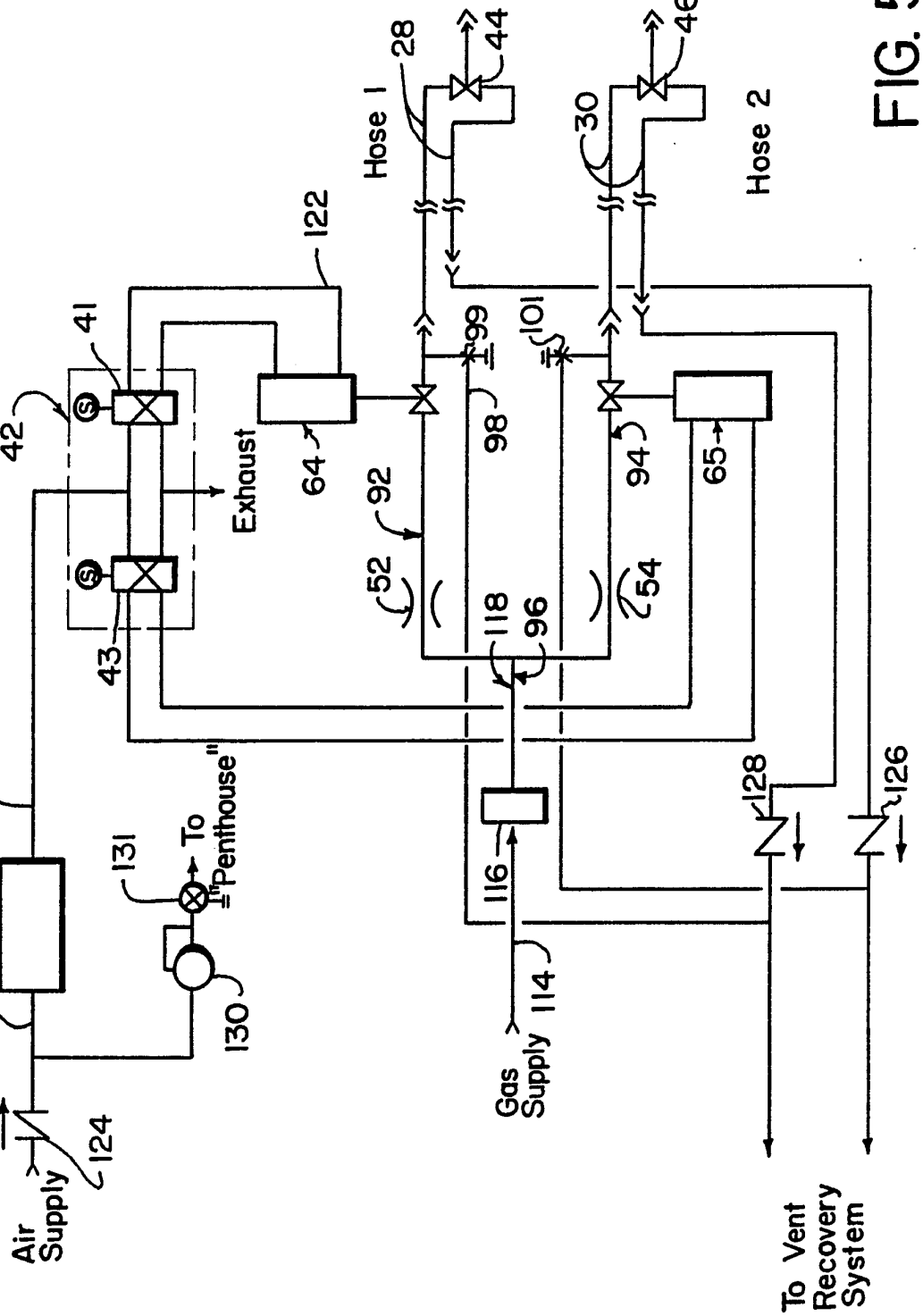

Hose 1
Hose 2
28
44
46
30
122
41
42
43
64
Exhaust
92
52
54
98
99
101
94
65
118
96
90
86
131
To "Penthouse"
130
110
124
Air Supply
116
114
Gas Supply
128
126
To Vent Recovery System

FIG. 5

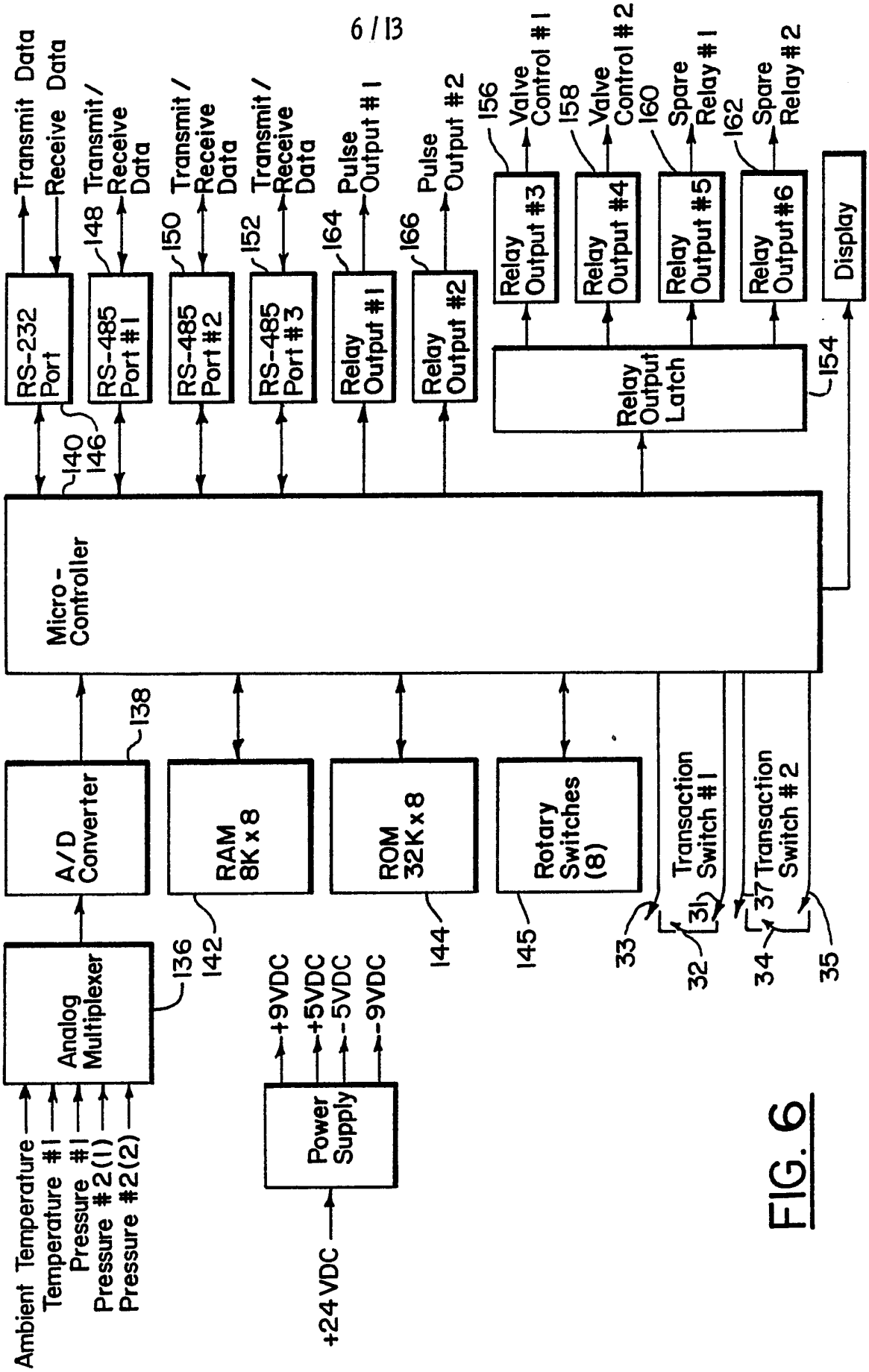

Ambient Temperature
Temperature #1
Pressure #1
Pressure #2(1)
Pressure #2(2)
Analog Multiplexer
136
A/D Converter
138
+24 VDC
Power Supply
+9VDC
+5VDC
-5VDC
-9VDC
RAM 8K x 8
142
ROM 32K x 8
144
Rotary Switches (8)
145
Micro-Controller
33
Transaction Switch #1
31
32
37
Transaction Switch #2
34
35
140
146
RS-232 Port
Transmit Data
Receive Data
RS-485 Port #1
148
Transmit / Receive Data
RS-485 Port #2
150
Transmit / Receive Data
RS-485 Port #3
152
Transmit / Receive Data
Relay Output #1
164
Pulse Output #1
Relay Output #2
166
Pulse Output #2
Relay Output Latch
154
Relay Output #3
156
Valve Control #1
Relay Output #4
158
Valve Control #2
Relay Output #5
160
Spare Relay #1
Relay Output #6
162
Spare Relay #2
Display

FIG. 6

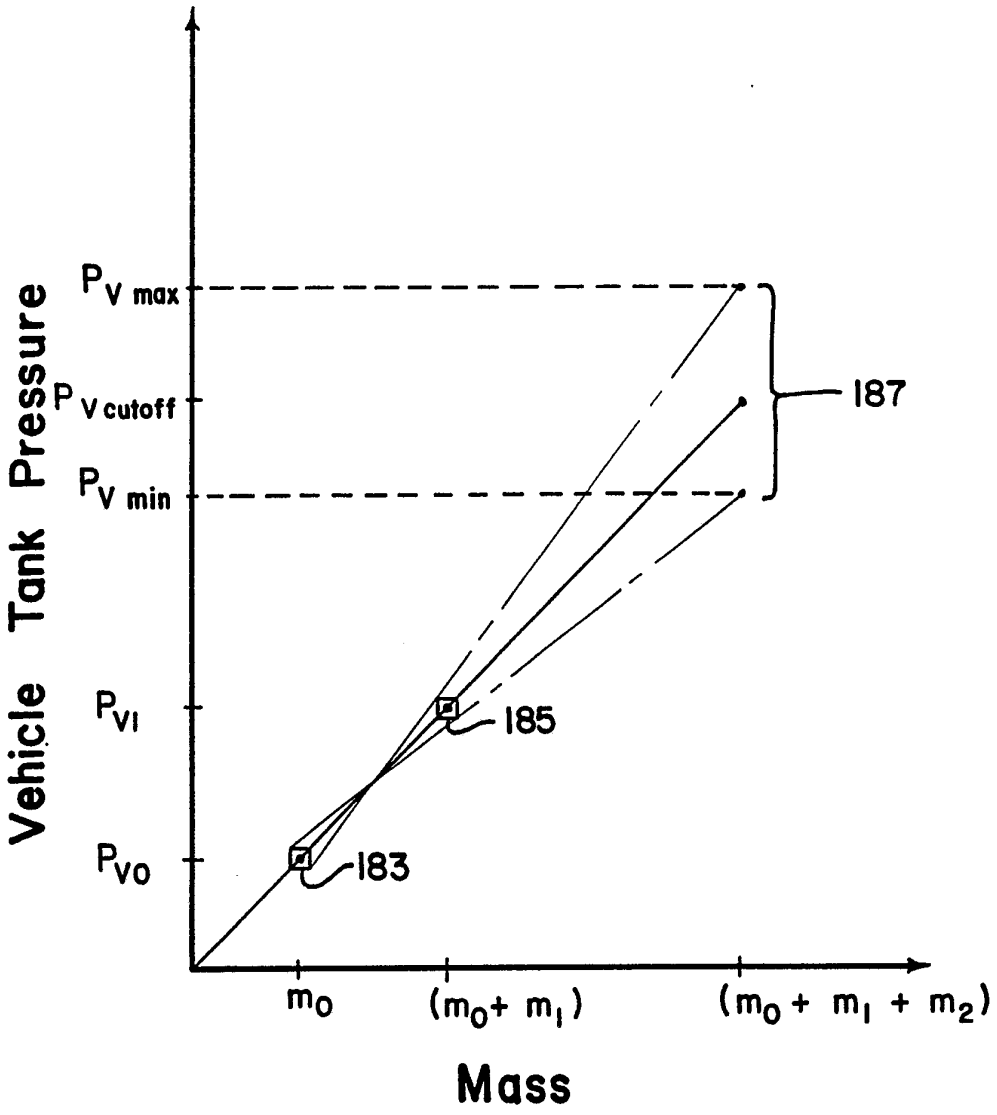

Vehicle Tank Pressure
$P_{V\,max}$
$P_{V\,cutoff}$
$P_{V\,min}$
$P_{VI}$
$P_{VO}$
187
185
183
$m_0$
$(m_0 + m_1)$
$(m_0 + m_1 + m_2)$
Mass

FIG. 7

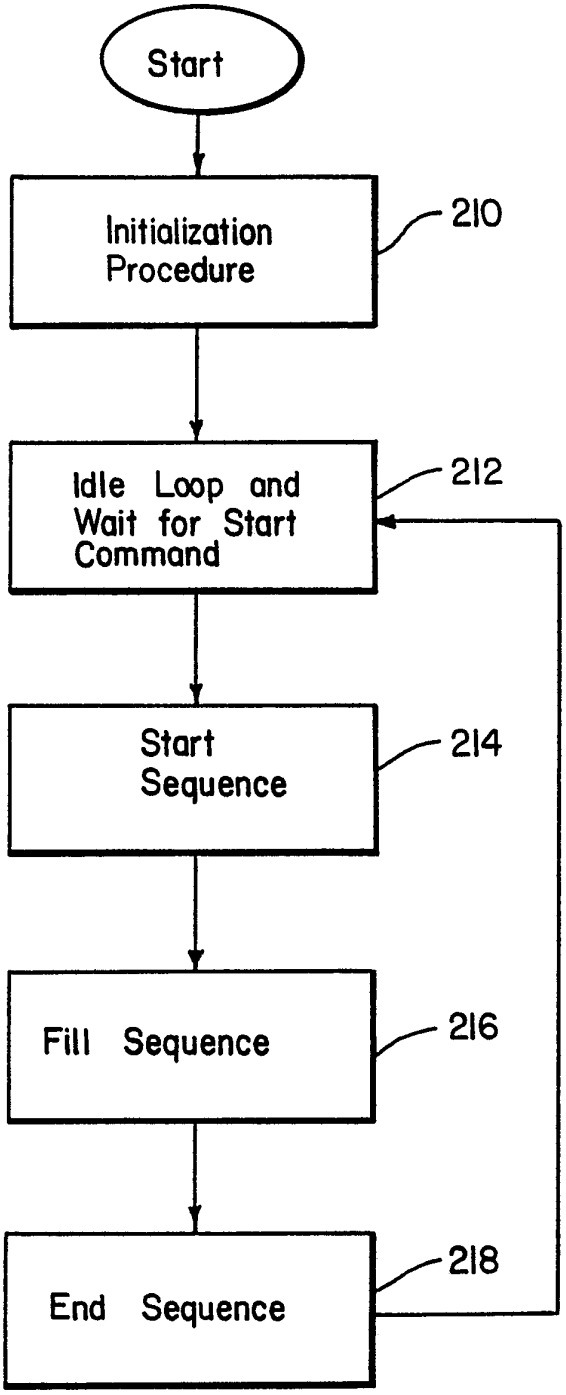

Start
Initialization Procedure
210
Idle Loop and Wait for Start Command
212
Start Sequence
214
Fill Sequence
216
End Sequence
218

FIG. 8

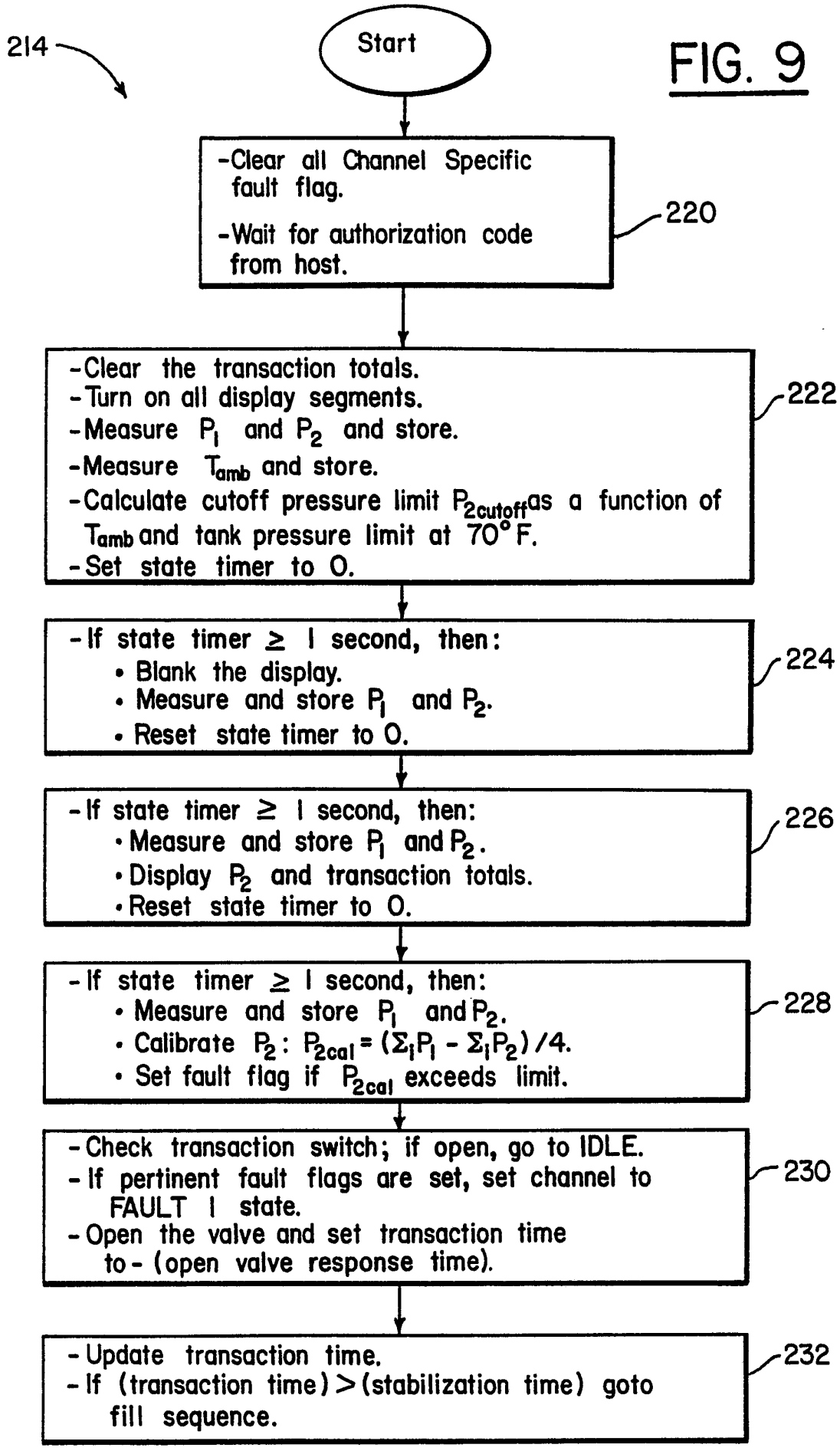

214
Start
-Clear all Channel Specific fault flag.
-Wait for authorization code from host.
220
-Clear the transaction totals.
-Turn on all display segments.
-Measure $P_1$ and $P_2$ and store.
-Measure $T_{amb}$ and store.
-Calculate cutoff pressure limit $P_{2cutoff}$ as a function of $T_{amb}$ and tank pressure limit at 70° F.
-Set state timer to 0.
222
-If state timer ≥ 1 second, then:
• Blank the display.
• Measure and store $P_1$ and $P_2$.
• Reset state timer to 0.
224
-If state timer ≥ 1 second, then:
• Measure and store $P_1$ and $P_2$.
• Display $P_2$ and transaction totals.
• Reset state timer to 0.
226
-If state timer ≥ 1 second, then:
• Measure and store $P_1$ and $P_2$.
• Calibrate $P_2$: $P_{2cal} = (\Sigma_1 P_1 - \Sigma_1 P_2)/4$.
• Set fault flag if $P_{2cal}$ exceeds limit.
228
-Check transaction switch; if open, go to IDLE.
-If pertinent fault flags are set, set channel to FAULT 1 state.
-Open the valve and set transaction time to - (open valve response time).
230
-Update transaction time.
-If (transaction time) > (stabilization time) goto fill sequence.
232

FIG. 9

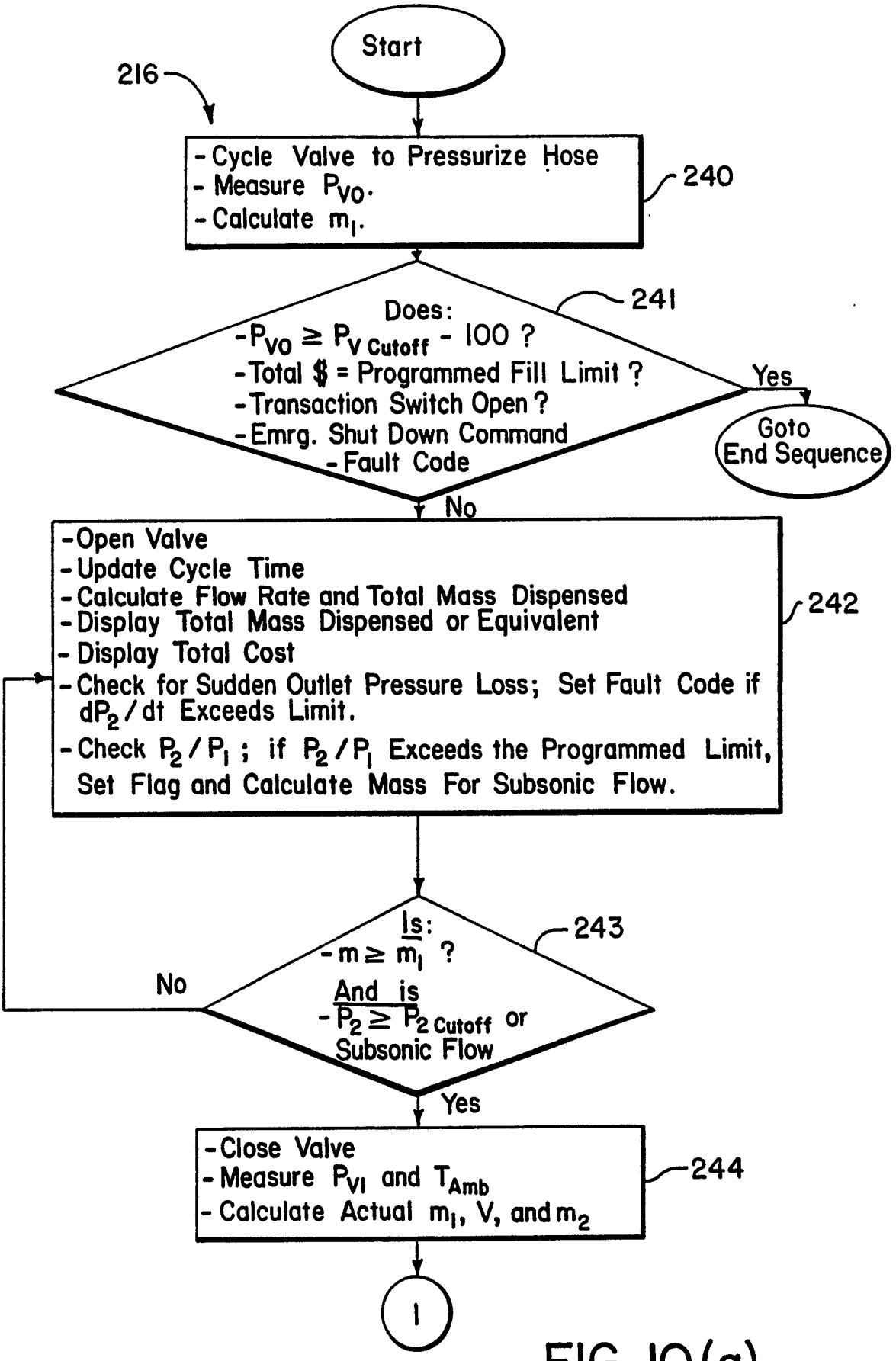

Start
216
- Cycle Valve to Pressurize Hose
- Measure $P_{VO}$.
- Calculate $m_1$.
240
Does:
- $P_{VO} \geq P_{V\ Cutoff}$ - 100 ?
- Total $ = Programmed Fill Limit ?
- Transaction Switch Open ?
- Emrg. Shut Down Command
- Fault Code
241
Yes
Goto End Sequence
No
- Open Valve
- Update Cycle Time
- Calculate Flow Rate and Total Mass Dispensed
- Display Total Mass Dispensed or Equivalent
- Display Total Cost
- Check for Sudden Outlet Pressure Loss; Set Fault Code if $dP_2/dt$ Exceeds Limit.
- Check $P_2/P_1$ ; if $P_2/P_1$ Exceeds the Programmed Limit, Set Flag and Calculate Mass For Subsonic Flow.
242
Is:
- $m \geq m_1$ ?
And is
- $P_2 \geq P_{2\ Cutoff}$ or Subsonic Flow
243
No
Yes
- Close Valve
- Measure $P_{V1}$ and $T_{Amb}$
- Calculate Actual $m_1$, V, and $m_2$
244
1

FIG. 10(a)

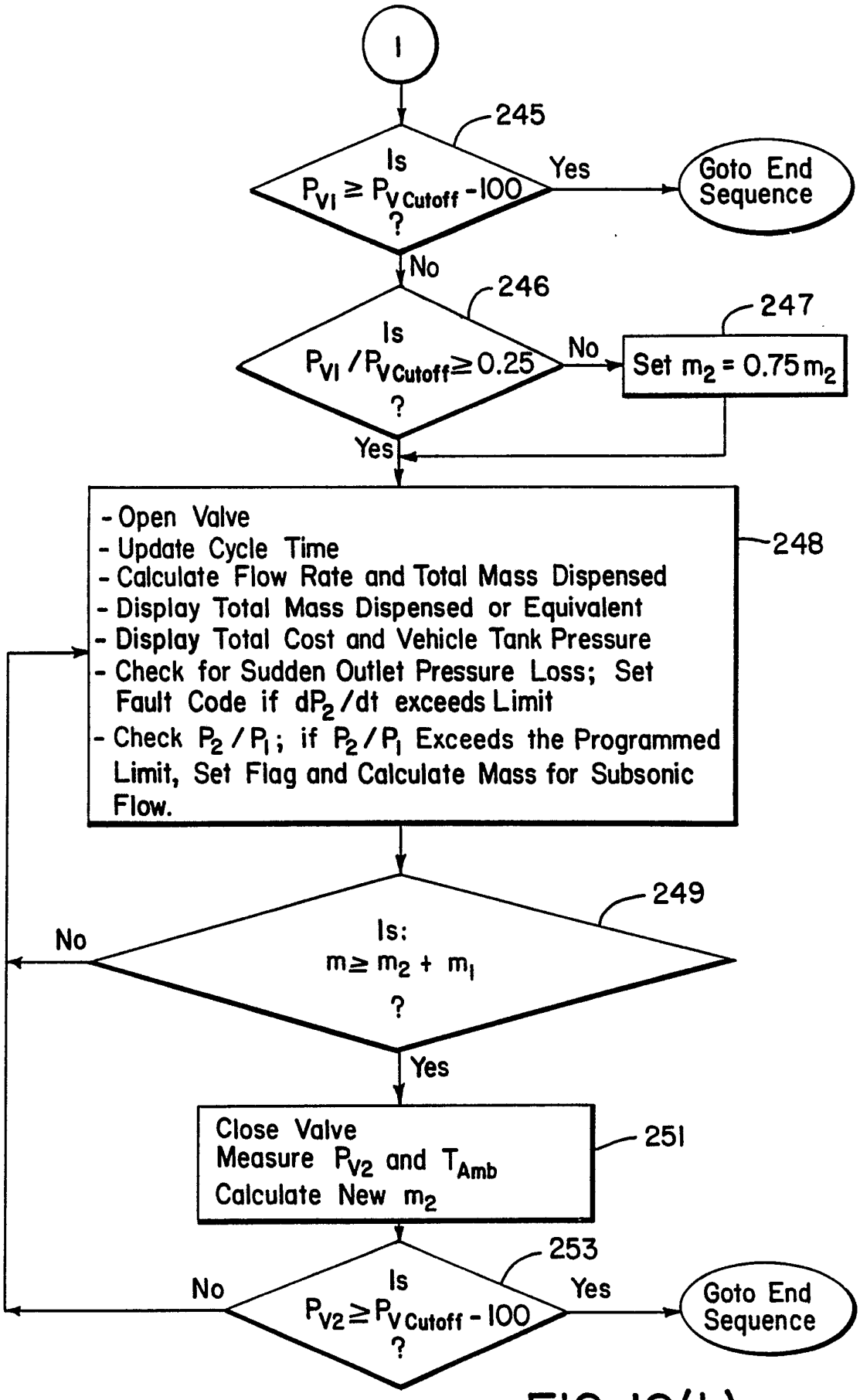

1
245
Is $P_{VI} \geq P_{V\,Cutoff} - 100$ ?
Yes
Goto End Sequence
No
246
Is $P_{VI} / P_{V\,Cutoff} \geq 0.25$ ?
No
247
Set $m_2 = 0.75\,m_2$
Yes
- Open Valve
- Update Cycle Time
- Calculate Flow Rate and Total Mass Dispensed
- Display Total Mass Dispensed or Equivalent
- Display Total Cost and Vehicle Tank Pressure
- Check for Sudden Outlet Pressure Loss; Set Fault Code if $dP_2/dt$ exceeds Limit
- Check $P_2/P_1$; if $P_2/P_1$ Exceeds the Programmed Limit, Set Flag and Calculate Mass for Subsonic Flow.
248
249
Is: $m \geq m_2 + m_1$ ?
No
Yes
Close Valve
Measure $P_{V2}$ and $T_{Amb}$
Calculate New $m_2$
251
253
Is $P_{V2} \geq P_{V\,Cutoff} - 100$ ?
No
Yes
Goto End Sequence

FIG. 10(b)

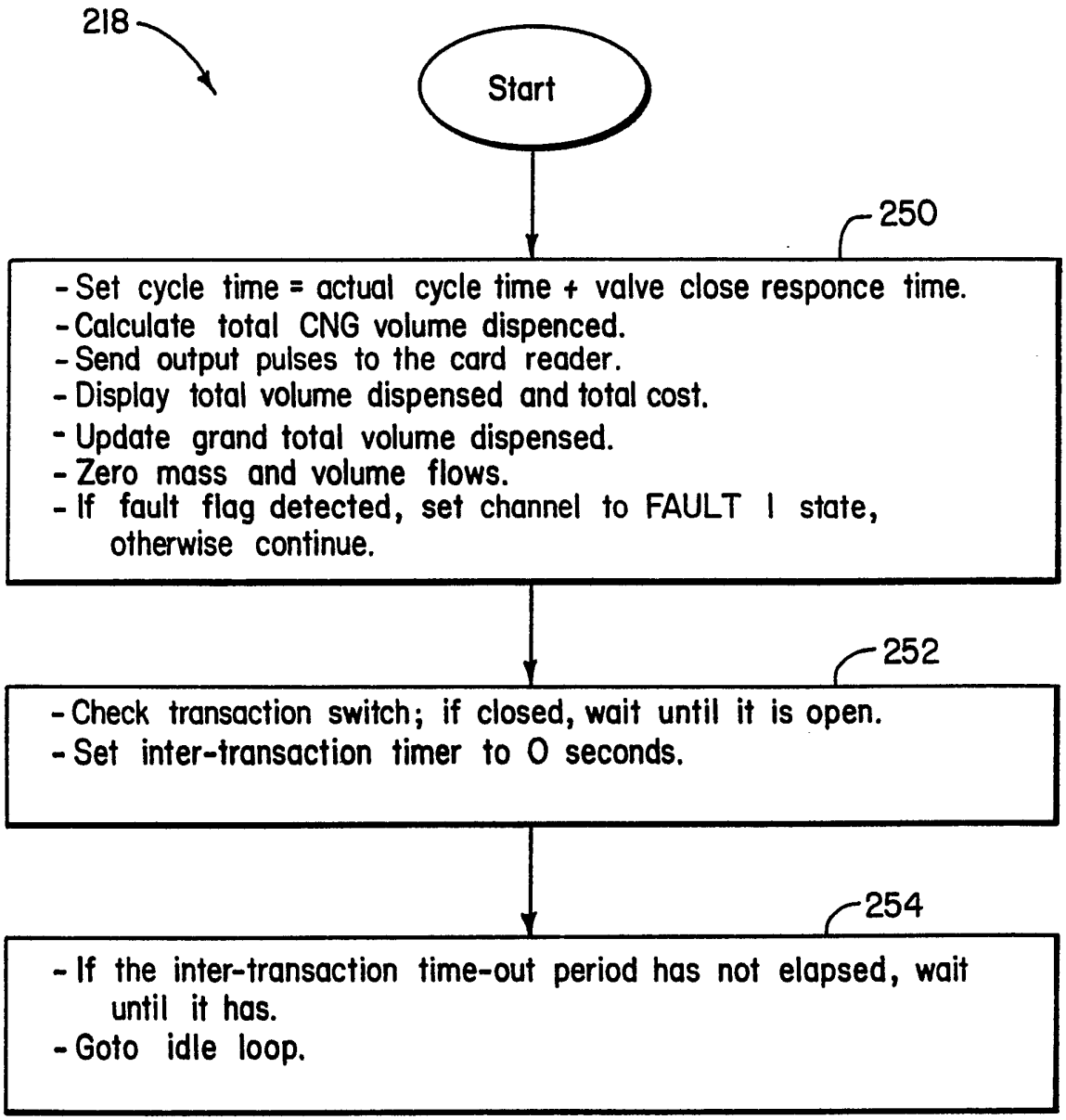

218
Start
250
- Set cycle time = actual cycle time + valve close responce time.
- Calculate total CNG volume dispenced.
- Send output pulses to the card reader.
- Display total volume dispensed and total cost.
- Update grand total volume dispensed.
- Zero mass and volume flows.
- If fault flag detected, set channel to FAULT 1 state, otherwise continue.
252
- Check transaction switch; if closed, wait until it is open.
- Set inter-transaction timer to 0 seconds.
254
- If the inter-transaction time-out period has not elapsed, wait until it has.
- Goto idle loop.

FIG. 11

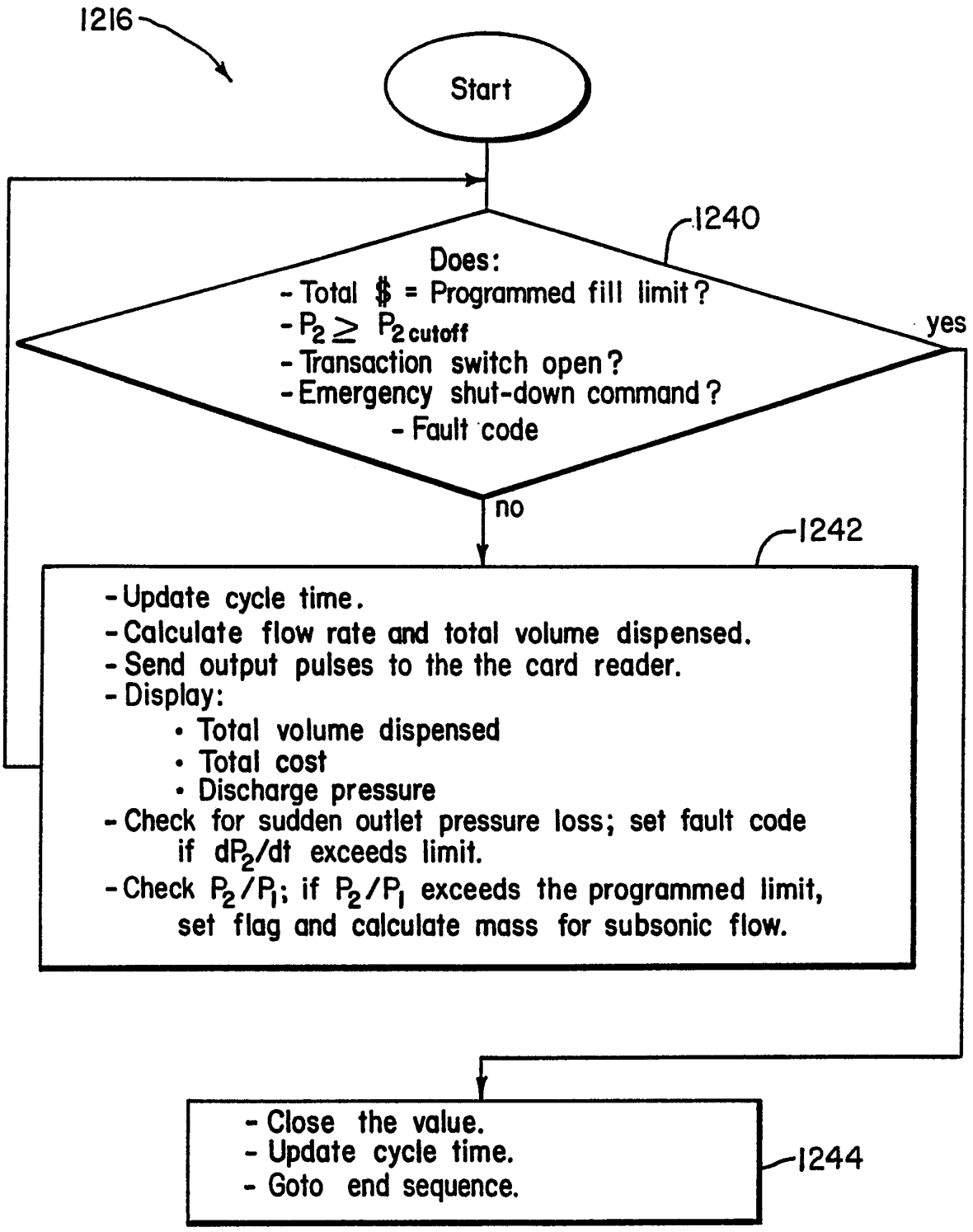

1216
Start
1240
Does:
- Total $ = Programmed fill limit?
- $P_2 \geq P_{2\,cutoff}$
- Transaction switch open?
- Emergency shut-down command?
- Fault code
yes
no
1242
- Update cycle time.
- Calculate flow rate and total volume dispensed.
- Send output pulses to the the card reader.
- Display:
• Total volume dispensed
• Total cost
• Discharge pressure
- Check for sudden outlet pressure loss; set fault code if $dP_2/dt$ exceeds limit.
- Check $P_2/P_1$; if $P_2/P_1$ exceeds the programmed limit, set flag and calculate mass for subsonic flow.
- Close the value.
- Update cycle time.
- Goto end sequence.
1244

FIG. 12

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/US92/05538

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :B65B 31/00
US CL :141/004
According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 141/2.3, 18, 21, 37, 51, 83, 94, 95, 231, 39, 47-49. 48/190,191. 222/54,52. 137/79, 80. 364/465,557,558,564

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X<br>Y | US, A, 4,966,206 (BRAUMANN ET AL.) 30 OCT 1990 (SEE ENTIRE DOCUMENT) | 1,10,18-21, 26,30,33,<br>9,25 |
| Y | JA,A, 2-0283099 (TOKICO LTD) 19 NOV 1990 (SEE ABSTRACT) | 9,25 |
| P , A | US, A, 5,029,622 (MUTTER) 09 JUL 1991 (SEE ENTIRE DOCUMENT) | |
| A | US, A, 4,705,082 (FANSHAWE ET AL) 10 NOV 1987 (SEE ENTIRE DOCUMENT) | 1-33 |
| A | US, A, 4,527,600 (FISHER ET AL) 09 JUL 1985 (SEE ENTIRE DOCUMENT) | 1-33 |
| A | US, A, 4,531,558 (ENGEZ ET AL) 30 JUL 1985 (SEE ENTIRE DOCUMENT) | 1-33 |

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

| | | | |
|---|---|---|---|
| * | Special categories of cited documents: | "T" | later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention |
| "A" | document defining the general state of the art which is not considered to be part of particular relevance | "X" | document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone |
| "E" | earlier document published on or after the international filing date | "Y" | document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art |
| "L" | document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) | "&" | document member of the same patent family |
| "O" | document referring to an oral disclosure, use, exhibition or other means | | |
| "P" | document published prior to the international filing date but later than the priority date claimed | | |

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