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(54) **FLUID COMPRESSOR AND MOTOR VEHICLE REFUELLING APPARATUS**

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F04B 25/04	(2006.01)
F04B 9/113	(2006.01)

(52) **U.S. Cl.**
CPC ***F04B 5/02*** (2013.01); ***F04B 25/005*** (2013.01); ***F04B 25/04*** (2013.01); ***F04B 9/113*** (2013.01)
USPC **417/266**

(58) **Field of Classification Search**
USPC 417/225, 266, 244, 487, 267, 268, 486, 417/491, 525, 533, 269, 530, 254
See application file for complete search history.

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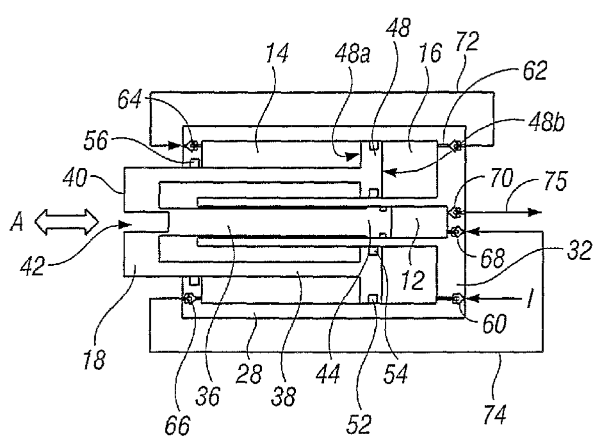
(57) **ABSTRACT**

A fluid compressor **10** comprising a stator **22**, having a bore shaped first chamber **26** and an annular second chamber **30**, and a piston **18** comprising a central piston rod **36** having a first piston head **44** and a concentrically arranged cylindrical piston sleeve **38** having a second piston head **48**. The stator **22** and piston **18** together define a first compression chamber **12**, a second compression chamber **14** provided concentrically around the first chamber **12**, and a third compression chamber **16** provided concentrically around the first chamber **12** and linearly with the second chamber **14**. The compression chambers **12**, **14**, **16** are interconnected via intercooling conduits **72**, **74**. A hydraulic actuator **20** is coupled to the piston **18** by a hydraulic ram **82**. During left to right movement of the piston **18** fluid enters the third chamber **16** and fluid is compressed in the second chamber **14**.

24 Claims, 6 Drawing Sheets



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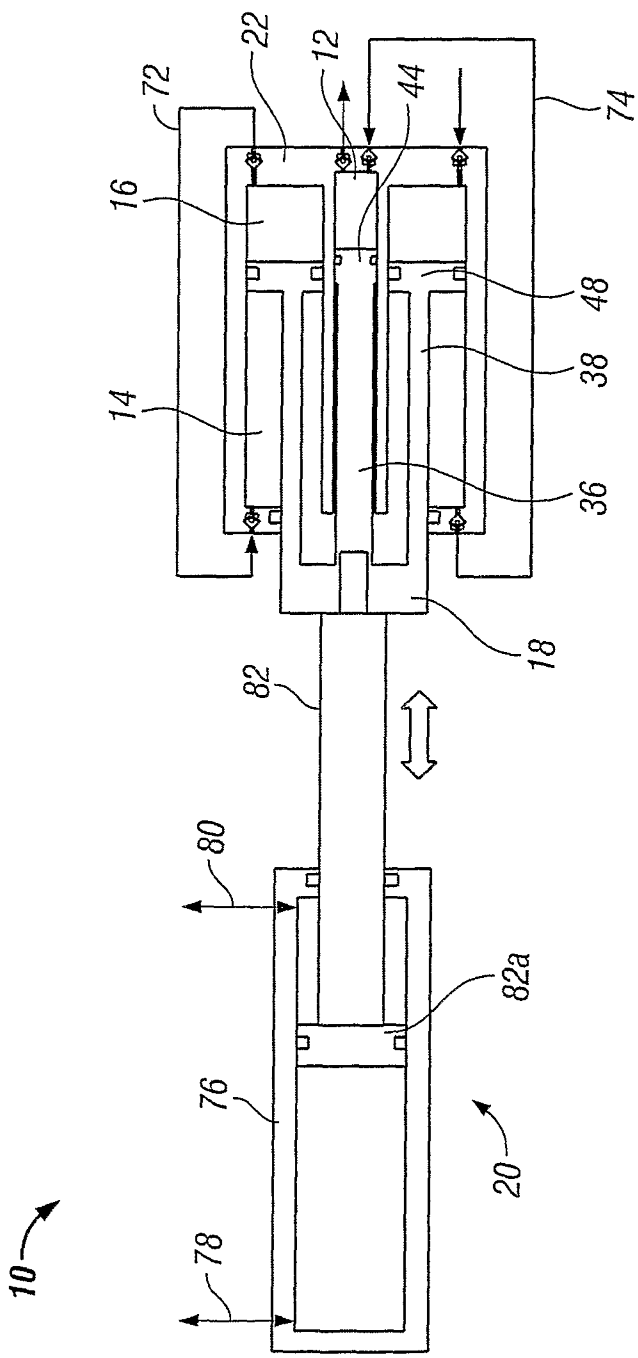


FIG. 1

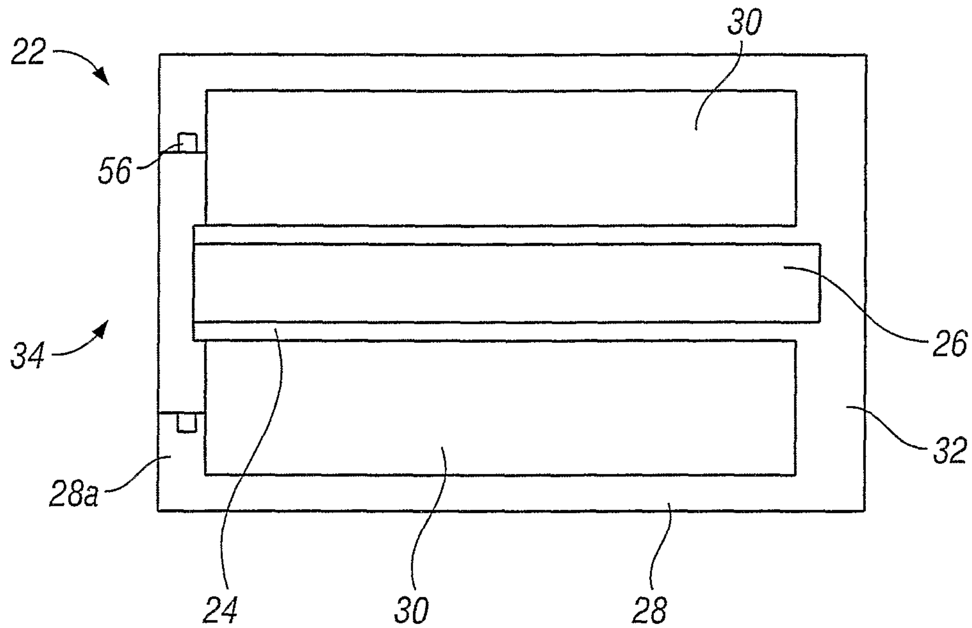


FIG. 2

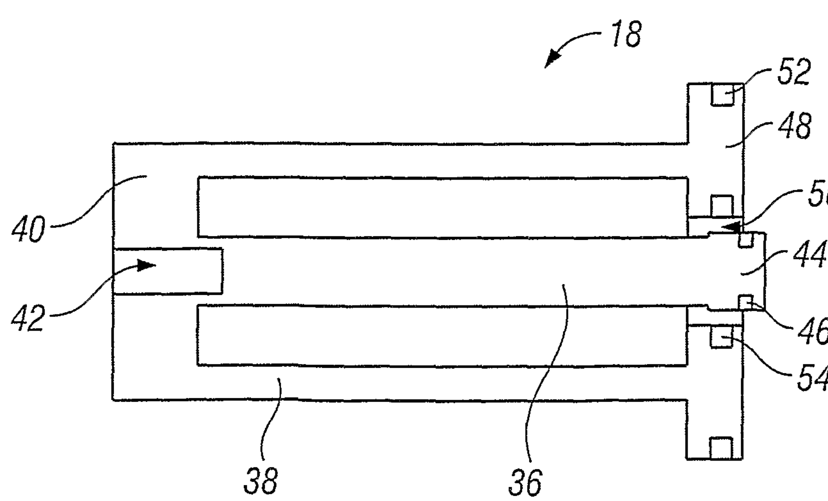
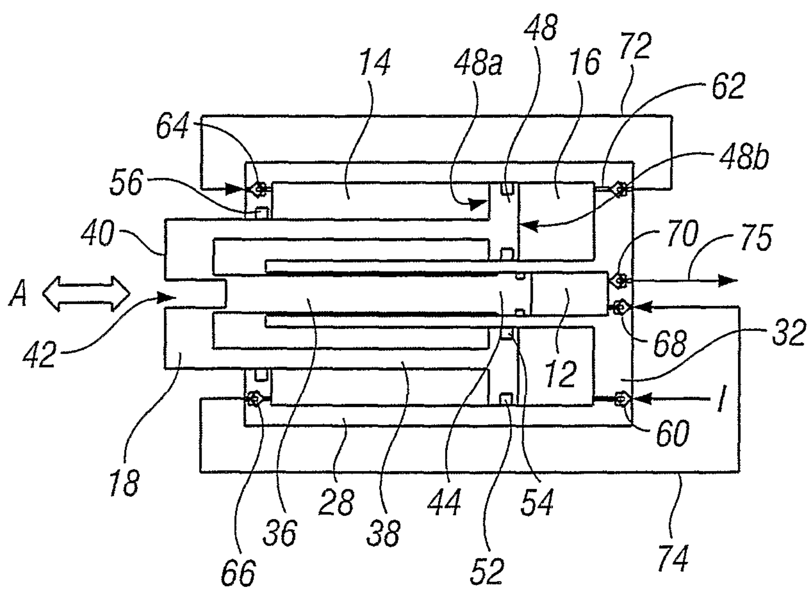


FIG. 3


48
72
14
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16
62
64
48b
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40
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75
A
42
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I
60
18
28
36
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44
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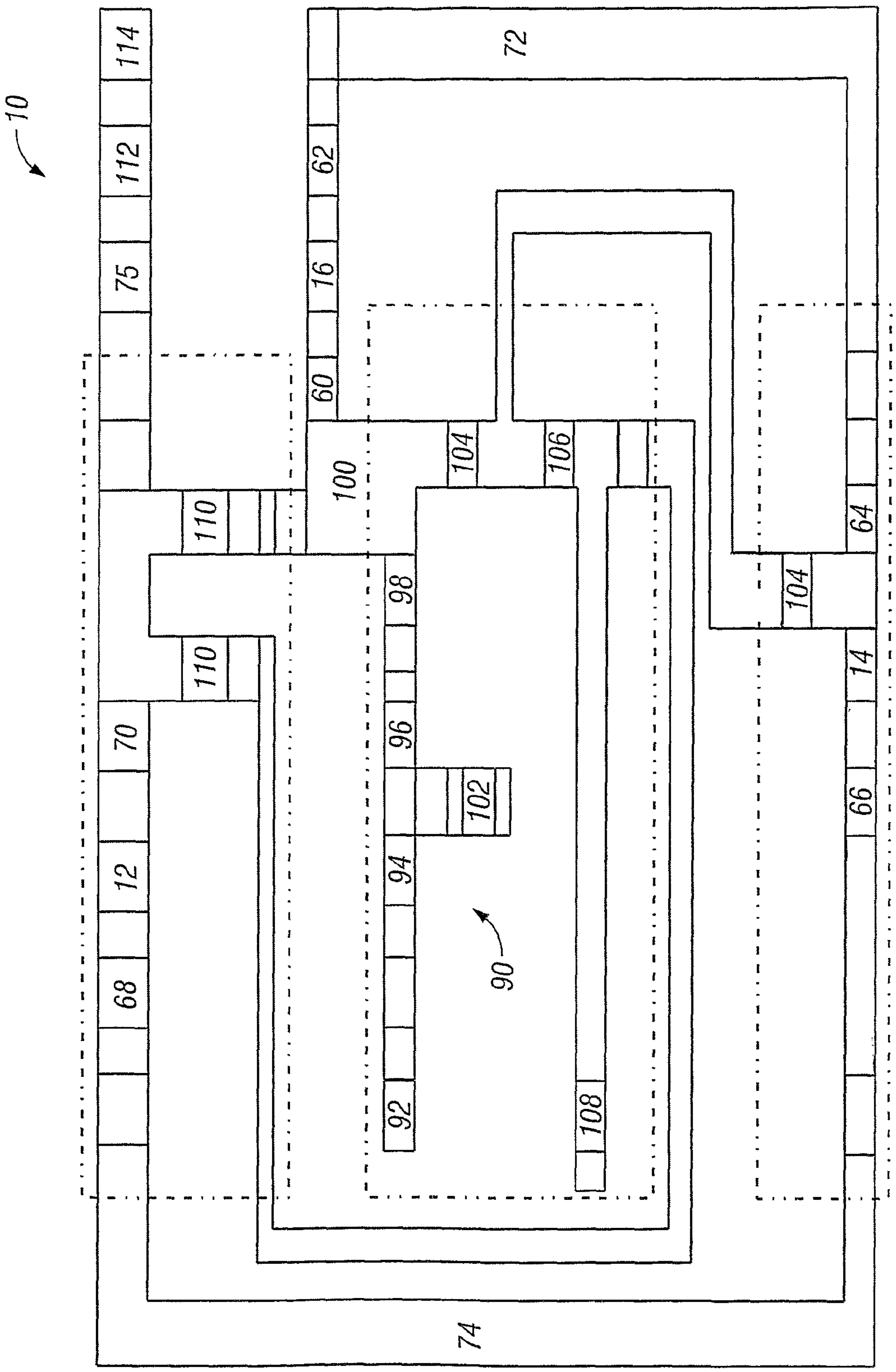
52
66
74

FIG. 4


10
114
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62
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60
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104
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110
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FIG. 5

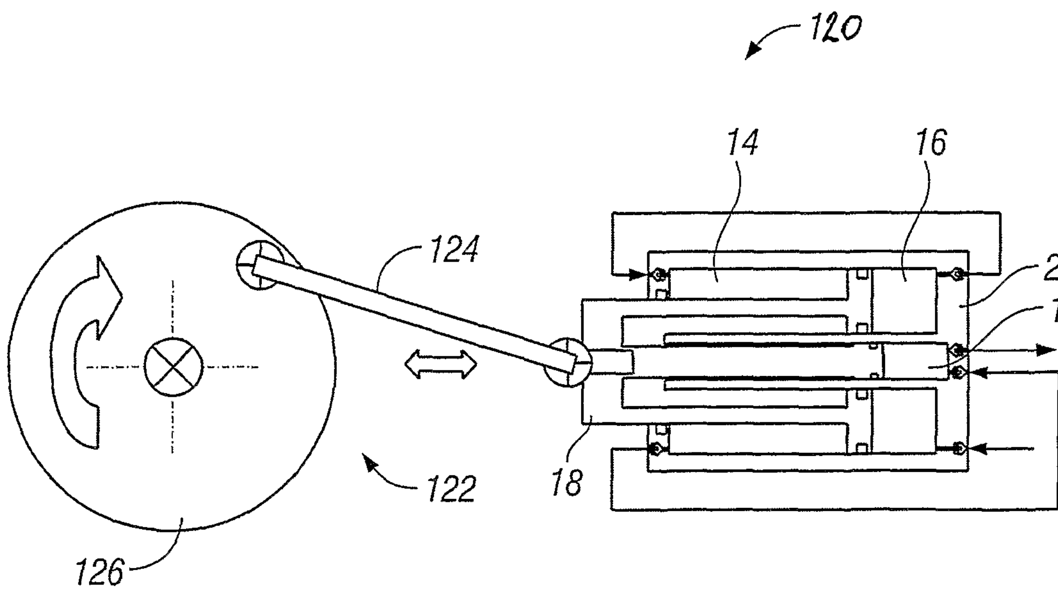

FIG. 6

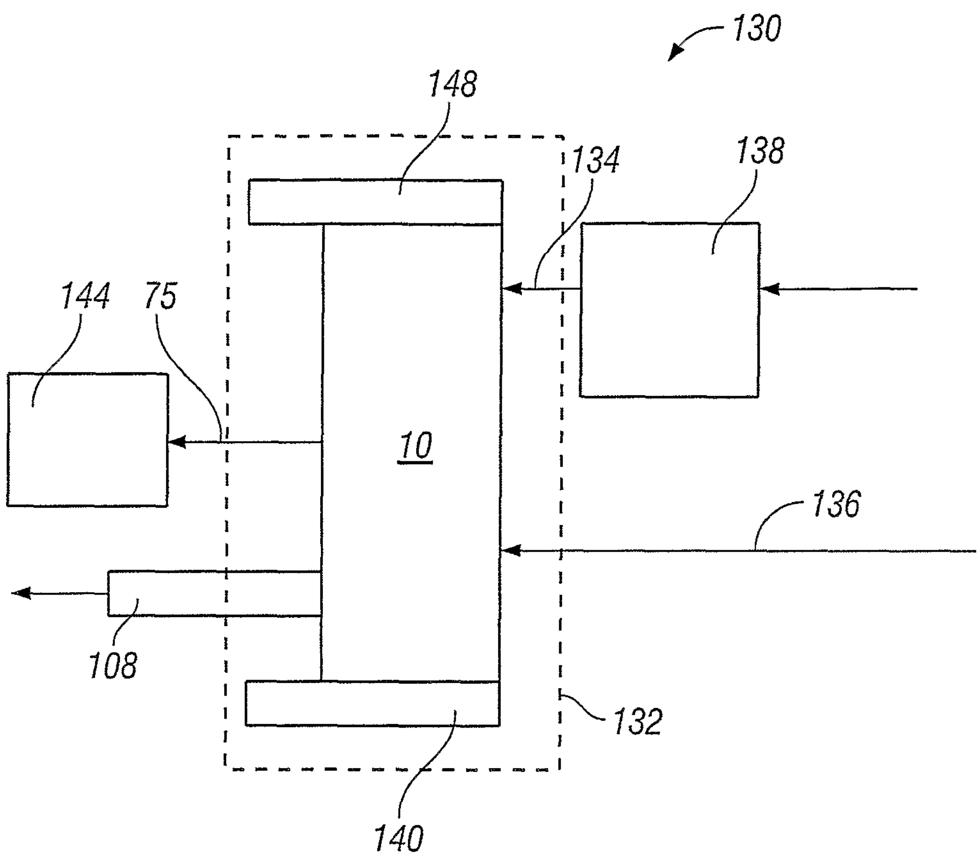

FIG. 7

FLUID COMPRESSOR AND MOTOR VEHICLE REFUELLING APPARATUS

CLAIM OF PRIORITY

This Application claims the benefit of priority under 35 USC §365 of International Patent Application Serial No. PCT/GB2007/050060 filed on Feb. 13, 2007, designating the United States of America, which in turn claims the benefit of priority under 35 USC §119 of United Kingdom Patent Application Serial No. GB0603117.3 filed on Feb. 16, 2006.

FIELD OF THE INVENTION

The invention relates to a fluid compressor and to motor vehicle refuelling apparatus incorporating the fluid compressor.

An increasing number of motor vehicles are available which use compressed natural gas (CNG) or hydrogen as fuel. As with conventional petrol or diesel vehicles, compressed gas fuelled vehicles need to be regularly refuelled, but the number of refuelling stations providing CNG are few and far between in comparison with the number of petrol stations, and there are only a handful of hydrogen refuelling stations in existence. Using compressed gas fuelled vehicles is therefore currently seen as being inconvenient and impractical.

One solution to the lack of compressed gas refuelling stations that has been put forward is the provision of residentially located compressors that compress natural gas and deliver it direct to the fuel tank of a motor vehicle, such a system is described in WO 2004/031643. No detail of the construction of the gas compressor is provided in WO 2004/031643, but there are many known gas compressors which may be suitable for compressing natural gas, such as those described in U.S. Pat. No. 4,478,556, U.S. Pat. No. 5,782,612, U.S. Pat. No. 4,761,118, and WO 2004/018873. However, known gas compressors generally have high power ratings and require high power, generally 3-phase, electric power supplies, making them unsuitable for residential operation.

SUMMARY OF THE INVENTION

According to a first aspect of the present invention there is provided a fluid compressor comprising:

- a first compression chamber of a first volume;
- a compressed fluid outlet conduit coupled to the first compression chamber;
- a second compression chamber of a second, larger volume provided concentrically around the first compression chamber;
- a piston mounted for linearly reciprocating movement, the piston comprising a first piston head movable to compress fluid within the first compression chamber and a second piston head movable to compress fluid within the second compression chamber; and
- actuation means operable to drive the piston,
- whereby as the piston is driven in a first linear direction fluid enters the second compression chamber and fluid in the first compression chamber is compressed, and as the piston is driven in the opposite direction fluid in the second compression chamber is compressed and compressed fluid from the second compression chamber is delivered to the first compression chamber.

The fluid compressor preferably further comprises a third compression chamber of a third volume, larger than each of the first volume and the second volume, the third compression chamber being provided concentrically around the first compression chamber. Preferably, the third compression chamber is part co-linear with the second compression chamber, the second piston head separating the second and third compression chambers.

The fluid compressor may further comprise at least one additional compression chamber of an intermediate volume, the additional compression chamber being provided concentrically around the first compression chamber and being concentric with at least one of the second and third compression chambers. The piston may further comprises at least one additional piston head movable to compress fluid within the at least one additional compression chamber.

The fluid compressor preferably further comprises a stator defining first and second concentric stator chambers, the piston and the stator together defining the fluid compression chambers. Preferably, the first stator chamber forms the first fluid compression chamber and the second and third compression chambers comprise parts of the second stator chamber defined by the piston and one or more walls of the second stator chamber. The at least one additional compression chamber may be formed between the piston and one or more walls of the first or second stator chambers.

The piston preferably comprises a central piston rod and a concentric piston sleeve, the central piston rod having the first piston head at its distal end and being movably received within the first stator chamber, and the piston sleeve having the second piston head at its distal end and being movably received within the second stator chamber. The second fluid compression chamber preferably comprises the volume of the second stator chamber between the outermost surface of the piston sleeve, the external wall of the second stator chamber and part of one side of the second piston head. The third fluid compression chamber preferably comprises the volume of the second stator chamber between the other side of the second piston head and the walls of the second stator chamber.

The fluid compressor preferably further comprises fluid seals between the piston heads and the respective walls of the stator. The fluid compressor may further comprise fluid seals between the piston rod and the piston sleeve and the respective walls of the stator.

The ratio of the volumes of the compression chambers is preferably selected to provide for substantially the same amount of fluid compression within each compression chamber.

Preferably, each compression chamber is provided with an inlet valve and an outlet valve, the outlet valve of a first compression chamber being coupled to the inlet valve of a subsequent compression chamber by a respective inter-cooling conduit. The inlet and outlet valves are preferably uni-directional valves.

The fluid compressor preferably further comprises a fluid recovery vessel coupled between the compressed fluid outlet conduit and the first compression chamber, the fluid recovery vessel receiving compressed fluid present within the outlet conduit prior to decoupling the outlet conduit from a receiving compressed fluid storage vessel, thereby lowering the fluid pressure within the delivery conduit prior to decoupling.

The actuation means preferably comprises a hydraulic actuator coupled to the piston. The actuation means may alternatively comprise a crank shaft driven by a cam coupled to an electric motor. The electric motor may have a variable drive speed. Alternatively, the cam may be an eccentric cam or a cam having a non-circular profile. The actuation means can preferably be powered from a single phase electrical power supply. The actuation means preferably drives the piston at a cycle rate of approximately 20 cycles per minute.

The fluid compressor preferably further comprises fluid metering means operable to measure the volume of fluid input into the fluid compressor. The fluid metering means preferably comprises piston cycle counting means, a fluid temperature sensor, a fluid pressure sensor, a non-transitory tangible computer readable storage medium operable to store the value of the volumetric capacity of the compression chamber into which fluid to be compressed is delivered from an external fluid supply, and processor means operable to convert the number of piston cycles (being the number of times that the compression chamber is filled with fluid from the external supply) into the volume of fluid delivered from the external fluid supply to the fluid compressor. The processor means is preferably operable to write the volume of fluid delivered to the fluid compressor during a single operation of the fluid compressor to the non-transitory tangible computer readable storage medium, and is preferably further operable to add together the volumes of fluid delivered to the fluid compressor during a plurality of operations of the fluid compressor. The piston cycle counting means preferably comprises a top dead centre position sensor provided at one end of the stator and a bottom dead centre position sensor provided at the other end of the stator.

Preferably, none of the elements of the fluid compressor which come into contact with fluid being processed by the fluid compressor have any lubricants, such as oils, thereby making the fluid compressor free from contamination on its fluid side.

The fluid is preferably a gas, and may be natural gas, nitrogen, hydrogen or air.

According to a second aspect of the invention there is provided motor vehicle compressed natural gas refuelling apparatus comprising:

- a fluid compressor according to the first aspect of the invention provided within a compressor housing;
- a gas inlet conduit coupled at one end to a fluid inlet of the fluid compressor and having connection means at its other end for connection to a natural gas supply; and
- electrical power connection means coupled to the actuation means.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described in detail, by way of example only, with reference to the accompanying drawings, in which:

FIG. **1** is a diagrammatic cross-sectional view of a fluid compressor according to a first embodiment of the invention;

FIG. **2** shows the stator of FIG. **1**;

FIG. **3** shows the piston of FIG. **1**;

FIG. **4** is an enlarged cross-sectional view of the stator and piston of the fluid compressor of FIG. **1**;

FIG. **5** is a schematic representation of the fluid pathways of the fluid compressor of FIG. **1**;

FIG. **6** is a diagrammatic cross-sectional view of a fluid compressor according to a second embodiment of the invention; and

FIG. **7** is a schematic representation of motor vehicle compressed natural gas refuelling apparatus according to a third embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIGS. **1** to **5**, a first embodiment of the invention provides a fluid compressor **10** comprising a first compression chamber **12**, a second compression chamber **14**, a third compression chamber **16**, a piston **18**, a hydraulic actuator **20** and a stator **22**.

In this example, as shown in FIG. **2**, the stator **22** has a cylindrical inner wall **24**, which defines a bore shaped first stator chamber **26**, and a cylindrical outer wall **28** arranged concentrically around the inner wall **24**. Between the inner wall **24** and the outer wall **28** a second, annular stator chamber **30** is defined. An end wall **32** closes the first and second stator chambers **26**, **30** at one end. The outer wall **28** extends inwardly at its other end to form a part closure **28***a*, defining an opening **34** through which the piston **18** is received, as will be described in more detail below.

Referring to FIG. **3**, the piston **18** comprises a central piston rod **36** and a concentrically arranged cylindrical piston sleeve **38**. The rod **36** and the sleeve **38** are interconnected by a coupling piece **40**, in which a coupling recess **42** is provided for coupling with the hydraulic ram **20**.

A first piston head **44** is provided at the distal end of the piston rod **36**. The external diameter of the piston head **44** closely matches the internal diameter of the first stator chamber **26**. A PTFE (or PTFE/rubber composite) seal **46** is provided around and within the first piston head **44**, to ensure a tight seal is formed between the first piston head **44** and the inner surface of the inner wall **24** of the stator **22**.

A second piston head **48** is provided at the distal end of the piston sleeve **38**. The second piston head **48** is ring shaped and extends to either side of the piston sleeve **38**. A central aperture **50** is provided in the second piston head **48** through which the first piston head **44** partially extends. PTFE (or rubber) seals **52**, **54** are provided around and within external and internal edges of the second piston head **48**, to ensure a tight seal is formed between the second piston head **48** and the internal surface of the outer wall **28** of the stator **22** and between the second piston head **48** and the external surface of the inner wall **24** of the stator **22** respectively, as shown in FIG. **4**. A PTFE (or PTFE/rubber composite) seal **56** is also provided within the part closure **28***a* of the external wall **28** of the stator **22**, for sealing with the external surface of the piston sleeve **38**.

Referring to FIGS. **2** and **4**, it can be seen that the first stator chamber **26** forms the first compression chamber **12**. The second compression chamber **14** comprises that part of the second stator chamber **30** located between the inner surface of the outer stator wall **28**, the outer surface of the piston sleeve **38** and the part of the left hand face **48***a* (as shown in FIG. **4**) of the second piston head **48** that extends outwardly from the piston sleeve **38**. The third compression chamber **16** comprises that part of the second stator chamber **30** located between the end wall **32** of the stator **22** and the right hand face **48***b* (as shown in FIG. **4**) of the second piston head **48**. It will be appreciated that the relative volumes of the second compression chamber **14** and the third compression chamber **16** will change as the piston **18** reciprocates back and forward (as indicated by arrow A), moving the second piston head **48** through the second stator chamber **30**.

The third compression chamber **16** is provided with a one-way inlet valve **60** through which fluid (such as natural gas) is delivered (as indicated by arrow I) into the third compression chamber **16**. A one-way outlet valve **62** is also provided for exhausting compressed gas from the third compression chamber **16**. The second compression chamber **14** is similarly provided with a one-way inlet valve **64** and a one-way outlet valve **66**, and the first compression chamber **12** is also provided with a one-way inlet valve **68** and a one-way outlet valve **70**.

The outlet valve **62** of the third compression chamber **16** is connected to the inlet valve **64** of the second compression chamber **14** via a first intercooling conduit **72**. The outlet valve **66** of the second compression chamber **14** is connected to the inlet valve **68** of the first compression chamber **12** via a second intercooling conduit **74**. The outlet valve **70** of the first compression chamber **12** is coupled to the compressed fluid outlet conduit **75** of the fluid compressor **10**.

Referring to FIG. **1**, the hydraulic actuator **20** comprises a hydraulic cylinder **76** having inlet/outlet valves **78**, **80** and a ram **82** coupled at its distal end to the piston **18** via the coupling recess **42**. The hydraulic actuator **20** operates in a manner that will be well known to the person skilled in the art and so its operation will not be described in detail here.

Referring to FIG. **5**, the fluid compressor **10** further comprises a fluid inlet pathway **90** comprising (in fluid series) an inlet connector **92**, a fluid filter **94**, and isolation valve **96**, a non-return valve **98** and a gas recovery vessel **100**, coupled to the inlet valve **60** of the first compression chamber **16**. The filter **94** acts to prevent particles entering the compression chambers **12**, **14**, **16**, thereby preventing incorrect operation of the inlet and outlet valves **60**, **62**, **64**, **66**, **68**, **70**, and general contamination of moving parts and surfaces. The isolation valve **96** is operable to isolate the fluid compressor **10** from an external gas supply (not shown) if required, for example for reasons of safety. A pressure sensor **102** is provided between the filter **94** and the isolation valve **96**, operable to measure the pressure of incoming fluid.

Burst discs **104**, a burst disc failure detector **106** and an emergency fluid outlet **108** are provided within the fluid compressor **10** to protect the fluid compressor **10** in the event that fluid pressure within the fluid compressor **10** exceeds the normal operating range, for example due to failure of one or more components within the fluid compressor **10**. In addition, solenoid offload valves **110** are provided to allow fluid within the fluid compressor **10** to vent to atmosphere in the event of an electrical power failure.

The fluid outlet conduit **75** is provided with a flow restrictor **112** and a breakaway connector **114** at its distal end.

In operation, the starting position (top dead centre: TDC) of a two stroke piston cycle has the ram **82** of the hydraulic actuator **20** and the piston **18** fully to the right (as orientated in the drawings) within their respective chambers; the volumes of the first and third compression chambers **12**, **16** are essentially zero and the volume of the second compression chamber **14** is at its maximum. As the ram **82** and the piston **18** move to the left, the movement of the second piston head **48** through the third compression chamber **16** causes fluid (for example natural gas) to be sucked (induction) in through the inlet path **90** and the inlet valve **60** into compression chamber **16**. The third compression chamber **16** fills with gas as the volume of the chamber **16** progressively increases during the first piston stroke. At the same time, the volume of the second compression chamber **14** progressively decreases and any gas within the second compression chamber **14** will be forced out of the second chamber **14**, through the second intercooling conduit **74**, into the third compression chamber **16**, thereby being compressed from the volume of the second chamber **14** to the smaller volume of the third compression chamber **16**.

When the ram **82** and the piston **18** reach the end of the first piston stroke (bottom dead centre: BDC) they are located fully to the left (as orientated in the drawings). At BDC the volumes of the first and third compression chambers **12**, **16** are at their maximum and the volume of the second compression chamber **14** is at its minimum.

During the second stroke of the piston cycle, the ram **82** and piston **18** move from BDC to TDC. This forced gas in the third compression chamber **16** out of the third chamber **16**, through the first intercooling conduit **72**, and into the second compression chamber **14**, thereby compressing the gas from the volume of the third chamber **16** to the smaller volume of the second compression chamber **14**.

Simultaneously, any gas in the first compression chamber **12**, is forced out of the first compression chamber **12** and through the gas outlet conduit **75**, the flow restrictor **112** and the breakaway connector **114** into an external gas storage vessel (not shown). The gas is delivered from the first compression chamber **12** at a gas pressure equal to the current gas pressure in the external storage vessel, up to a maximum of 200 bar in this example.

As the volumes of the first and third chambers **12**, **16** are decreasing the volume of the second compression chamber **14** is simultaneously increasing back to its maximum. The duration of the complete piston cycle (TDC to BDC to TDC) is approximately 2.9 s.

As the gas flows through the intercooling conduits **72**, **74** any heat absorbed by the gas during compression is dissipated, thereby improving the thermal efficiency of compression in the next stage of compression.

None of the above described elements of the fluid compressor **10** which come into contact with fluid being processed have any lubricants, such as oils, provided on them, thereby making the fluid compressor free from contamination by lubricants on its fluid side.

The specifications of the fluid compressor **10** to deliver compressed gas having a pressure of 200 Bar are:

Compression chamber	3rd	2nd	1st
Bore diameter (mm)	120	120	20
Sleeve diameter (mm)	30	110	
Stroke length (mm)	180	180	180
Piston Area (m^2)	0.010602	0.0018	0.0003
Swept Volume (l)	1.908517	0.3251	0.0565
Gas Pressures:			
Inlet pressure (mBarg)	21		
Delivery pressure (Barg)			200
Isothermal Stage Pressure (Bara)	6.292	34.797	201.013
Gas Gamma	1.2	1.2	1
Isentropic Stage Pressure (Bara)	9.105	46.248	201.013
Compression Ratio	8.804	5.079	4.346
Gas Intake eff	90.00%		
Gas intake (l at stp)	1.655		

Where Barg is gauge pressure and Bara is absolute pressure—typically Barg+1.01325.

The hydraulic actuator **20** has a nominal 2:1 ram piston **82*a*** pressure ratio. The larger hydraulic ram piston **82*a*** area (left side: direction BDC to TDC) drives the piston **18** in the direction left to right, compressing gas within the first and third compression chambers **12**, **16**, whilst the smaller hydraulic ram piston **82*a*** area (right side: drives TDC to BDC) drives the piston **18** in the direction right to left, compressing gas within the second compression chamber **14**. By this means, the hydraulic pressure in each direction can be balanced (made the same pressure) to optimise the hydraulic pressures required in order to minimise the hydraulic flows and hence hydraulic losses within the hydraulic actuator **20**.

The specifications of the hydraulic actuator **20** are as follows:

	BDC to TDC	TDC to BDC
Bore diameter (mm)	39.5979797	39.59798
Sleeve (Drive Rod diameter) (mm)	0	28
Stroke Length (mm)	180	180
Area (m^2)	0.0012315	0.000616
Swept Volume (l)	0.22167078	0.110835
	TDC	BDC
Hydraulic Pressure (Bara)	134.459	148.185
Hydraulic Flow rate (l/m)	6.75	6.75
Stroke time (s)	1.97040691	0.985203
Peak Power (kW)	1.51266164	1.66708

The drive gear pump operates at 2.5 cc and the motor speed is 2700 rpm.

The piston cycle repeats until the pressure of the gas stored in the external storage vessel reaches a predetermined level (typically 200 bar). The compressed gas output flow rate from the fluid compressor **10** is 2.078 m^3/hour. Once the external storage vessel is full, a gas pressure sensor within the external storage vessel sends a "full" signal to the fluid compressor **10**, causing the hydraulic actuator **20** to stop.

Before the compressed fluid delivery conduit **75** can be decoupled from the external storage vessel it is necessary to remove any pressurised gas from the delivery conduit **75**. To do this, the fluid compressor **10** is 'over-run' slightly before shutdown, whilst being isolated from the external gas supply. This allows any gas remaining within the fluid compressor **10** to be processed through the compression chambers **12**, **14**, **16** and in so doing creates a vacuum in the recovery vessel **100**. The vacuum allows pressurised gas present in the delivery conduit **75** to be released into the recovery vessel **100** so that pressure in the delivery conduit **75** can be made safe without venting gas to atmosphere. The delivery conduit **75** can then safely be decoupled from the external storage vessel.

The recovery vessel **100** has a nominal volume of 20 liters, and a further 2 liters recovery volume (being the volume of the third compression chamber **16**) are available by parking the fluid compressor **10** at shutdown with the piston **18** at BDC. Without this depressurisation facility, the pressure in the inlet vessel would typically rise to 0.73 Barg (Bar gauge), which is too high for safe uncoupling. Using the recovery vessel **100** depressurisation mechanism, the pressure prior to decoupling typically falls to 35 mBarg which is a safe pressure at which to decouple the delivery conduit **75** and which does not compromise the inlet pressure at the next start up of the fluid compressor **10**

The recovery vessel **100** also has a recovery mode during operation of the fluid compressor **10**. The recovery vessel **100** acts to smooth out pressure perturbations in the inlet gas pressure supplied to the fluid compressor **10** from the external gas supply caused by the suction of the fluid compressor **10** via the induction stroke of the piston **18** within the third compression chamber **16**.

The fluid compressor **10** further comprises a fluid metering system comprising piston cycle counting means in the form of piston position sensors (not shown) operable to detect the position of the piston **18** at TDC and BDC, an incoming gas temperature sensor provided along side the incoming gas pressure sensor **102** and a microcontroller (not shown). The microcontroller is operable to count the number of times the piston **18** is located at TDC and BDC, from which the number of piston cycles can be obtained (by dividing by two), and to multiply the number of piston cycles by the volume of the third compression chamber **16**, taking account of the incoming gas pressure and temperature, to obtain the volume of gas delivered into the fluid compressor **10** from the external gas supply during an operation of the fluid compressor **10**. The microprocessor is further operable to store the incoming gas volume for a number of operations of the fluid compressor **10** and to sum these volumes to obtain the total volume of gas supplied to the fluid compressor **10** over a period of time.

A fluid compressor **120** according to a second embodiment of the invention is shown in FIG. **6**. The fluid compressor **120** of this embodiment is substantially the same as the fluid compressor **10** of the previous embodiment with the following modifications. The same reference numbers are retained for corresponding features.

In this embodiment the actuation means **122** takes the form of connecting rod **124** driven by a cam **126** coupled to an electric motor (not shown). The distal end of the connecting rod **124** is received within the coupling recess **42** on the piston **18**. The connecting rod has a length of 313 mm.

The electric motor is a 120 kW electric motor supplied by a single phase electric power supply. The electric motor is operable at a variable drive speed, in order to limit the peak power requirements which occur when the piston **18** approaches TDC and BDC. The speed of the motor driving the connecting rod **124** is primarily adjusted to limit the peak motor power so as to enable the fluid compressor **120** to be operated from a domestic single phase electrical supply.

Reducing the motor speed as the piston **18** approaches TDC and BDC has the additional advantage slowing the speed of movement of the seals **46**, **52**, **54**, **56** at their highest pressure loading points, and in so doing reduces seal wear and increases the operational lifetimes of the seals **46**, **52**, **54**, **56**. Controlling the motor speed in this way also allows higher gas throughput while pressure loading on the seals **46**, **52**, **54**, **56** is low, thereby maximising the performance when the wear attrition on the seals **46**, **52**, **54**, **56** is least.

The overall average rotational speed of the electric motor is sufficient to deliver an output compressed fluid flow of 2 m^3/hour at 200 Bar pressure.

An alternative to operating the electric motor at a variable speed is to use an eccentric cam or a non-circular cam. This would result in the effective mechanical length of the connecting rod **124** varying over a piston cycle such that the maximum torque and speed at any point around the cam is limited by the cam profile (the torque changes according to the ratio of the cam radius to the length of the connecting rod **124**) whilst the cam is driven at constant speed.

FIG. **7** shows a motor vehicle compressed natural gas refuelling apparatus **130** according to a third embodiment of the invention. The apparatus comprises a fluid compressor **10** according to the first embodiment of the invention (although it will be appreciated that the fluid compressor **120** of the second embodiment could equally well be used), a compressor housing **132**, a gas inlet conduit **134**, and an electrical power supply cable **136**.

The gas inlet conduit **134** is coupled at one end to a fluid inlet of the fluid compressor **10** and is provided with a connector at its other end for connection to a natural gas supply, in this example a domestic gas supply meter **138**.

The compressor housing **132** is provided with an air inlet **140** and an air outlet **142**, by which the apparatus **130** can be aircooled.

The compressed gas delivery conduit **75** is coupled, via its breakaway connector **114**, to the compressed gas storage vessel **144** of a motor vehicle, such as a car.

Various modifications may be made without departing from the scope of the present invention. For example, it will be appreciated that the fluid compressors **10**, **120** may be used to compress gas to a different pressure to that described, with corresponding changes in the gas flow rate. For example, if the gas is to be compressed to 20 Barg, the gas flow rate can typically be increased to 3.337 m^3/hour as a result of the reduction in the maximum torque required to drive the piston **18**.

The fluid compressors may have a different number of compression chambers to those described, and in particular may have two compression chambers (being the first and second compression chambers of the above described examples) or may have four compression chambers. The fourth compression chamber comprising the volume of the second stator chamber between the outer surface of the inner stator wall and the inner surface of the piston sleeve. It will be appreciated that additional inlet and outlet valves will be required for additional compression chambers, together with additional intercooling conduits.

Although the fluid compressors have been described in operation compressing natural gas, it will be appreciated that other gases such as nitrogen, hydrogen and air may also be compressed, as may non gaseous fluids.

The described embodiments provide various advantages as follows. Since the fluid compressors are oil-less the compressed gas is not contaminated with by an lubricants.

The nominal gas throughput of the fluid compressor **10** is 2 m^3/hour at full load, is achieved with a relatively slow moving, piston action, typically having a duration of 2.9 seconds per complete piston cycle (TDC to BDC to TDC). Compared to known fluid compressors designed to perform this type of duty, the distance travelled by the seals is less than $1/20^{th}$ of the distance travelled by seals in conventional compressors, and hence their operational lifetimes are significantly longer meaning the fluid compressors can operate longer between seal replacements. Furthermore, using a variable speed motor driven crank shaft to drive the piston further improves the longevity of the seals by slowing their speed at the point of greatest pressure loading.

The gas flow rate is determined by the swept volume of the third compression chamber, its volumetric efficiency and speed of operation (stroke time), whilst the relative sizes of swept volume determines the gas compression ratio for each stage.

The low speed of operation of the actuation means allows the hydraulic ram and the electric motor to be powered by a single phase electric power supply, enabling the fluid compressors to be used in a domestic environment.

The recovery vessel enables off-loading gas to be recycled through the compressor rather than being vented to the atmosphere prior to decoupling the delivery conduit.

It will be apparent to those skilled in the art that various modifications and variations can be made to the present invention without departing from the spirit and scope of the invention. Thus, it is intended that the present invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

The invention claimed is:

1. A fluid compressor comprising:

a first compression chamber of a first volume;

a compressed fluid outlet conduit coupled to the first compression chamber;

a second compression chamber of a second, larger volume extending concentrically around the first compression chamber;

a third compression chamber of a third volume, larger than each of the first volume and the second volume, the third compression chamber extending concentrically around the first compression chamber and being part co-linear with the second compression chamber;

a piston mounted for linearly reciprocating movement, the piston comprising a piston sleeve extending concentrically around a central piston rod, a first piston head at a distal end of the piston sleeve movable to compress fluid within the first compression chamber, and a second piston head at a distal end of the piston sleeve separating the second and third compression chambers, the second piston head being movable to compress fluid within the second compression chamber and the third compression chamber;

actuation means operable to drive the piston,

whereby as the piston is driven in a first linear direction fluid in the first and third compression chambers is compressed and compressed fluid from the third compression chamber is delivered to the second compression chamber, and, simultaneously, any gas in the first compression chamber is forced out of the first compression chamber and through the compressed fluid outlet conduit into an external gas storage vessel, and whereby as the piston is driven in the opposite direction fluid enters the third compression chamber, and any fluid in the second compression chamber is compressed and any fluid from the second compression chamber is forced out of the second compression chamber, and delivered into the first compression chamber; and

a stator defining a second stator chamber extending concentrically around a first stator chamber, the piston and the stator together defining the fluid compression chambers, the first stator chamber forming the first fluid compression chamber and the second and third compression chambers comprise parts of the second stator chamber defined by the piston and one or more walls of the second stator chamber, wherein the second fluid compression chamber comprises the volume of the second stator chamber between an outermost surface of the piston sleeve, an external wall of the second stator chamber and part of one side of the second piston head, the third fluid compression chamber comprising the volume of the second stator chamber between the other side of the second piston head and the walls of the second stator chamber.

2. A fluid compressor as claimed in claim **1**, wherein the ratio of the volumes of the compression chambers is selected to provide for substantially the same amount of fluid compression within each compression chamber.

3. A fluid compressor as claimed in claim **1**, wherein each compression chamber is provided with an inlet valve and an outlet valve, the outlet valve of the first compression chamber being coupled to the inlet valve of a subsequent compression chamber by a respective inter-cooling conduit.

4. A fluid compressor as claimed in claim **1**, wherein the actuation means comprises a hydraulic actuator coupled to the piston.

5. A fluid compressor as claimed in claim **1**, wherein the actuation means comprises a crank shaft driven by a cam coupled to an electric motor.

6. A fluid compressor as claimed in claim **5**, wherein the electric motor has a variable drive speed or the cam is an eccentric cam or a cam having a non-circular profile.

7. A fluid compressor as claimed in claim **1**, wherein the fluid compressor further comprises fluid metering means operable to measure the volume of fluid input into the fluid compressor.

8. A fluid compressor as claimed in claim **1**, wherein no part of the compressor which comes into contact with fluid being processed by the fluid compressor has any lubricants, thereby making the fluid compressor oil-less on its fluid side.

9. A fluid compressor as claimed in claim **1**, wherein the fluid comprises a gas.

10. The fluid compressor as claimed in claim **1**, further comprising:

a gas inlet conduit coupled at one end to a fluid inlet of the fluid compressor and having connection means at its other end for connection to a natural gas supply; and

electrical power connection means coupled to the actuation means.

11. A fluid compressor comprising:

a first compression chamber of a first volume;

a compressed fluid outlet conduit coupled to the first compression chamber;

a second compression chamber of a second, larger volume extending concentrically around the first compression chamber;

a third compression chamber of a third volume, larger than each of the first volume and the second volume, the third compression chamber extending concentrically around the first compression chamber and being part co-linear with the second compression chamber;

a piston mounted for linearly reciprocating movement, the piston comprising a first piston head movable to compress fluid within the first compression chamber, and a second piston head separating the second and third compression chambers, the second piston head being movable to compress fluid within the second compression chamber and the third compression chamber;

actuation means operable to drive the piston,

whereby as the piston is driven in a first linear direction fluid in the first and third compression chambers is compressed and compressed fluid from the third compression chamber is delivered to the second compression chamber, and, simultaneously, any gas in the first compression chamber is forced out of the first compression chamber and through the compressed fluid outlet conduit into an external gas storage vessel, and whereby as the piston is driven in the opposite direction fluid enters the third compression chamber, and any fluid in the second compression chamber is compressed and any fluid from the second compression chamber is forced out of the second compression chamber, and delivered into the first compression chamber, and

wherein the fluid compressor further comprises a fluid recovery vessel coupled between the compressed fluid outlet conduit and the first compression chamber, the fluid outlet conduit being arranged to be selectively coupled to and decoupled from a receiving compressed fluid storage vessel, and the fluid recovery vessel being arranged to receive compressed fluid present within the outlet conduit prior to decoupling the outlet conduit from the receiving compressed fluid storage vessel, thereby lowering the fluid pressure within the delivery conduit prior to decoupling.

12. A fluid compressor comprising:

a first compression chamber of a first volume;

a compressed fluid outlet conduit coupled to the first compression chamber;

a second compression chamber of a second, larger volume extending concentrically around the first compression chamber;

a third compression chamber of a third volume, larger than each of the first volume and the second volume, the third compression chamber extending concentrically around the first compression chamber and being part co-linear with the second compression chamber;

a piston mounted for linearly reciprocating movement, the piston comprising a first piston head movable to compress fluid within the first compression chamber, and a second piston head separating the second and third compression chambers, the second piston head being movable to compress fluid within the second compression chamber and the third compression chamber;

actuation means operable to drive the piston,

whereby as the piston is driven in a first linear direction fluid in the first and third compression chambers is compressed and compressed fluid from the third compression chamber is delivered to the second compression chamber, and, simultaneously, any gas in the first compression chamber is forced out of the first compression chamber and through the compressed fluid outlet conduit into an external gas storage vessel, and whereby as the piston is driven in the opposite direction fluid enters the third compression chamber, and any fluid in the second compression chamber is compressed and any fluid from the second compression chamber is forced out of the second compression chamber, and delivered into the first compression chamber,

wherein the actuation means comprises a crank shaft driven by a cam coupled to an electric motor, wherein the electric motor has a variable drive speed or the cam is an eccentric cam or a cam having a non-circular profile; and a metering means comprising piston cycle counting means, a fluid temperature sensor, a fluid pressure sensor, a non-transitory tangible computer readable storage medium operable to store the value of the volumetric capacity of the compression chamber into which fluid to be compressed is delivered from an external fluid supply, and processor means operable to convert the number of piston cycles into the volume of fluid delivered from the external fluid supply to the fluid compressor, wherein the number of piston cycles corresponds to the number of times that the compression chamber is filled with fluid from the external supply.

13. A fluid compressor as claimed in claim **12**, wherein the processor means is operable to write the volume of fluid delivered to the fluid compressor during a single operation of the fluid compressor to the non-transitory tangible computer readable storage medium, and is further operable to add together the volumes of fluid delivered to the fluid compressor during a plurality of operations of the fluid compressor.

14. A fluid compressor comprising:

a first compression chamber of a first volume;

a compressed fluid outlet conduit coupled to the first compression chamber;

a second compression chamber of a second, larger volume extending concentrically with the first compression chamber;

a third compression chamber of a third volume, larger than each of the first volume and the second volume, the third compression chamber extending concentrically with the first compression chamber and being part co-linear with the second compression chamber;

a piston mounted for linearly reciprocating movement, the piston comprising a first piston head at the distal end of the piston movable to compress fluid within the first compression chamber and a second piston head separating the second and third compression chambers, the second piston head being movable to compress fluid within the second compression chamber and the third compression chamber;

actuation means operable to drive the piston,

whereby as the piston is driven in a first linear direction fluid in the first and third compression chambers is compressed, and compressed fluid from the third compression chamber is delivered to the second compression chamber, and whereby as the piston is driven in the opposite direction fluid enters the third compression chamber and fluid in the second compression chamber is compressed and compressed fluid from the second compression chamber is delivered to the first compression chamber; and

a stator defining a second stator chamber extending concentrically with a first stator chamber, the piston and the stator together defining the fluid compression chambers, the first stator chamber forming the first fluid compression chamber and the second and third compression chambers comprise parts of the second stator chamber defined by the piston and one or more walls of the second stator chamber, wherein the second fluid compression chamber comprises the volume of the second stator chamber between an outermost surface of the piston, an external wall of the second stator chamber and part of one side of the second piston head, the third fluid compression chamber comprising the volume of the second stator chamber between the other side of the second piston head and the walls of the second stator chamber.

15. A fluid compressor as claimed in claim **14**, wherein the ratio of the volumes of the compression chambers is selected to provide for substantially the same amount of fluid compression within each compression chamber.

16. A fluid compressor as claimed in claim **14**, wherein each compression chamber is provided with an inlet valve and an outlet valve, the outlet valve of the first compression chamber being coupled to the inlet valve of a subsequent compression chamber by a respective inter-cooling conduit.

17. A fluid compressor as claimed in claim **14**, wherein the fluid compressor further comprises a fluid recovery vessel coupled between the compressed fluid outlet conduit and the first compression chamber, the fluid outlet conduit being arranged to be selectively coupled to and decoupled from the receiving compressed fluid storage vessel, and the fluid recovery vessel being arranged to receive compressed fluid present within the outlet conduit prior to decoupling the outlet conduit from the receiving compressed fluid storage vessel, to thereby lower the fluid pressure within the delivery conduit prior to decoupling.

18. A fluid compressor as claimed in claim **14**, wherein the actuation means comprises a hydraulic actuator coupled to the piston.

19. A fluid compressor as claimed in claim **14**, wherein the actuation means comprises a crank shaft driven by a cam coupled to an electric motor.

20. A fluid compressor as claimed in claim **19**, wherein the electric motor has a variable drive speed or the cam is an eccentric cam or a cam having a non-circular profile.

21. A fluid compressor as claimed in claim **14**, wherein the fluid compressor further comprises fluid metering means operable to measure the volume of fluid input into the fluid compressor.

22. A fluid compressor as claimed in claim **21**, wherein the fluid metering means comprises piston cycle counting means, a fluid temperature sensor, a fluid pressure sensor, a non-transitory tangible computer readable storage medium operable to store the value of the volumetric capacity of the compression chamber into which fluid to be compressed is delivered from an external fluid supply, and processor means operable to convert the number of piston cycles into the volume of fluid delivered from the external fluid supply to the fluid compressor, wherein the number of piston cycles corresponds to the number of times that the compression chamber is filled with fluid from the external supply.

23. A fluid compressor as claimed in claim **22**, wherein the processor means is operable to write the volume of fluid delivered to the fluid compressor during a single operation of the fluid compressor to the a non-transitory tangible computer readable storage medium, and is further operable to add together the volumes of fluid delivered to the fluid compressor during a plurality of operations of the fluid compressor.

24. A motor vehicle compressed natural gas refuelling apparatus comprising:

a compressor housing comprising:

a first compression chamber of a first volume;

a compressed fluid outlet conduit coupled to the first compression chamber;

a second compression chamber of a second, larger volume extending concentrically with the first compression chamber;

a third compression chamber of a third volume, larger than each of the first volume and the second volume, the third compression chamber extending concentrically with the first compression chamber and being part co-linear with the second compression chamber;

a piston mounted for linearly reciprocating movement, the piston comprising a first piston head at the distal end of the piston movable to compress fluid within the first compression chamber and a second piston head separating the second and third compression chambers, the second piston head being movable to compress fluid within the second compression chamber and the third compression chamber;

actuation means operable to drive the piston,

whereby as the piston is driven in a first linear direction fluid in the first and third compression chambers is compressed, and compressed fluid from the third compression chamber is delivered to the second compression chamber, and whereby as the piston is driven in the opposite direction fluid enters the third compression chamber and fluid in the second compression chamber is compressed and compressed fluid from the second compression chamber is delivered to the first compression chamber; and

a stator defining a second stator chamber extending concentrically with a first stator chamber, the piston and the stator together defining the fluid compression chambers, the first stator chamber forming the first fluid compression chamber and the second and third compression chambers comprise parts of the second stator chamber defined by the piston and one or more walls of the second stator chamber, wherein the second fluid compression chamber comprises the volume of the second stator chamber between an outermost surface of the piston, an external wall of the second stator chamber and part of one side of the second piston head, the third fluid compression chamber comprising the volume of the second stator chamber between the other side of the second piston head and the walls of the second stator chamber;

a gas inlet conduit coupled at one end to a fluid inlet of the fluid compressor and having connection means at its other end for connection to a natural gas supply; and

electrical power connection means coupled to the actuation means.

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