Nov. 10, 1964 P. W. CURWEN 3,156,405

RESONANT PISTON COMPRESSOR

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FIG. 1.

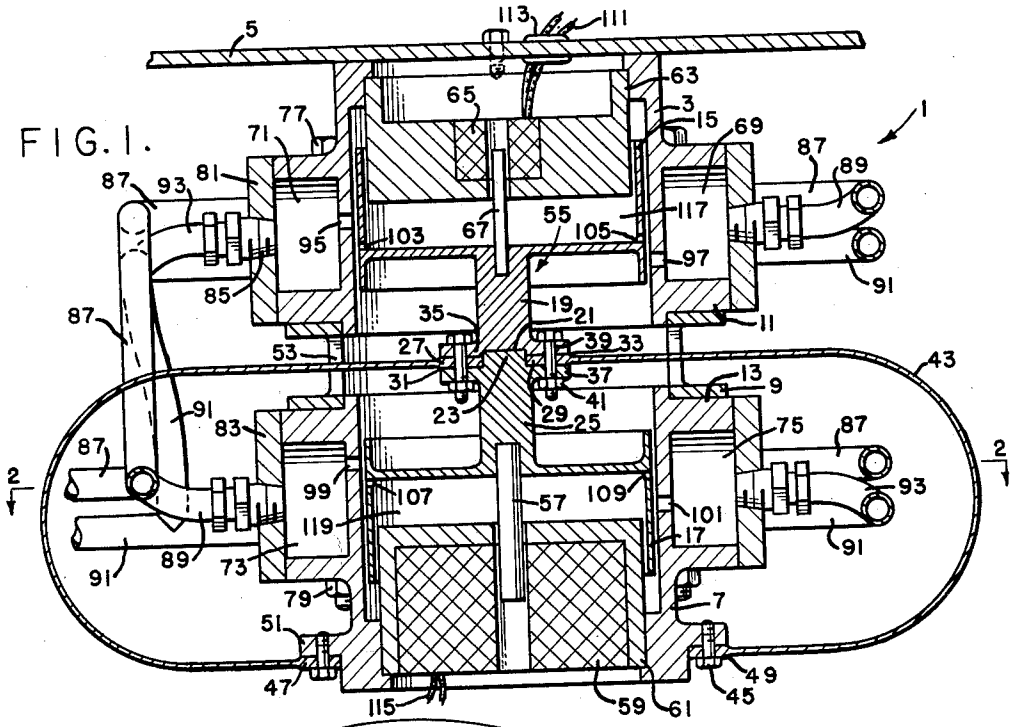
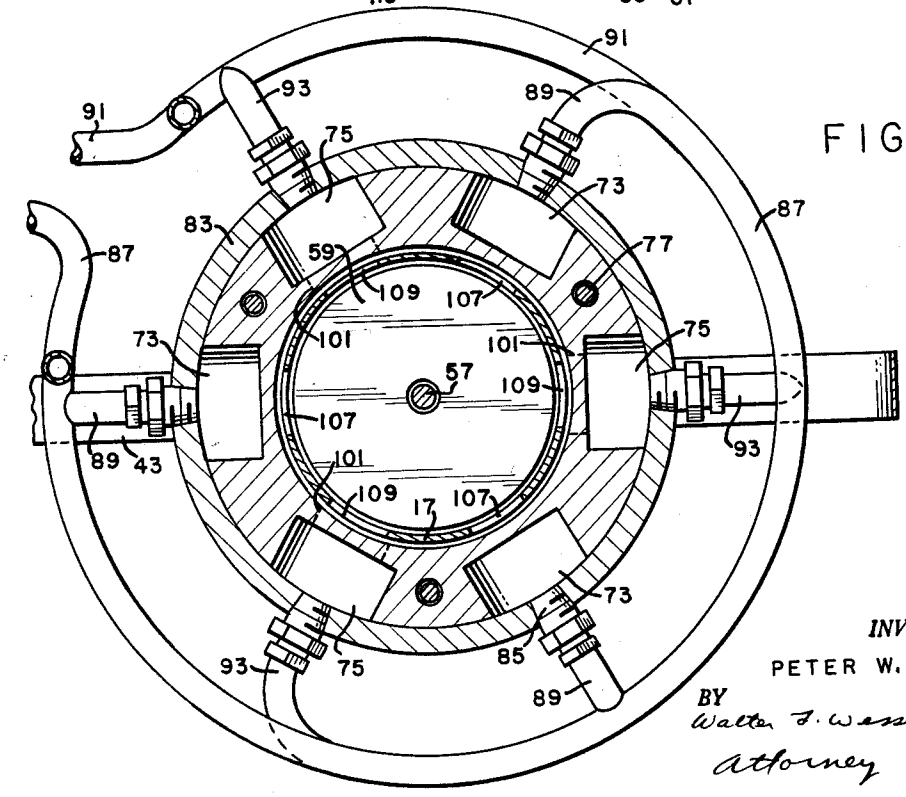


FIG. 2.



INVENTOR.
PETER W. CURWEN
BY
Walter J. Wessendorf
Attorney

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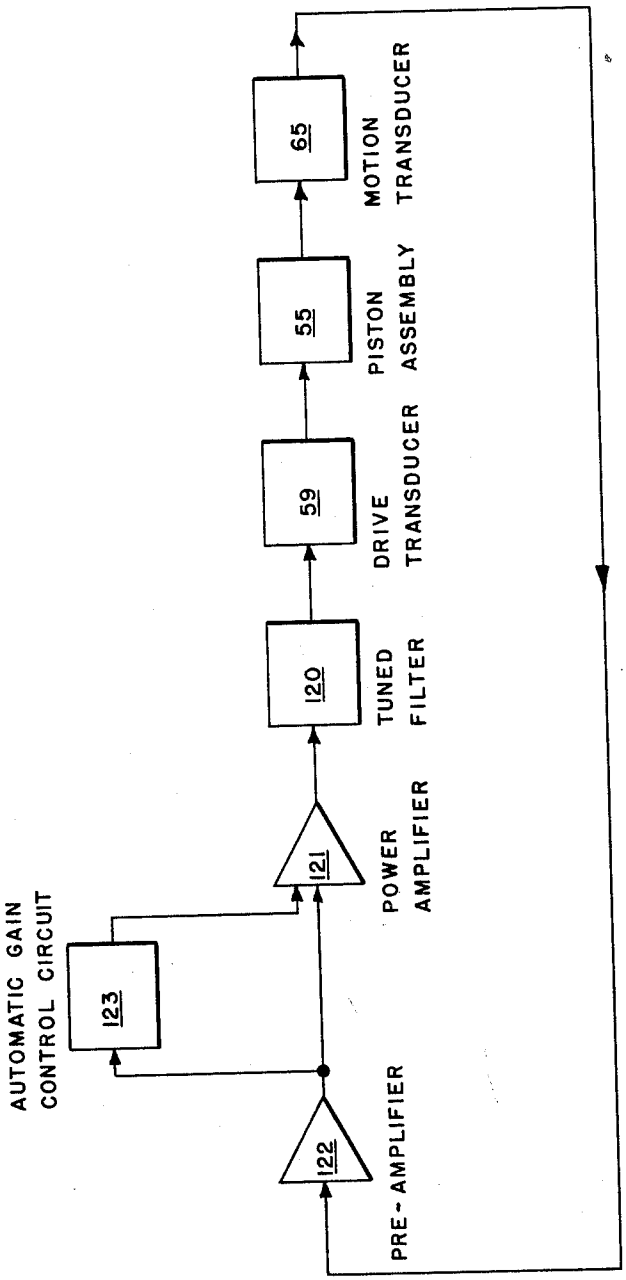


FIG. 3.

INVENTOR.
PETER W. CURWEN
BY
Walter F. Wessendorf Jr
attorney

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RESONANT PISTON COMPRESSOR

Peter W. Curwen, Burnt Hills, N.Y., assignor to Mechanical Technology Incorporated, Latham, N.Y., a corporation of New York

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18 Claims. (Cl. 230—55)

This invention relates to the art of piston compressors and is particularly well adapted for use in satellites, missiles and other terrestrial or celestial space vehicles to supply compressed gas. On the one hand the piston compressor, as adapted, may be utilized to supply compressed gas to gas bearing gyroscopes, accelerometers and the like where a closed gas system is required; on the other hand, however, the compressor may be utilized in open gas systems as represented by such common devices as aquarium air pumps, paint spraying or atomizing devices.

The problems in the art are to provide a compressor which is simple of design, will be of long life, will be highly reliable and is a small compact package.

This invention solves the problems in the art and inclusive of its features is the elimination of rubbing and sliding parts concomitant with a minimum of mechanical parts and no wearing surfaces of the parts.

An electronic drive and control circuit is coupled to the piston assembly of the piston-flexure or spring-mass system by means of electromechanical force and motion transducers. The combination of drive and control circuitry, transducers and piston-flexure system are interconnected to form a closed loop, self-oscillating system. The piston-flexure system is always driven at the fundamental resonant frequency of the electromechanical system regardless of shifts in this resonant frequency caused by temperature or aging effects on the component parts of the system.

These features and accomplishments and others should be appreciated from the detailed specification taken in conjunction with the drawings in which like reference numerals refer to similar parts throughout the views, in which:

FIG. 1 is a sectional view of the invention;

FIG. 2 is a sectional view taken along the line 2—2 of FIG. 1;

FIG. 3 is a block-diagram of the control and drive circuitry.

Reference numeral 1 generally refers to the invention showing an upper cylinder 3 suitably secured to support structure 5. Arranged intermediate upper cylinder 3 and lower cylinder 7 and suitably secured therewith is cylindrical spacer 9 of U-shaped configuration in cross-section. Flange 11 formed in the bottom portion of upper cylinder 3 and flange 13 formed in the top portion of lower cylinder 7 receive spacer 9 in abutting relationship therewith.

Received and reciprocable within the cylinders 3 and 7 is a double piston comprising an upper piston 15 and a lower piston 17. The piston body 19 of upper piston 15 has formed in the bottom portion thereof a female recess 21 to receive therein a male member 23 formed in the top portion of lower piston body 25 of lower piston 17.

Tails 27 and 29 of the U-shaped spring, rectangular in cross-section, are received in respective complemental slotted openings 31 and 33 formed by the flanges 35 and 37 that extend laterally from their respective upper piston body 19 and lower piston body 25.

As arranged and disposed in the slotted openings 31 and 33, tails 27 and 29 are secured between flanges 35 and 37 by bolts 39 disposed through aligned holes formed

in flanges 35 and 37 and tails 27 and 29, with nuts 41 engaged with the threaded portions of bolts 39.

Notwithstanding the flat and U-shaped configuration of spring 43, spring 43 may be of any appropriate configuration provided the spring performs the function hereinafter described.

Cap screw 45, extending through holes formed in tails 47 and 49 of spring 43, engage tapped holes formed in flange 51 which extends laterally from the bottom portion of lower cylinder 7.

Two slotted openings 53 formed in opposed sides of cylindrical spacer 9 permit free movement of spring 43 therein.

The piston assembly, also referred to as the piston-flexure or spring mass system, is referred to generally by reference numeral 55 and comprises the pistons 15, 17 and spring 43. Reciprocation or vibration of the piston assembly 55 is effected by a magnetized or plain iron core 57 of the solenoid or drive transducer 59. Transducer 59 is suitably secured to the internal flange 61 formed in lower cylinder 7. The core 57 is suitably secured to lower piston body 25.

Suitably secured to internal flange 63 formed in upper cylinder 3 is feedback motion transducer 65, also designated as displacement or velocity transducer, with its core 67 suitably secured to upper piston body 19.

Formed in the upper cylinder 3 are three intake chambers 69 and alternately disposed therebetween are three discharge chambers 71 with symmetrical arrangement thereall maintained of such disposition.

Formed in lower cylinder 7 are three intake chambers 73 and alternately disposed therebetween are three discharge chambers 75 with symmetrical arrangement thereall maintained of such disposition.

The suitable securement of upper cylinder 3, lower cylinder 7 and cylindrical spacer 9 is effected by bolts 77 disposed in aligned holes formed through cylinders 3, 7 and spacer 9 with nuts 79 engaged with the threaded portion of bolts 77 as shown.

Suitably secured to upper cylinder 3 and lower cylinder 7 are respective chamber closure rings 81 and 83. Tapped holes are formed laterally adjacent through each of the chamber closure rings 81 and 83 to permit communication internally of chambers 69, 71, 73 and 75 by means of male pipe fittings 85. Disposed externally of the cylinders 3 and 7 is a common intake manifold 87 in communication with the intake chambers 69 and 73 by appropriate piping branches 89 leading from common intake manifold 87.

Disposed externally of cylinders 3 and 7 is a common discharge manifold 91 in communication with discharge chambers 71 and 75 by appropriate piping branches 93 leading from common discharge manifold 91.

In the upper cylinder 3, slotted openings or discharge ports 95 are formed in the top portion of discharge chamber 71 and slotted openings or intake ports 97 are formed in the bottom portion of intake chamber 69; and in the lower cylinder 7, slotted openings or intake ports 99 are formed in the top portion of intake chamber 73 and slotted openings or discharge ports 101 are formed in the bottom portion of discharge chamber 75.

In radial alignment for registration with the slotted openings or ports 95, 97, 99 and 101 are respective slotted discharge ports 103 and slotted intake ports 105 formed in the upper piston 15 for communication internally of piston 15, and respective slotted intake ports 107 and slotted discharge ports 109 formed in the lower piston 17 for communication internally of piston 17.

Wires 111 lead from feedback motion transducer 65 through grommet 113 to electronic control and drive circuitry. Wires 115 lead from solenoid 59 to the same control and drive circuitry.

Either conventional or specially designed electronic circuits may be utilized with the embodiment of the invention described and shown so long as the operative function described below is obtained; the electronic circuits may utilize either vacuum tube or solid-state circuit elements. The solenoid or drive transducer 59 is connected to and becomes part of the tuned filter circuit 120. The tuned filter circuit 120 is designed to have approximately the same resonant frequency as the piston-flexure-gas system. It should be noted and appreciated that the gas in each one of the compression chambers 117 and 119 exerts a restoring force on their respective pistons 15 and 17 as the gas in these compression chambers 117 and 119 is compressed. The gas hence acts as a pneumatic spring. This pneumatic spring effect along with spring 43 and the mass of the pistons 15 and 17 determine the resonant frequency of the piston assembly 55. Electrical power is supplied to the tuned filter circuit 120 and the drive transducer 59 by the power amplifier 121. The electrical signal from the feedback motion transducer 65, which detects the motion of piston assembly 55, is amplified by the pre-amplifier 122. The electrical signal from pre-amplifier 122 drives power amplifier 121. The piston-flexure system, drive and motion transducers, and electronic drive circuit are thus connected in a closed loop feedback oscillator configuration. When the voltage gain of pre-amplifier is adjusted to a sufficiently high value, self-oscillation of the electromechanical system begins and the piston undergoes a reciprocating or vibrating motion at the resonant frequency of the electro-mechanical system. The electrical signal from pre-amplifier 122 also feeds into the automatic gain control circuit 123. The automatic gain control circuit controls the gain of the power amplifier 121 such that the amplitude of the reciprocating or vibrating motion of the piston assembly 55 is maintained at a pre-selected constant value.

Radial clearance around the pistons 15 and 17 will be approximately 0.0005 inch to minimize leakage from their respective chambers 117 and 119. The separate common manifolds for each of the intake and discharge ports maintain balanced forces on the piston assembly 55 preventing wobble or other eccentric movement.

The small leakage of gas provides a hydrostatic gas lubricating film between the piston skirts and the walls of the cylinders, and which can be characterized as a telescopic relationship. This film, in addition to very precise manufacturing tolerances and symmetry of piston loadings, eliminates actual sliding contact between the piston assembly and the cylinders. Losses attributable to viscous shear between piston assembly and cylinders, and total leakage flow, are negligible in terms of system performance.

Excitation of solenoid 59, suffice it to say, actuates the reciprocation or vibration of the piston assembly 55 with downward movement placing a compressive force on spring 43 and upward movement placing the spring 43 under tension.

When ports 105, upon downward movement, are in communication with openings 97, gas will be drawn into chamber 117 as a result of the partial vacuum in chamber 117. Further downward movement of piston assembly 55 will permit ports 109 to communicate with openings 101 and release the compressed gas trapped in chamber 119.

Upward movement of piston assembly 55 first relieves the compressive force upon spring 43 and further upward movement places the spring 43 under tension. When ports 107, upon upward movement are in communication with openings 99, gas will be drawn into chamber 119 as a result of the partial vacuum in chamber 119. Further upward movement of the piston assembly 55 will permit ports 103 to communicate with openings 95 and release the compressed gas trapped in chamber 117.

Having thusly described my invention, I claim:

1. A resonant piston compressor for compressing gas and supplying same to a gas system, comprising a piston assembly, an electronic drive circuit including electromechanical force and motion transducers, and upper and lower cylinders; said piston assembly being coupled to said electronic drive circuit through said electromechanical force and motion transducers to always drive said piston assembly at resonance, said piston assembly comprising upper and lower pistons received within and reciprocable within said cylinders with a spring connected to said piston assembly and to one of said cylinders, said upper and lower cylinders having intake and discharge chambers communicating internally of said cylinders and pistons, said electromechanical force and motion transducers including a feedback motion transducer, a drive transducer operatively connected to one of said pistons to drive said piston assembly and with the motion of said driven piston assembly detected by said feedback motion transducer operatively connected to the other one of said pistons to thereby drive said piston assembly at its resonant frequency.

2. The subject matter as claimed in claim 1, wherein are provided separate common intake and discharge manifolds having piping branches communicating with said respective intake and discharge chambers of said cylinders.

3. The subject matter as claimed in claim 2, wherein said intake and discharge chambers of said cylinders are laterally disposed.

4. The subject matter as claimed in claim 3, wherein each one of said cylinders has three intake chambers and three discharge chambers disposed therebetween.

5. The subject matter as claimed in claim 1, wherein said spring is of flat and U-shaped configuration.

6. The subject matter as claimed in claim 1, wherein said drive transducer has a core secured to one of said piston bodies.

7. The subject matter as claimed in claim 6, wherein said feedback motion transducer has a core secured to the other of said piston bodies.

8. The subject matter as claimed in claim 1, wherein one of said pistons has a female recess formed in its body to receive a male member formed on the body of said other piston, wherein said spring has tails, wherein said piston bodies have flanges laterally extending therefrom, and wherein said tails of said spring are received in complemental slotted openings formed in said flanges.

9. The subject matter as claimed in claim 1, wherein a cylindrical spacer is disposed between said cylinders and wherein a slotted opening is formed on each side of said cylindrical spacer to permit free movement of said spring therein.

10. The subject matter as claimed in claim 1, wherein said intake and discharge chambers having openings formed therethrough for communication internally of said cylinders from said intake and discharge chambers.

11. The subject matter as claimed in claim 10, wherein said pistons have ports formed therethrough for communication internally of said chambers upon registration of said openings and ports.

12. The subject matter as claimed in claim 1, wherein each of said discharge chambers of said upper cylinder has a slotted opening formed through its upper portion for communication internally of said upper cylinder from each of said upper cylinder discharge chambers, wherein each of said intake chambers of said upper cylinder has a slotted opening formed through its lower portion for communication internally of said upper cylinder from each of said upper cylinder intake chambers, wherein each of said intake chambers of said lower cylinder has a slotted opening formed through its upper portion for communication internally of said lower cylinder for each of said lower cylinder intake chambers, and wherein each of said discharge chambers of said lower cylinder has a slotted opening formed through its lower portion for communication internally of said lower cylinder from each of said lower cylinder discharge chambers.

13. The subject matter as claimed in claim 12, wherein said upper piston has intake and discharge ports formed therethrough in radial alignment, respectively, with said slotted openings formed through said intake and discharge chambers of said upper cylinder for communication internally of said upper piston from said upper cylinder intake and discharge chambers upon registration of said slotted openings and ports, respectively, and wherein said lower piston has intake and discharge ports formed therethrough in radial alignment, respectively, with said slotted openings formed through said intake and discharge chambers of said lower cylinder for communication internally of said lower piston from said lower cylinder intake and discharge chambers upon registration of said slotted openings and ports, respectively.

14. A resonant piston compressor for compressing gas and supplying same to a gas system, comprising a piston assembly, an electronic drive circuit including electromechanical force and motion transducers, and upper and lower cylinders; said piston assembly being coupled to said electronic drive circuit through said electromechanical force and motion transducers to always drive said piston assembly at resonance, said piston assembly comprising upper and lower pistons and a spring, said upper and lower cylinders each having intake and discharge chambers communicating internally of said cylinders and said pistons, said intake and discharge chambers of each cylinder being arranged laterally of each cylinder, coplanar and symmetrically disposed, said upper and lower pistons being received within and reciprocable within said cylinders, said spring having tails and each of said pistons of said piston assembly having a body, said piston bodies having flanges laterally extending therefrom, said tails of said spring being received in complemental slotted openings formed in said flanges, said electromechanical force and motion transducers including a feedback motion transducer, a drive transducer operatively connected to one of said pistons to drive said piston assembly and with the motion of said driven piston assembly detected by said feedback motion transducer operatively connected to the other one of said pistons to thereby drive said piston assembly at its resonant frequency.

15. The subject matter as claimed in claim 14, wherein said cylinders have flanges formed internally thereof and wherein said drive and feedback motion transducers are secured in abutting relationship with said internally formed flanges of said cylinders.

16. The subject matter as claimed in claim 14, wherein

are provided a common intake manifold having piping branches communicating with said intake chambers of said cylinders and a common discharge manifold having piping branches communicating with said discharge chambers of said cylinders.

17. The subject matter as claimed in claim 14, wherein each of said discharge chambers of said upper cylinder has a slotted opening formed through its upper portion for communication internally of said upper cylinder from each of said upper cylinder discharge chambers, wherein each of said intake chambers of said upper cylinder has a slotted opening formed through its lower portion for communication internally of said upper cylinder from each of said upper cylinder intake chambers, wherein each of said intake chambers of said lower cylinder has a slotted opening formed through its upper portion for communication internally of said lower cylinder from each of said lower cylinder intake chambers and wherein each of said discharge chambers of said lower cylinder has a slotted opening formed through its lower portion for communication internally of said lower cylinder from each of said lower cylinder discharge chambers.

18. The subject matter as claimed in claim 17, wherein said upper piston has intake and discharge ports formed therethrough in radial alignment, respectively, with said slotted openings formed through said intake and discharge chambers of said upper cylinder for communication internally of said upper piston from said upper cylinder intake and discharge chambers upon registration of said slotted openings and ports, respectively, and wherein said lower piston has intake and discharge ports formed therethrough in radial alignment, respectively, with said slotted openings formed through said intake and discharge chambers of said lower cylinder for communication internally of said lower piston from said lower cylinder intake and discharge chambers upon registration of said slotted openings and ports, respectively.

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LAURENCE V. EFNER, *Primary Examiner.*

ROBERT M. WALKER, JOSEPH H. BRANSON, JR., *Examiners.*