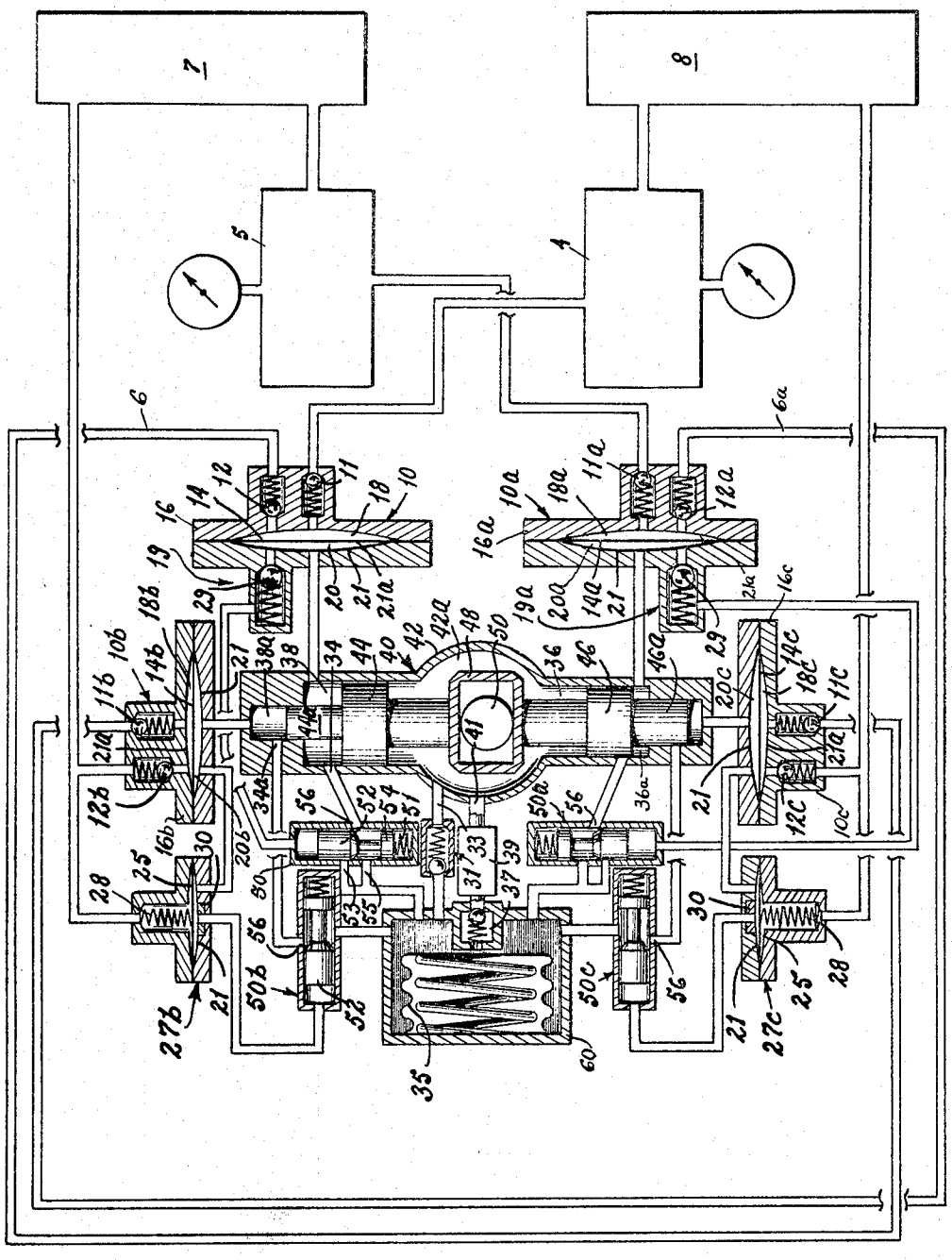
Oct. 4, 1966 J. R. JONES ETAL 3,276,673

CONTAMINANT FREE COMPRESSOR

Filed May 10, 1963



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United States Patent Office

3,276,673

Patented Oct. 4, 1966

3,276,673

CONTAMINANT FREE COMPRESSOR

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Filed May 10, 1963, Ser. No. 279,585
9 Claims. (Cl. 230—20)

This invention relates to compressors and more particularly to contaminant free compressors and control systems therefor.

It is an object of this invention to provide a compressor in which the compressed medium or media are kept free of contaminants.

A further object of the invention is to provide a dual stage compressor for two different gases.

Still another object of the invention is to provide a compressor having a plurality of stages in which the compressor actuating fluid and the compressed media are segregated to keep the compressed media contaminant free.

A further object of the invention is to provide a dual stage compressor for two gases in which the gases are segregated from the compressor actuating fluid by resilient diaphragm members, the actuating fluid flow being regulated by a servo system.

Other objects and advantages of the present invention will become more apparent upon reference to the following specification and annexed figure.

In the present invention a compressor system having high efficiency performance capability is obtained through the use of what is termed a multiple stage duplex system. The compressor is adapted to compress two separate and distinct gases in a plurality of stages and the compressed gases may then be utilized in cooperation with other elements, such as in a refrigeration cycle. The compressor of the present invention uses a plurality of hydraulically actuated compressor elements which have a barrier in the form of a resilient diaphragm to segregate the compressor actuating fluid from the compressed medium. This assures that the compresser medium will not become contaminated with foreign substances or particles. Additionally, the present invention includes a hydraulic servo system to correlate and automatically regulate the interaction of the actuating fluid driving mechanism and the diaphragmed compressor elements. A compressor of the type disclosed herein, due to its high efficiency and other advantageous factors is ideally suited for use in high performance cooling systems that are generally categorized as extremely low temperature or cryogenic systems.

The compressor, actuating mechanism and control system is schematically illustrated in the figure. A two stage system is shown for operating with two separate and distinct gas supplies **4** and **5**. These supplies may contain the same or different gases which may be, for example, nitrogen and hydrogen respectively. The primary or first stage compressor elements are designated by the reference numerals **10** and **10***a* and are each connected to respective gas supply source **4** and **5**. The secondary stage compressor elements, designated by the reference numerals as **10***b* and **10***c*, are arranged to cooperate with the respective primary compressor elements **10** and **10***a*. This dual stage operation contributes an important factor to the exceptionally high performance characteristics of the present device.

Each of the four compressor elements **10**, **10***a*, **10***b*, and **10***c* is of the diaphragm type and of substantially the same configuration, the only variation being in the sizing of the primary stage and secondary stage elements. The description which follows applies to all four compressor elements **10**, **10***a*, **10***b*, and **10***c*.

Each of the compressor elements is provided with a respective resilient diaphragm member **14**, **14***a*, **14***b* and **14***c* which is situated within a cavity having walls **21** and **21***a* formed in a respective housing **16**, **16***a*, **16***b* and **16***c*. The resilient diaphragms are preferably of metal although other suitable material may be used. For purposes of clarity, each diaphragm member is shown in a middle position within its respective cavity to clearly illustrate the fact that a diaphragm segregates its cavity into two distinct chambers. The respective chambers **18**, **18***a*, **18***b* and **18***c* on one side of the diaphgrams are exposed to the media to be compressed while the chambers **20**, **20***a*, **20***b* and **20***c* on the other side of the diaphragms are exposed to an actuating fluid. The shape of each cavity is such that it will readily accommodate the shape of its diaphragm when the diaphragm is deflected in one direction or the other.

The chambers **18**, **18***a*, **18***b* and **18***c* formed between one side of a respective compressor element and resilient member **14**, **14***a*, **14***b* and **14***c* form portions of two closed loop gas systems. In the present arrangement which is illustrative of a cascaded closed cycle high performance refrigeration system, the chambers **18** and **18***c* of the compressor elements **10**, **10***c* form part of a first gas circuit while the chambers **18***a* and **18***b* of the compressor elements **10***a* and **10***b* are part of a separate second gas circuit.

Each of the elements **10**, **10***a*, **10***b* and **10***c* is provided with a respective gas inflow valve **11**, **11***a*, **11***b* and **11***c* and a gas outflow valve **12**, **12***a*, **12***b* and **12***c*. The valves are schematically illustrated as being conventional spring loaded check valves. Inlet valves **11** and **11***a* are between the respective sources **4** and **5** and compressor elements **10** and **10***a* while valves **11***b* and **11***c* control the flow of gas from the elements **10** and **10***a* to the respective elements **10***c* and **10***b*. The outflow valves **12**, **12***a*, **12***b* and **12***c* are utilized to facilitate the exit of gases being compressed from a respective gas chamber **18**, **18***a*, **18***b* and **18***c*. Valves **12***b* and **12***c* communicate with the utilization devices **7** and **8** which may be, for example, cryostats.

A plurality of conduits are arranged to permit the inflow and outflow valves just mentioned to communicate. There, the gases compressed in the primary stage compressors **10** and **10***a* are directed through outflow valves **12** and **12***a* by means of conduits **6** and **6***a* to the corresponding inflow valves **11***b* and **11***c* of the second stage compressors.

The surfaces of the resilient diaphragm members **14**, **14***a*, **14***b* and **14***c* in the respective chambers **20**, **20***a*, **20***b* and **20***c* are exposed to an actuating fluid. When the fluid is directed against a diaphragm member under sufficient pressure to overcome the resiliency of the diaphragm and the pressure of the gas in the respective chamber on the other side of the diaphragm, the diaphragm is displaced until it abuts the extremity **21***a* of the cavity on the chamber side holding the gas. This compresses the gas and directs it through the outflow valve of the compressor element. In this manner each compressor element in the system performs its function of increasing the pressure of the gas in its particular circuit or loop.

The compressor elements are operated in a two stage sequence by an actuating fluid pumping mechanism **40**. The pumping mechanism is driven by some external means which may, for example, take the form of an electric motor (not shown). The pumping mechanism is located in a housing **42** and includes a pair of stepped pistons **44**, **44***a*, and **46**, **46***a* which are fixed to and disposed on either side of a yoke member **48**. If desired individual piston and yoke drives may be used instead of the dual arrangement shown. Connected to the yoke member **48** to impart a reciprocal motion thereto, is

an eccentrically mounted drive shaft **50**. The shaft is driven by an external power source.

When the shaft **50** is rotated, the yoke member **48** and the other associated mechanisms including stepped pistons **44**, **44***a* and **46**, **46***a* are caused to reciprocate within correspondingly stepped and stationary upper and lower cylinder heads **38**, **38***a* and **36**, **36***a* respectively. In this manner the reciprocating pistons within the stationary cylinders cooperate to alternately pump, in well known fashion, an actuating fluid, such as oil, from a reservoir **60**, first to one stepped cylinder head which accommodates pistons **44** and **44***a* and then the oppositely disposed cylinder head which accommodates stepped piston **46**, **46***a*. The fluid in reservoir **60** is kept under pressure by a bellows **35**.

The pumping system provides for the pumping of fluid by the undersurfaces of the wider area pistons **44** and **46**, within a control portion of the housing **42**, which will hereinafter be referred to as the crankcase **42***a*. Pistons **44** and **46** pump the actuating fluid through an outlet port **41** in the crankcase **42** and then thence through a conduit into a cooling element **39**. The actuating fluid dissipates heat in the cooling element **39** before being delivered through a check valve **37** into the fluid reservoir **60**.

As illustrated in the drawing, conduit **33** and its associated check valve **31** parallels the cooling element **39** and provides for the direct communication of actuating fluid between the fluid reservoir **60** and the crankcase **42***a* of the pumping mechanism. In this connection, it should be noted that the actuating fluid cools, by contact with the resilient diaphragm members in the compressor elements, the gases being compressed. This cooling arrangement, which is inherent in the compressor system, removes most of the heat of compression from the gas. However, a portion of the actuating fluid is continuously circulated through the cooler **39** thereby maintaining the fluid temperature and all other related mechanisms at a relatively constant desirable temperature, which is unusually low for compressors of comparable performance.

The fluid chambers **20** and **20***b* of compressor elements **10** and **10***b*, which correspond respectively to the first stage compressor for a first gas compression loop (source **4**) and the second stage compressor for a second gas compression loop (source **5**) respectively, are adapted to communicate with the upper stepped cylinder heads **38** and **38***a* respectively. The piston member **44**, **44***a* is accommodated within the stepped cylinder **38**, **38***a* so that when the piston moves into these cylinders, pressure is transmitted to the actuating fluid. This displaces the fluid and causes it to exert force on the resilient diaphragm members **14**, **14***b* of the compressor elements **10** and **10***b*. Consequently, the diaphragms **14** and **14***b* are caused to deflect thereby affecting compression of the gases in their respective chambers **18** and **18***b*.

Since the opposite extremity of the pumping mechanism is equipped with the stepped piston **46**, **46***a* which is accommodated with the stepped cylinder **36**, **36***a*, when the piston is actuated through the yoke mechanism in the direction opposite to that just described, actuating fluid is compressed thereby and delivered in similar fashion to the diaphragms **14***a* and **14***c* of the compressor elements **10***a* and **10***c*. This causes the gases in the respective chamber **18***a* and **18***c* to be compressed thereby operating the second stage of the first loop and the first stage of the second loop.

The injection of hydraulic fluid into the cylinder heads of the actuating pump mechanism **40** is of great importance to the overall efficiency of the compressor mechanism. Accordingly, a fluid metering system is provided to effectively control the admission of actuating fluid to the cylinder heads so that the piston elements are not required to pump more fluid than is necessary to actuate the compressor elements and supply actuating fluid to a self-regulating servo control system.

To carry out the fluid metering uni-directional check valves **19** and **19***a* are provided for the two primary stage compressor elements **10** and **10***a*. These check valves are shown as being of the conventional spring loaded variety which operate in well known fashion to overcome the spring force and permit flow when sufficient force has been applied against the valve sealing member **29**. Additional check valves **27***b* and **27***c* are provided to cooperate with the second stage compressor elements **10***b* and **10***c* to regulate the inflow of actuating fluid to the reduced area portions of the stepped cylinders of the actuating fluid pump which are connected to the actuating fluid chambers **20***b* and **20***c* of the second stage compressor elements. Each of the check valves **19**, **19***a* and **27***b*, **27***c* is arranged to communicate with a respective actuating fluid chambers **20**, **20***a*, **20***b* and **20***c* and operate to direct actuating fluid to respectively connected fluid metering valves **50**, **50***a*, **50***b*, and **50***c* disposed between the actuating fluid chambers of the compressor elements and the actuating fluid supply reservoir **60**.

Since the primary function of the relief check valves **19**, **19***a*, **27***b* and **27***c* is to bypass that fluid under pressure not actually required to drive the diaphragm of the respectively connected compressor elements, each valve is effectually responsive to the pressure of the gas being compressed in the respectively connected element. For this reason the relief valves **27***b*, **27***c* associated with the second stage of compression elements **10***b* and **10***c* are of modified configuration and consequently are better able to accommodate the extremely high pressures in the second stage compression without the attendant need to subject the compressor element diaphragm members to excessive stresses. To accomplish this the valves **27***b*, **27***c* which perform a function comparable to that of the previously described valves **19** and **19***a* are provided with resilient diaphragms **25** which are exposed on one side to the pressure of the gases being compressed in the second stages of compression and additionally biased in the same direction by a spring force provided by springs **28**. These forces are opposed by the actuating fluid pressures which are communicated from the fluid chambers of the second stage compressor elements to the opposite sides of diaphragms **25** of each valve **27***b*, **27***c*. Consequently the force unbalance on either side of the diaphragms **25** causes the diaphragms **25** to assume a reference position with respect to a respective fluid outflow port **30** thereby affecting a throttling action and regulating the flow of actuating fluid which is permitted to escape through the port **30** and through suitable conduits to the fluid metering valves **50***b* and **50***c*.

The metering of actuating fluid to the various cylinders of the actuating pump **46** is related to the position of the control elements of the metering valves. These valves affect the amount of flow of actuating fluid from the reservoir supply **60** to the respective cylinders. Each of the metering valves **50**, **50***a*, **50***b* and **50***c* is identical in function as well as configuration and for this reason a description of one suffices for all.

The metering valve **50** is provided with fluid inflow ports **53** and **55** which are in communication with the pressurized fluid reservoir **60**. An outflow port **56** communicates between valve **50** and the upper fluid pump cylinder head. Interposed between the inflow and outflow ports is a variable position double spool **52**, **54** which is adapted to be biased in one direction by a spring **51** and in the opposite direction by the fluid pressure communicated from the connected bypass valve **19**. It will be noted that the undersurface of the spool **52** is provided with a chamfer which in combination with the outflow port provides a modulated fluid flow to the cylinder **38**. It will be further noted that the inflow ports **53** and **55** are so disposed with relation to the spool, that when the spool is in one extreme position the spring **51** is fully extended

and the flow from the inflow ports to the outflow port is unimpeded. Such is the condition upon start up, prior to the time when the fluid pump generates fluid pressure.

Once in operation however the fluid bypassed by the valve **19** reacts against the undersurface of spool **52** tending to counteract the spring force and modulate the position of the spool according to the amount of flow of actuating fluid communicated from the fluid chamber **20** of the compressor element **10**.

The spools **52** of the other metering valves **50***a*, **50***b* and **50***c* are controlled by the fluids in the respective chambers **20***a*, **20***b* and **20***c* of the elements **10***a*, **10***b* and **10***c* as applied to the spools through the respective bypass valves **19***a*, **27***b* and **27***c*. In this manner the quantity of fluid admitted into the upper and lower stepped cylinders of the fluid pump **40** is a function of the bypass valve settings which is in turn a function of the compressed gas pressure. Accordingly the amount of fluid admitted to the pump is tailored to the needs of the system so that only the necessary amount of fluid is pumped. This contributes to the high efficiency of the system.

A typical cycle of operation of the system will now be described. With the machine at rest the closed loop gas circuit, which in the present system contains gas under pressure, causes the gas chambers **18**, **18***a* of the first stage compressor elements **10** and **10***a*, and chambers **18***b*, **18***c* of the second stage compressor elements **10***b* and **10***c* to become filled by virtue of the respective inflow valves **11**, **11***a*, **11***b* and **11***c*. Additionally, the relief valves **27***b*, **27***c* will be pressurized by the gas. Therefore, the resilient diaphragm members in each compressor element as well as the diaphragm members **25** in the relief valves **27***b*, **27***c*, these members not being influenced by actuating fluid due to the inaction of the pump, are deflected by the gases and bedded against the surfaces **21** of each of their respective cavities. Since fluid actuating pressure will not be generated by the pump until the drive shaft is rotated, the spools of each of the metering valves **50**, **50***a* **50***b* and **50***c* will be dead ended against their respective housings with the springs **51** fully extended. In this manner the actuating fluid under slight pressure from the reservoir **60** by virtue of bellows **35** is permitted to flow unimpeded through the metering valves **50** and **50***b* thereby filling the vacant cylinder heads **38***a* and **38**.

As the drive shaft **50** is rotated and the stepped piston **44**, **44***a* moves into the cylinder heads **38**, **38***a*, actuating fluid is displaced and directed against the diaphragm **14**, **14***b* of the first stage-first gas loop and second stage-second gas loop compressor elements **10**, **10***b*. When the pressure of the actuating fluid is sufficient to overcome the resistance offered by the gas pressure against the resilient diaphragms **14** and **14***b*, the diaphragms are displaced until they come to rest against the opposing surfaces **21***a* of their respective cavities. Consequently the gas in chamber **18** of the first compression stage and the gas in chamber **18***b* of the second compression stage overcome the set point of their respective outflow valves **12**, **12***b* permitting the gases now compressed to a higher value, to exit into their respective loops.

It must be remembered that the actuating fluid pump capacity is greater than that required to displace the compressor diaphragms **14**, **14***b* so that when said diaphragms have reached their limit of travel the actuating fluid pressure in the fluid chambers **20** and **20***b* rapidly increases until the spring pressure of relief valve **19** and the spring pressure in the bypass valve **27***b* are overcome, permitting fluid flow through these valves. The flow of actuating fluid in valves **19** and **27***b* is then directed into the metering valves **50** and **50***b* against the upper surface of the spools **52** in the manner previously described. Consequently the position of the spools within the valve body and particularly with respect to the fluid inflow ports **53** and **55** and the outflow port **56** is modified thereby influencing and reducing the further flow of fluid into the cylinders of the pump.

It should be appreciated that the foregoing description of operation related only to a single upward stroke of the piston elements. However, a single stroke in the opposite direction would produce the same result with the alternately disposed gas compression elements and actuating fluid circuitry. Of course it is understood that continued operation of the mechanism produces rapid strokes first in one direction then the other thereby enabling the two gases to be compressed, one of the gases through the first stage and the other gas through the second stage of compression while during the opposite stroke of the pump the first and second compression stages of the two gases are alternated.

Of course it will be appreciated that the arrangements provided herewith contain many underlying advantages and improvements which cooperate to provide a contaminant free compressor that is capable of operational performance that had not heretofore been possible.

Additionally it should be understood and appreciated that the mechanism heretofore described and shown is by way of example only and obviously many changes and alternatives may be utilized without departing from the spirit of the invention.

What is claimed is:

1. A duplex compressor system for operation with first and second working fluid sources comprising first and second independent closed fluid loops, a pair of first compressor elements, a pair of second compressor elements, each of said compressor elements being formed by a housing having a cavity which is divided into two chambers by a resilient diaphragm member, said first compressor elements providing low compression relative to said second compressor elements, one chamber of one of said first and second compressors forming a portion of one of said closed loops and one chamber of the other of said first and second compressors forming a portion of the other of said closed loops, means for supplying actuating fluid to the other chamber of each said element, and means for pumping said actuating fluid to alternately depress simultaneously the diaphragm members of said first element in said first loop and said second element in said second loop and then depress simultaneously the diaphragm members of said second element in said first loop and said first element in said second loop, thereby compressing the working fluid therein, the actuating fluid and the working fluid in each cavity being separated from each other by said resilient diaphragm.

2. A duplex gas compressor system as set forth in claim **1** wherein said resilient diaphragm member is made of a heat conductive material so that heat is transferred from the gas to the actuating fluid in each cavity.

3. A duplex compressor system as set forth in claim **1** and further comprising means connected between said means for supplying actuating fluid and said pumping means and respective to the working fluid pressure in at least one compressor element for controlling the amount of actuating fluid supplied to said pumping means.

4. A duplex compressor system as set forth in claim **3** further comprising means in each of said first and second closed fluid loops for sensing the pressure of the working fluid in the respective loop, and means connecting said sensing means to said means for controlling the amount of actuating fluid supplied.

5. A duplex gas compressor system comprising first and second closed gas loops, each of said first and second loops having respective first and second compressor elements, each of said compressor elements being formed by a housing having a cavity which is divided into two chambers by a resilient diaphragm member, means for supplying gas to one chamber of each compressor element, a source of actuating fluid for the other chamber of each said compressor element, the actuating fluid and the gas in each cavity being separated from each other by said resilient diaphragm, means for pumping said ac-

tuating fluid under pressure to each compressor element to depress the diaphragm member in each compressor cavity thereby compressing the gas therein, a relief valve means connected to the gas chamber of each said compressor and responsive to the gas pressure therein, a respective metering valve means connected to and operated by each said relief valve means, the said metering valve means being connected between said source of actuating fluid and said pumping means and actuated by the respectively connected relief valve means to control the amount of actuating fluid supplied from the source to the pumping means.

6. A duplex gas compressor system comprising first and second closed gas loops, each of said first and second loops having respective first and second compressor elements, each of said compressor elements being formed by a housing having a cavity which is divided into two chambers by a resilient diaphragm member, means for supplying gas under pressure to one chamber of each compressor element, a source of actuating fluid for the other chamber of each said compressor cavity, the actuating fluid and the gas in each cavity being separated from each other by a resilient diaphragm, and pumping means operating to alternately pump actuating fluid under pressure from the fluid source to the first compressor element of the first loop and the second element of the second loop and then to the second element of the first loop and the first element of the second loop to compress the gas in each respective chamber.

7. A duplex gas compressor system comprising first and second closed gas loops, each of said first and second loops having respective first and second compressor elements, each of said compressor elements being formed by a housing having a cavity which is divided into two chambers by a resilient diaphragm member, means for supplying gas under pressure to one chamber of each compressor element, a source of actuating fluid for the other chamber of each said compressor cavity, the actuating fluid and the gas in each cavity being separated from each other by a resilient diaphragm, pumping means operating to alternately pump actuating fluid under pressure from the fluid source to the first compressor element of the first loop and the second element of the second loop and then to the second element of the first loop and the first element of the second loop to compress the gas in each respective chamber, and means connected between said source of actuating fluid and said pumping means and responsive to the gas pressure in at least one compressor element for controlling the amount of actuating fluid supplied to said pumping means.

8. A duplex gas compressor system comprising first and second closed gas loops, each of said first and second loops having respective first and second compressor elements, each of said compressor elements being formed by a housing having a cavity which is divided into two chambers by a resilient diaphragm member, means for supplying gas under pressure to one chamber of each compressor element, a source of actuating fluid for the other chamber of each said compressor cavity, the actuating fluid and the gas in each cavity being separated from each other by a resilient diaphragm, pumping means operating to alternately pump actuating fluid under pressure from the fluid source to the first compressor element of the first loop and the second element of the second loop and then to the second element of the first loop and the first element of the second loop to compress the gas in each respective chamber, means in each of the first and second gas loops for sensing the pressure of the gas in the respective loop, and means connected between said source of actuating fluid and said pumping means and actuated by said pressure sensing means to control the amount of actuating fluid supplied to said pumping means.

9. A duplex gas compressor system comprising first and second closed gas loops, each of said first and second loops having respective first and second compressor elements, each of said compressor elements being formed by a housing having a cavity which is divided into two chambers by a resilient diaphragm member, means for supplying gas under pressure to one chamber of each compressor element, a source of actuating fluid for the other chamber of each said compressor cavity, the actuating fluid and the gas in each cavity being separated from ecah other by a resilient diaphragm, pumping means operating to alternately pump actuating fluid under pressure from the fluid source to the first compressor element of the first loop and the second element of the second loop and then to the second element of the first loop and the first element of the second loop to compress the gas in each respective chamber, a relief valve means connected to the gas chamber of each said compressor element and responsive to the gas pressure therein, a respective metering valve means connected to and operated by each said relief valve means, the said metering valve means being connected between said source of actuating fluid and said pumping means and actuated by the respectively connected relief valve means to control the amount of actuating fluid supplied from the source to the pumping means.

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