March 9, 1954 H. R. RICARDO 2,671,606

COMPRESSOR FOR AIR OR OTHER GASEOUS FLUID

Filed Aug. 4, 1952 4 Sheets-Sheet 1

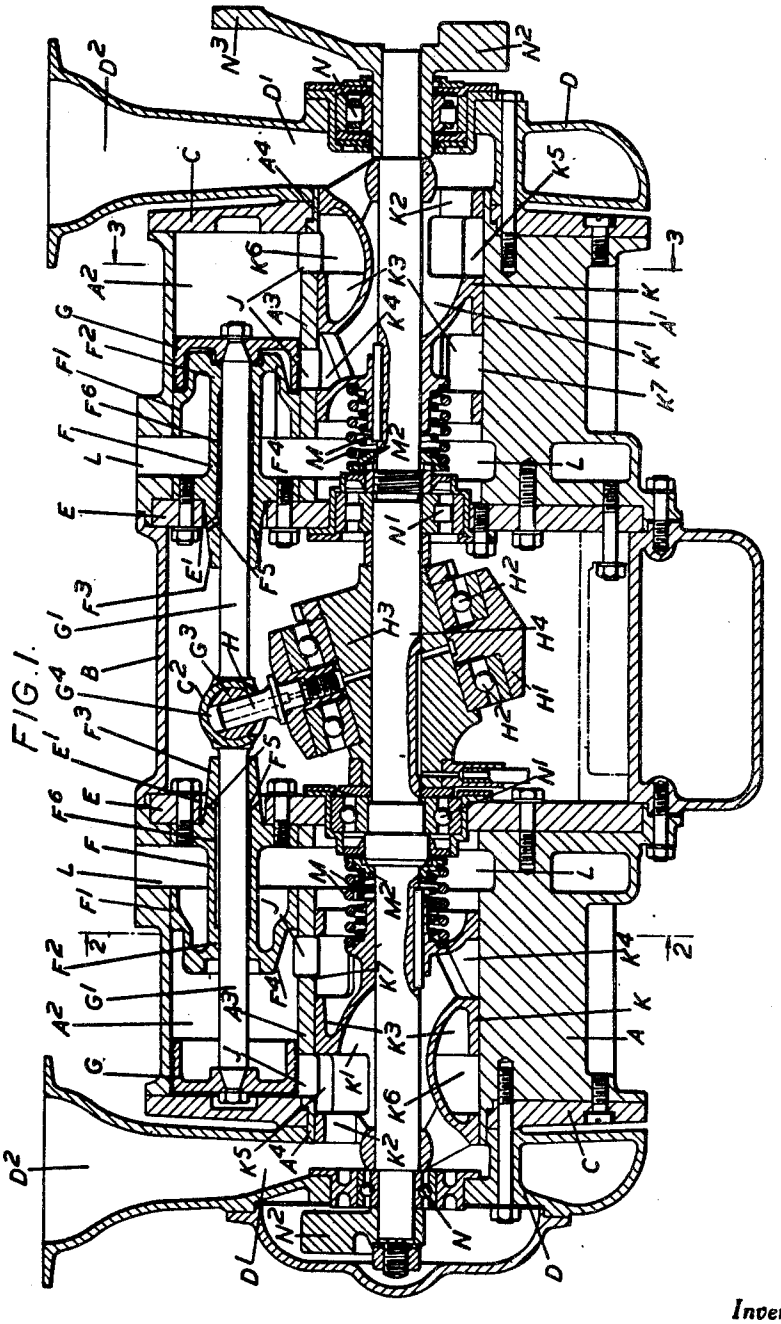

FIG. 1.

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FIG. 3.

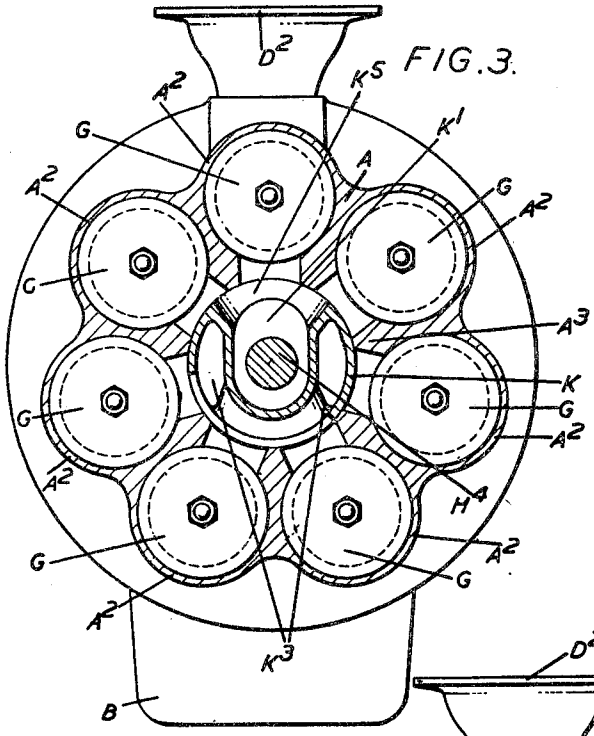

FIG. 2.

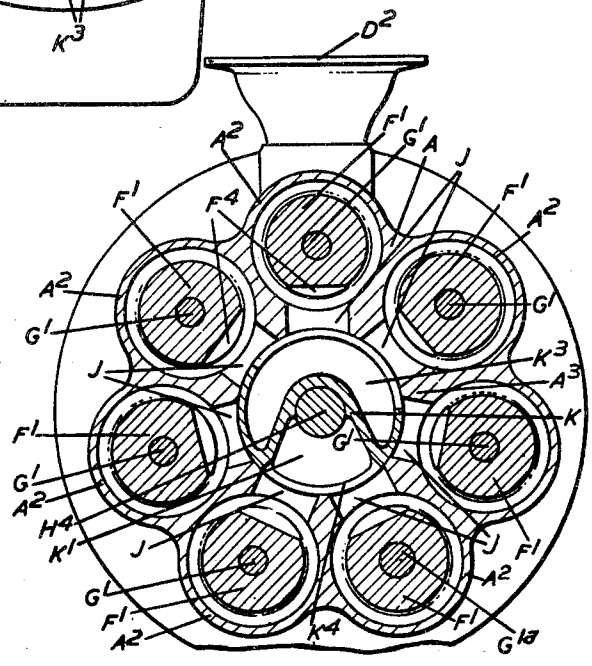

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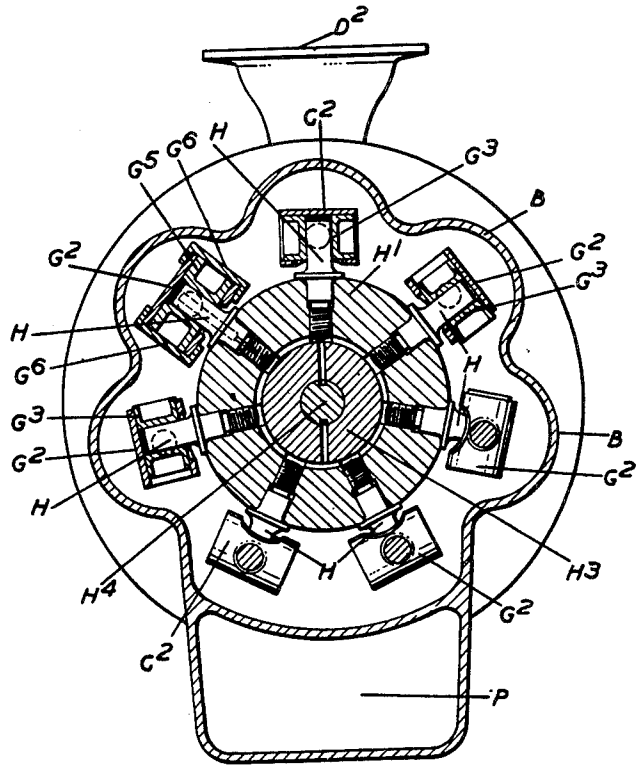
FIG. 4.



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COMPRESSOR FOR AIR OR OTHER GASEOUS FLUID

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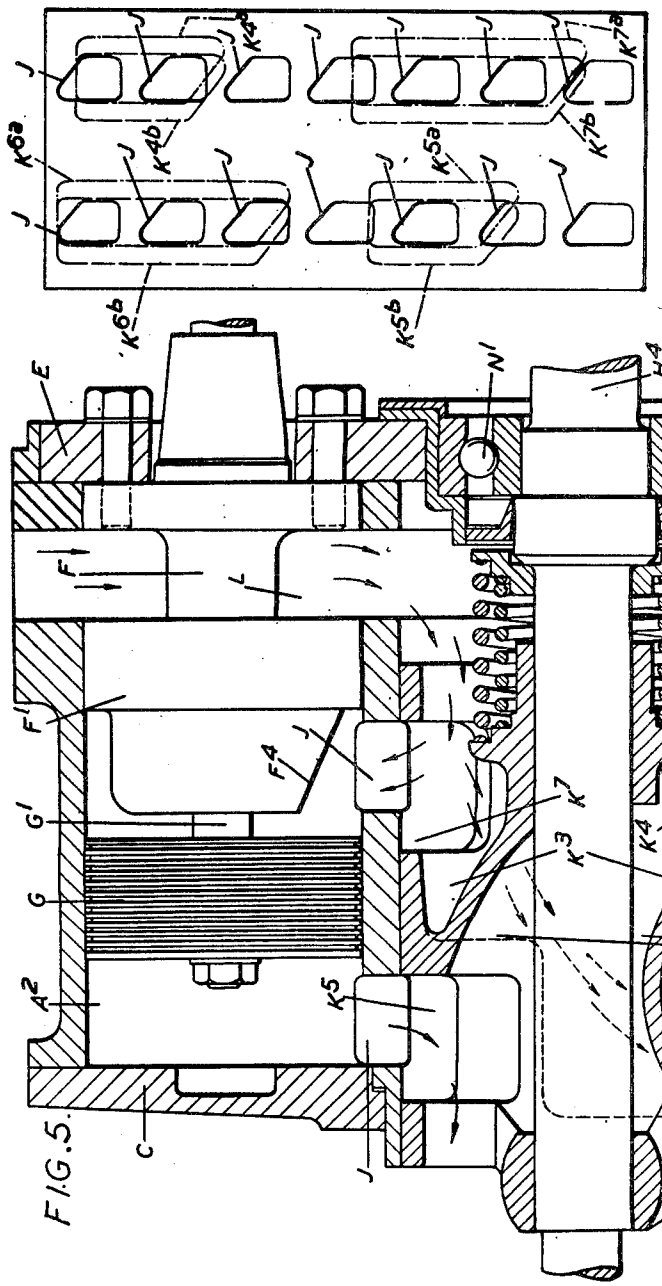

FIG. 6.

FIG. 5.

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UNITED STATES PATENT OFFICE

2,671,606

COMPRESSOR FOR AIR OR OTHER GASEOUS FLUID

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Application August 4, 1952, Serial No. 302,473

Claims priority, application Great Britain August 8, 1951

9 Claims. (Cl. 230—186)

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This invention relates to compressors of the reciprocating type for air or other gaseous fluid and of the general kind in which the admission of fluid to and delivery of fluid from the cylinder or each cylinder is controlled by a mechanically operated admission and delivery valve.

The invention is particularly, but not exclusively, applicable to compressors for gaseous fluid (hereinafter for convenience called air compressors) of the type comprising a series of working cylinders, which may be single or double acting, lying around the axis of a driving shaft with their axes extending axially, that is to say in a direction approximately parallel to the axis of the driving shaft, a piston within each cylinder connected to the driving shaft through swashplate or equivalent mechanism for converting rotary into reciprocating motion, and thus causing reciprocation of the pistons, and a rotary valve arranged in a cylindrical housing coaxially with the driving shaft and controlling combined admission and delivery ports communicating with the working chambers of the cylinders.

In this type of compressor as at present made the ports in the valves and in the cylindrical housing in which it lies are of rectangular shape so that the timing of the opening of both the admission and delivery ports is determined by the circumferential lengths of the ports in the valve and housing. Thus within a wide range a degree of internal compression in each working chamber before its associated delivery port opens can be provided by making the ports of appropriate circumferential length, since by delaying the opening of each delivery port the compression in the working chamber before the port opens can be increased as desired.

When it is desired to operate an air compressor of the general kind referred to over a wide range of delivery pressures, it is most desirable, for the sake of efficiency, to be able to vary the degree of compression which occurs in each working chamber before its associated delivery port opens, so that the port shall open at approximately the moment when the pressure in the working chamber has reached the delivery pressure. Moreover, with rises in the delivery pressure there are corresponding rises in the pressure in the clearance space representing the working chamber volume at the end of each delivery stroke, and for efficiency the compressed air in such clearance space should be re-expanded on the subsequent suction stroke down to atmospheric pressure before the associated admission port opens.

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The object of the present invention is to provide compressors of the general kind referred to with an improved form of control valve apparatus which will tend to allow for these factors.

In a compressor of the reciprocating type for air or other gaseous fluid according to the present invention having an admission and delivery valve comprising a cylindrical valve member and housing mounted to rotate relatively to one another so as to open and close admission and delivery ports formed in their co-operating circumferential walls, the valve member and its housing are capable of axial movement relatively to one another and have the ports in their walls so formed that such axial movement varies the points of opening of the delivery ports, and preferably also of the admission ports without substantially changing their points of closing, and means are provided whereby the relative axial position of the valve member and its housing is determined by and varied automatically with variations in the relationship between the admission pressure and the delivery pressure.

In a preferred arrangement the cylindrical valve member is formed and arranged so that the admission and delivery pressures act respectively on its two ends while one or more springs act on the valve member in the same direction as the admission pressure, so that with changes in the relationship between the admission pressure and the delivery pressure the valve moves axially automatically against or under the action of the spring to effect the required changes in the points of opening of the ports. In such an arrangement one end of the housing conveniently communicates with the admission passage and the other end with a delivery passage, while the admission and delivery passages or chambers in the valve member extend from the admission and delivery ports in its circumferential wall respectively through its two ends. Thus a simple arrangement is provided in which the two ends of the valve member are automatically subject to the desired pressures.

The form employed for the ports to achieve the desired variations in the points of opening thereof when relative axial movement occurs between the valve member and its housing may vary, but preferably the edges of the ports in the valve member and housing which pass over one another to open each port are similarly inclined to lines parallel to the axis of rotation, whereas the edges of the ports which pass over one another to close the ports are substantially parallel to such lines. Thus the desired rapid

opening of the ports during the initial opening period and rapid closing of the ports during the final closing period can be obtained for all axial settings of the valve member in its housing.

As mentioned the invention may be applied to air compressors of the general kind referred to having the cylinders and pistons arranged in various ways, but one arrangement according to the invention, as applied to a compressor incorporating also the invention of the present applicants' copending U. S. application, Serial No. 302,474, filed concurrently herewith, is illustrated by way of example in the accompanying drawings, in which:

Figure 1 is a sectional side elevation of the compressor, the section being taken in a plane containing the axis of the main shaft and the axis of one pair of cylinders,

Figure 2 is a cross section on the line 2—2 of Figure 1,

Figure 3 is a cross section on the line 3—3 of Figure 1,

Figure 4 is a cross section taken partly in the general plane of the wobble plate of the compressor and partly in a plane normal to the axis of the main shaft,

Figure 5 is an enlarged cross section showing the construction of one of the valves and its associated parts, the cross section being in a plane containing the axis of the valve, and

Figure 6 is a development view showing the form and arrangement of the ports in the valve and its housing.

In the construction shown in the drawings the compressor comprises a pair of similar cylinder blocks A and A^1 formed for example of cast aluminium alloy and each comprising seven cylinders A^2 evenly spaced around a cylindrical valve housing A^3 formed in the cylinder block with its axis parallel to the axes of the cylinders and having a bore somewhat larger than the bore of each cylinder and a length approximately equal to that of each cylinder.

The two cylinder blocks A and A^1 are secured to opposite ends of an intermediate housing B and each cylinder block has secured to its outer end an annular end plate C which closes the outer ends of the cylinders A^2 and through the central aperture of which a short extension A^4 of the valve housing A^3 projects. Secured to the outer face of each of the end plates C is a box section casting D, also conveniently of aluminium alloy, which contains a discharge passage D^1 into the inner end of which the adjacent end of the valve housing A^3, A^4 opens as shown, this discharge passage having a lateral exit opening D^2.

Secured to the inner end of each cylinder block A and A^1 so as to lie between it and the intermediate housing B is a plate having a central aperture therein surrounded by a series of seven circumferentially displaced apertures E^1 each of which is concentric with one of the cylinders A^2. Secured to each plate E so as to project through the apertures E^1 are tubular members F each connected by a circumferential flange to the plate and having a mushroom-like head F^1 which makes a fluid seal with the bore of the cylinder into which it projects so as to form in effect an inner cylinder head.

Disposed for reciprocation within each cylinder A^2 is a piston G each piston G in a cylinder A^2 in the cylinder block A being connected to one end of a piston rod member G^1 the other end of which is connected to the piston G in the coaxial cylinder in the block A^1.

Each piston rod member G^1 passes through the tubular members F associated with the inner ends of the cylinders in which its pistons operate and, as will be seen, each of these tubular members is of substantial length and has parts F^2, F^3 at its ends with which the piston rod member makes a close clearance sliding fit while its central part freely surrounds the piston rod member to provide an annular chamber F^6 to which lubricant-laden air has access through passages F^5.

As will be apparent the form of the part of each of the mushroom like heads F^1 of the members F which a piston closely approaches at the appropriate end of its stroke is such as to leave only a very small dead space between it and the adjacent face of the piston.

Each of the piston rod members G^1 is formed at the centre of its length with a cylindrical housing G^2 in which is mounted to rock a cylindrical coupling member G^3, six of which coupling members are identified by the reference letter G^3, while the seventh is of slightly different dimensions from the others and is identified by the reference letter G^5. Each coupling member G^3 and G^5 has a transverse bore G^4 therein in which is mounted to rotate and reciprocate a pin H projecting radially from a wobble plate H^1 supported on bearings H^2 on a member H^3 rigidly mounted on a main shaft H^4 and representing in effect a so-called Z crank on that shaft by which the wobble plate has the appropriate motion imparted to it.

As will be apparent from Figure 4, each of the coupling members G^3 is arranged so that it is free to slide axially to a limited extent within its housing G^2 so as to allow for limited circumferential movement of each of the associated pins H relatively to its piston rod member. In the case of the one coupling member G^5, however, the associated housing G^2 has end caps G^6 secured to and closing its ends and serving to prevent axial movement of the coupling member G^5 therein. The connection thus provided between the piston rod member and the wobble plate and including the coupling member G^5 thus serves to restrain the wobble plate from circumferential movement at the point of connection. Since this restraint imposes on the associated piston rod member G^1 a certain lateral stress, the associated piston rod member is of somewhat larger diameter than the other piston rods as shown at G^{1a} in Figure 2.

Each end of the valve housing A^3 communicates with the adjacent end of each of the cylinders A^2 through a combined suction and discharge port J, the part of each of the head members F^1 which lies adjacent to such a port being cut away as indicated at F^4 to facilitate the flow of gas through the port when the piston G closely approaches the member F^1.

Mounted for rotation in each of the valve housings A^3 is a rotary valve member K having formed therein a discharge chamber K^1 opening through the outer end of the valve as indicated at K^2, and a suction chamber K^3 which opens through the inner end of the valve housing into a suction chamber or passage L. The discharge chamber K^1 communicates with two discharge ports K^4, K^5 in the wall of the valve, these ports lying at diametrically opposite sides of the valve and respectively in the planes of the combined inlet and discharge ports at the ends of the associated

cylinders. Similarly the suction chamber K^3 communicates with two suction ports K^6, K^7 also disposed at diametrically opposite sides of the valve and lying respectively in the planes of the combined inlet and discharge ports J at the ends of the associated cylinders. As will be clear, more especially from Figure 5, the discharge chamber K^1 passes in effect through the centre of the suction chamber K^3 so as to provide for the required communication of each of these chambers with the appropriate ports situated towards opposite ends of the valve.

Each of the valves K is mounted upon the main H^4 and coupled thereto by a key or splines in a manner permitting it to move axially but not to rotate thereon, and a pair of springs M, is associated with each valve and acts at one end on the valve and at its other end on a thrust member M^2 on the shaft H^4 so as to tend to move the valve always towards the associated discharge passage D^1.

The main shaft H^4 is supported in bearings N, N^1 respectively in the castings D and the plates E, each of the bearings N also constituting a stop to limit the travel of the adjacent valve K under the action of its springs M, and balancing members N^2 are mounted on the ends of the main shaft to provide a couple during operation in opposition to that arising due to the motion of the wobble plate and pistons. One of these balancing members may also constitute part of a driving connection by which the main shaft is driven, as indicated at N^3.

The connecting rod members G^1 have such a close clearance fit in the tubular guide members F at the points F^2 and F^3 that they support and locate the pistons G within their cylinders A^2 in such manner that the pistons tend not to make contact with the cylinders and are thus enabled to operate substantially without lubrication. The pistons therefore, have no piston rings or equivalent sealing members but are preferably each provided with a series of closely spaced circumferential grooves as shown clearly in Figure 5 constituting in effect a labyrinth packing.

If desired, each valve member K may also be provided with a series of closely spaced circumferential grooves in its circumferentially complete areas as indicated in Figure 5 and in any case each valve is preferably supported upon the main shaft in such manner that it can operate substantially without lubrication between its circumferential surface and the wall of the valve housing A^3.

It will be apparent from the above description that the pressure in each of the delivery passages D^1 acts on the end of the associated valve K remote from the springs M and that, if the force applied by the springs be appropriately determined in relation to the range of delivery pressures at which the compressor is to operate, each valve K will, over the higher part at least of the range of delivery pressures, move axially against the action of its springs M with increases in the delivery pressure so that its axial position at any moment will in fact be determined by the delivery pressure.

Each of the ports J, K^4, K^5, K^6 and K^7 has a leading edge, that is to say, the edge at which during operation the port first begins to open, which is inclined to lines parallel to the axis of the valve as shown in Figure 6, in which the ports J are shown in full line and the ports K^4, K^5, K^6 and K^7 are shown in chain line and, for

illustration purposes, in two alternative axial positions, that is to say in the positions relatively to the ports J which they occupy respectively when the valve K is in the limiting position shown in Figure 5 and when it is in its other limiting position in which the springs M are compressed to the full extent permitted by the limited axial movement allowed to the valve K.

It will be apparent from Figure 6 that when the valve K occupies the position shown in Figure 5, that is to say the position it will occupy over the lower range of delivery pressures, the ports K^4, K^5, K^6 and K^7 then being in the position indicated by the reference letters K^{4b}, K^{5b}, K^{6b}, K^{7b} in Figure 6, each of the ports J will come into communication with each of the ports K^4, K^5, K^6 and K^7 somewhat sooner in each cycle than will be the case when the valve K is moved to the right in Figure 3 against the action of its springs M due to the delivery pressure exceeding a predetermined value and appreciably sooner than will be the case when the valve K is moved to the limit of its travel against the action of the springs M due to the delivery pressure exceeding some predetermined maximum.

Thus, over the higher range of delivery pressures at least, each delivery port K^4, K^5 will open later when the delivery pressures are higher than when they are lower and the arrangement is preferably such that the point at which each of these ports comes into communication with each of the ports J will always be approximately that at which the delivery pressure in the cylinder from which the port J opens is approximately equal to the pressure in the discharge passage D^1.

It will be apparent that the suction ports will also open somewhat later when the delivery pressure is high than when it is low.

What I claim as my invention and desire to secure by Letters Patent is:

1. A gas compressor of the reciprocating type including at least one working cylinder having a combined admission and delivery port, a working piston arranged for reciprocation within the cylinder, means for imparting reciprocation to said piston, an internally cylindrical valve housing through the wall of which the combined admission and delivery port opens, admission and delivery passages communicating with the housing, a cylindrical valve member mounted within the housing for rotation relatively thereto and having admission and delivery ports in its circumferential wall cooperating with the combined admission and delivery port for the control of the flow of working fluid to and from the working cylinder, the valve member and its housing being capable of axial movement relatively to one another and having the edges of the ports in their circumferential walls so formed that such axial movement varies the point of opening of both the admission and delivery ports without substantially changing their points of closing, and pressure responsive and resilient means which vary automatically the relative axial position of the valve member and its housing in response to variations in the relationship between the pressure respectively in the admission and delivery passages so as to vary the points of opening of the admission and delivery ports.

2. A gas compressor of the reciprocating type comprising at least one working cylinder having at least one combined admission and delivery port, a piston mounted to reciprocate within the working cylinder, means for imparting recipro-

cation to said piston, an internally cylindrical valve housing through the circumferential wall of which the combined admission and delivery port opens, a cylindrical valve member mounted for rotation within the valve housing and having admission and delivery ports formed in its circumferential wall and communicating with admission and delivery chambers in the valve member, admission and delivery passages rigid with the housing and arranged to communicate continuously with the admission and delivery chambers in the valve member, the valve member being capable of axial movement relatively to the housing and having the edges of the ports in its circumferential wall so formed that such axial movement varies the point of opening of both the admission and delivery ports without substantially changing their points of closing, and pressure responsive and resilient means for automatically varying the relative axial position of the valve member and its housing in response to variations in the relationship between the pressures respectively in the admission and delivery passages so as to vary the points of opening of the admission and delivery ports.

3. A gas compressor of the reciprocating type as claimed in claim 2, in which the admission and delivery chambers in the valve member open through its ends, the admission and delivery passages rigid with the housing communicate with the ends of the housing, and the means for automatically varying the relative axial positions of the valve member and its housing with variations in the relationship between the pressures respectively in the admission and delivery passages include a spring acting on the valve member in a direction tending to move it axially towards the delivery passage, this spring being therefore partially or wholly counterbalanced by the pressure in the delivery passage.

4. A gas compressor of the reciprocating type comprising a plurality of parallel working cylinders arranged symmetrically about an axis, a cylindrical valve housing coaxial with that axis and around which the working cylinders lie, each working cylinder having at least one combined admission and delivery port opening through the circumferential wall of the cylindrical valve housing, working pistons mounted for reciprocation within the working cylinders, means for imparting reciprocation to the working pistons including a main driving shaft coaxial with the said axis, admission and delivery passages rigid with the working cylinders and valve housing and communicating directly respectively with the two ends of the valve housing, a cylindrical valve member mounted for rotation and limited axial movement within the valve housing and containing admission and delivery chambers which communicate through the ends of the cylindrical valve member respectively with the admission and delivery passages and communicate with admission and delivery ports formed in the circumferential wall of the valve member for cooperation with the combined

admission and delivery ports of the cylinders, a driving connection between the valve member and the main driving shaft, the edges of the ports in the valve member and housing being so formed that axial movement of the valve member within the housing varies the points of opening of both the admission and delivery ports without substantially changing their points of closing, and pressure responsive and resilient means for varying automatically the axial position of the valve member within its housing in response to variations in the relationship between the pressures respectively in the admission and delivery passages so as to vary the points of opening of the admission and delivery ports.

5. A gas compressor of the reciprocating type as claimed in claim 4, in which the means for automatically varying the axial position of the valve member relatively to its housing include at least one spring acting on the valve member in a direction tending to move it always towards the delivery passage.

6. A gas compressor of the reciprocating type as claimed in claim 5, in which each of the working pistons is double-acting and the valve member includes admission and delivery chambers communicating respectively with the two ends of the valve member and each communicating with a pair of diametrically opposite ports in the circumferential wall of the valve member cooperating respectively with the combined admission and delivery ports at the opposite ends of the working cylinders.

7. A gas compressor of the reciprocating type as claimed in claim 4, in which the means for automatically moving the valve member axially relatively to its housing includes at least one spring tending always to move the valve member axially towards the delivery passage.

8. A gas compressor of the reciprocating type as claimed in claim 5, in which the edges of the ports in the valve member and in the valve housing which pass over one another to open each port are similarly inclined to lines parallel to the axis of rotation of the valve member, whereas the edges of the ports which pass over one another to close the ports are substantially parallel to such lines.

9. A gas compressor of the reciprocating type as claimed in claim 4, in which the edges of the ports in the valve member and in the valve housing which pass over one another to open each port are similarly inclined to lines parallel to the axis of rotation of the valve member, whereas the edges of the ports which pass over one another to close the ports are substantially parallel to such lines.

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