

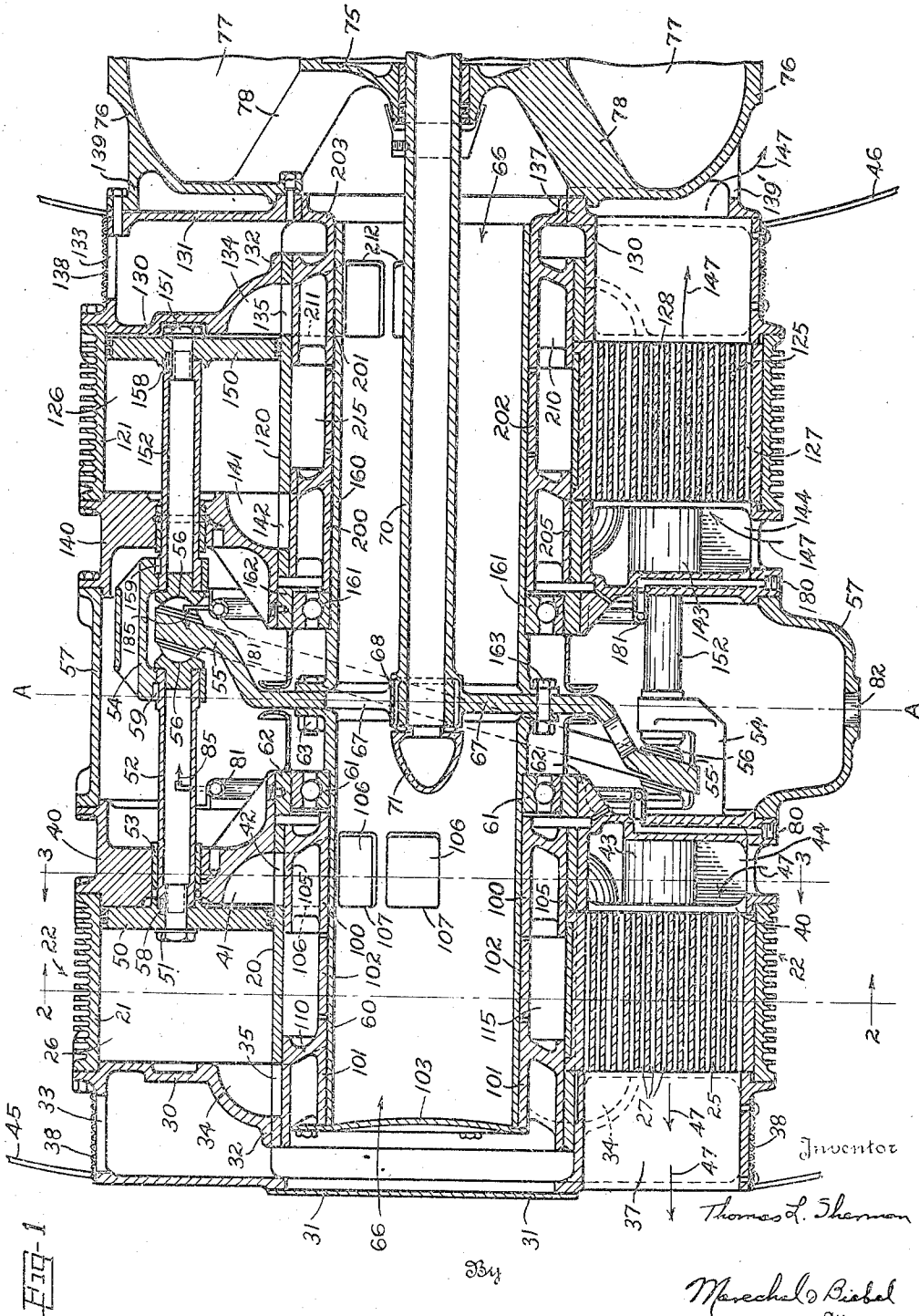
Aug. 23, 1949.

T. L. SHERMAN
PUMPING APPARATUS

2,479,876

Filed April 12, 1946

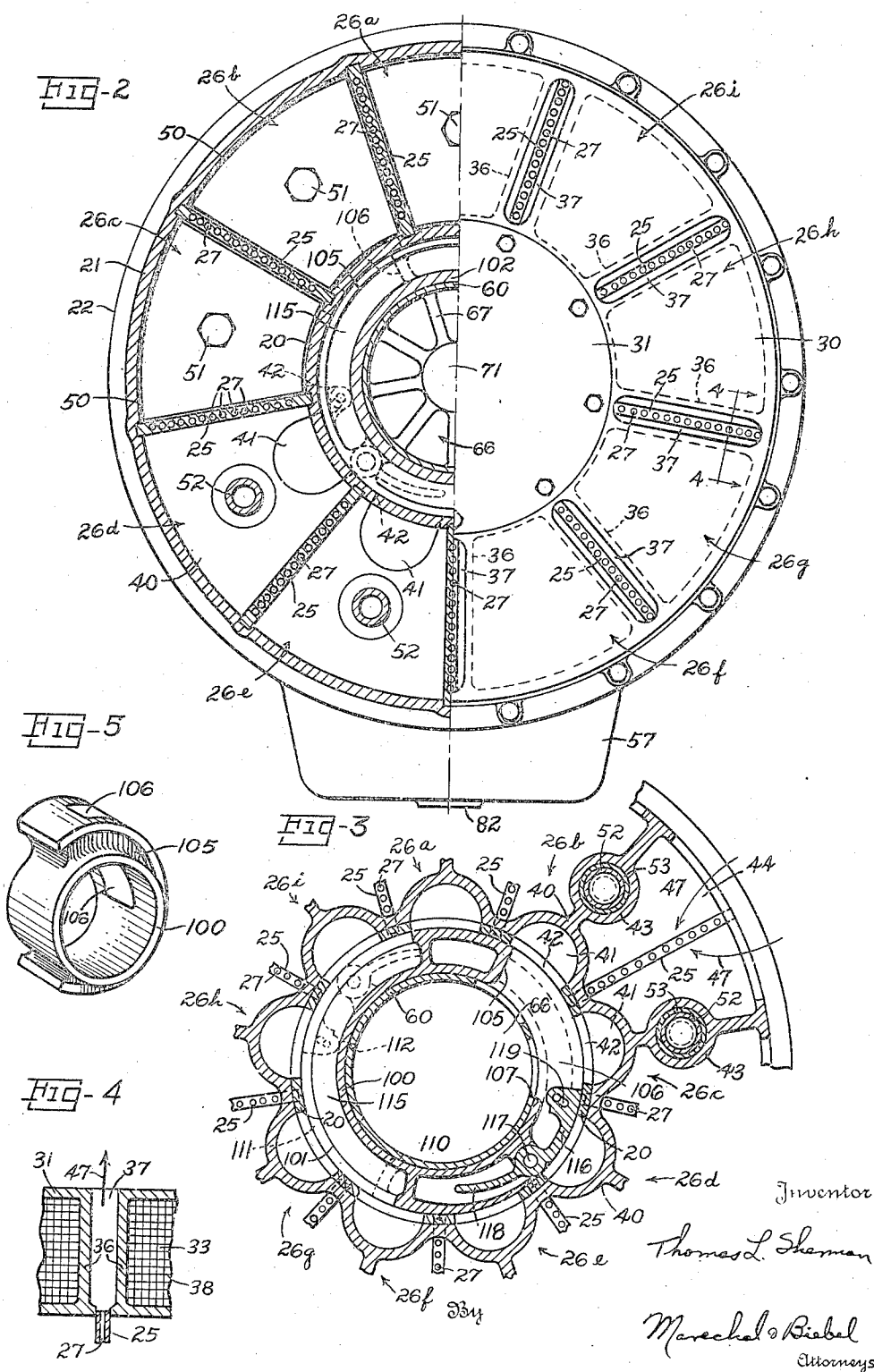
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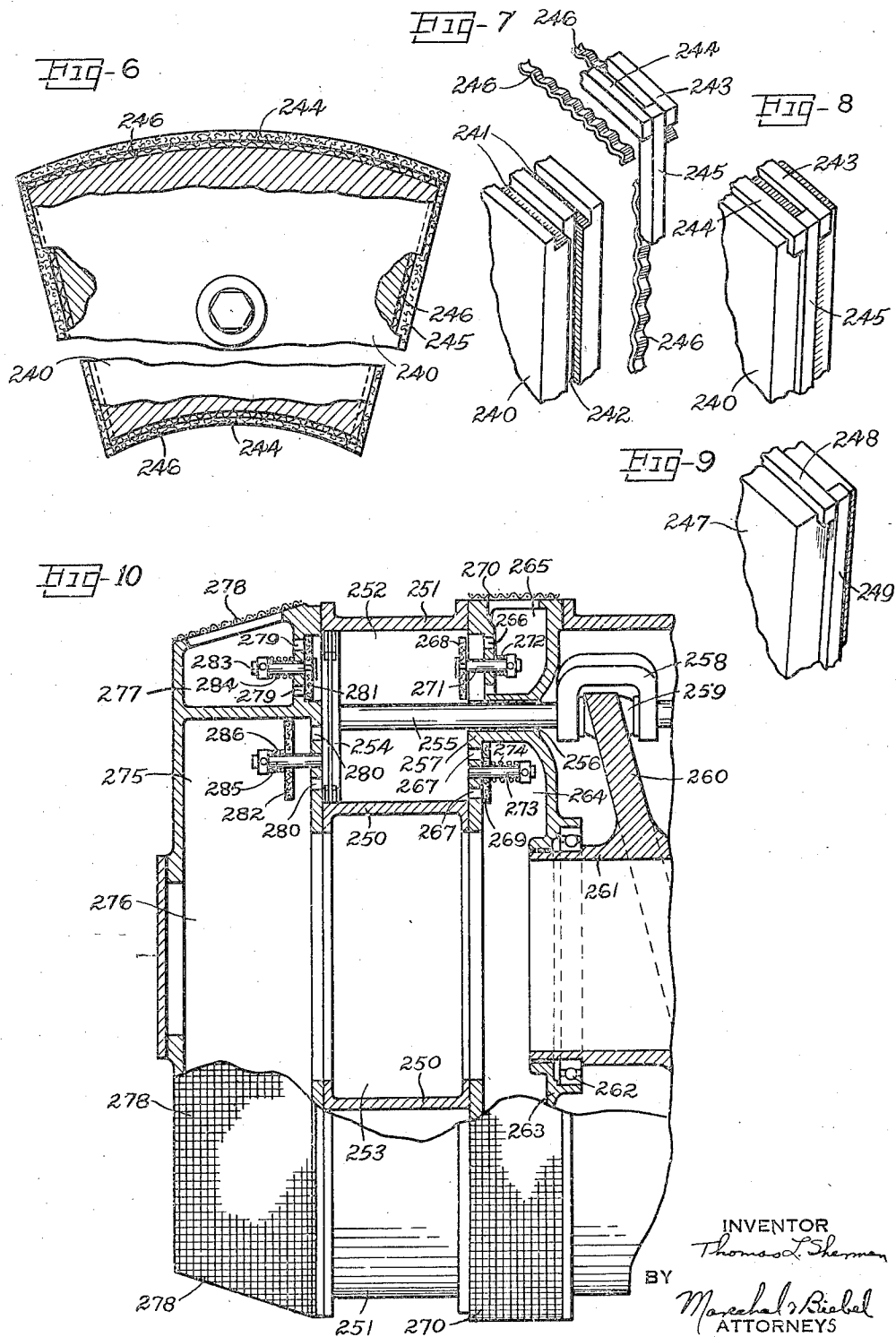
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UNITED STATES PATENT OFFICE

2,479,876

PUMPING APPARATUS

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16 Claims. (Cl. 230—186)

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This invention relates to apparatus for pump-
ing, compressing or blowing gaseous or liquid
fluids, and more particularly to positive displace-
ment apparatus capable of effective operation at
pressures above or below atmospheric pressure
for pumping, compressing or blowing gaseous or
liquid fluid and hereinafter referred to as pump-
ing apparatus.

One of the principal objects of the invention
is to provide such pumping apparatus which will
have a maximum piston displacement from a ma-
chine of given diametral dimensions. It is also
an object of the invention to provide apparatus
of the above type having high overall efficiency
in operation and which can be economically and
accurately manufactured.

An additional object of the invention is to pro-
vide such apparatus having positive displacement
under all pressure and speed conditions the out-
put of which is closely proportional to the speed
of operation.

Another object is to provide such pumping ap-
paratus which will be compact in shape and of
low weight and wherein the use of operated or
automatic type valves can be avoided.

A further object is to provide a simple and
effective cooling system for the walls of the cylin-
der in pumping apparatus of the above type.

A still further object is to provide such appa-
ratus wherein reciprocating movement is im-
parted to the pistons through a rotating slant
or swash plate without the use of special guides
for the bridge members by means of which the
pistons are connected together about the periph-
ery of the swash plate.

A still further object is to provide for simple
and effective sealing between the sides of a piston
and the adjacent walls of a cylinder such as may
be used in apparatus of the above type and which
will be effective whether the engaging piston and
cylinder surfaces are plane, concave or convex.

Other objects and advantages of the invention
will be apparent from the following description,
the accompanying drawings and the appended
claims.

In the drawings, which illustrate preferred em-
bodiments of the invention, and in which like
characters of reference designate like parts
throughout—

Fig. 1 is a view in longitudinal section illus-
trating a multi-cylinder compressor or blower
constructed in accordance with the present inven-
tion;

Fig. 2 is a composite view of the apparatus
shown in Fig. 1, the left half being in vertical

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section on the line 2—2 in Fig. 1, and the right
half being in end elevation looking from the left
in Fig. 1;

Fig. 3 is a fragmentary section through the
rotary valve taken on the line 3—3 in Fig. 1;

Fig. 4 is a fragmentary view in section substan-
tially on the line 4—4 in Fig. 2;

Fig. 5 is a perspective view illustrating one of
the rotary valve members employed in the device
shown in Figs. 1 to 3;

Fig. 6 is a fragmentary view partly in elevation
and partly broken away and in section illustrating
one of the pistons and the packing means therefor
utilized in the apparatus shown in Figs. 1 to 3;

Fig. 7 is an exploded detail view in perspective
of a corner of the piston shown in Fig. 6 illus-
trating the packing means utilized therewith;

Fig. 8 is a detail view in perspective illustrating
the parts shown in Fig. 7 in assembled position;

Fig. 9 is a view similar to Fig. 8 illustrating a
modified form of packing means; and

Fig. 10 is a fragmentary view, partly in eleva-
tion and partly in longitudinal section, illustrat-
ing a blower or compressor embodying a modifi-
cation of the invention.

As stated, the present invention is particularly
directed to the provision of positive displacement
pumping apparatus having maximum piston dis-
placement from apparatus of given diametral
dimensions and having also novel structural fea-
tures permitting economical and accurate man-
ufacture, and it is desired in this connection to
provide a construction equally applicable to appa-
ratus for pumping, compressing or blowing air or
other gases and liquids.

In accordance with the invention, these objec-
tives are obtained in apparatus wherein the cylin-
ders are arranged circumferentially about a cen-
tral air flow or discharge passage extending sub-
stantially the entire length of the apparatus and
wherein the pistons are reciprocated parallel to
this flow passage by means of a rotating slant or
swash plate having its axis of rotation substan-
tially coaxial with the central passage of the ma-
chine. This basic construction provides for a
number of other structural features which con-
tribute to the results achieved by means of the
invention. The pistons are readily made double
acting so that they displace substantially twice
the volume of the cylinders for each complete
cycle of reciprocation, and the invention also pro-
vides for valve means capable of directing the
entire discharge from all the cylinders into the
central flow passage. The use of the swash plate
drive also makes practical a double ended pump-

ing apparatus in which there are two sets of cylinders, one at each end of the apparatus, with the single swash plate positioned substantially intermediate these cylinders and operating to drive all of the pistons in rotation. It is also practical with the apparatus of the invention to utilize cylinders having in cross section the shape of a sector of a circular annulus, thus providing for a great increase of the effective cylinder volume over conventional apparatus of comparable diametral dimensions utilizing cylinders of circular or other conventional shapes.

The present invention provides positive displacement apparatus which is compact, low in weight and highly efficient. This apparatus has good control characteristics permitting two or more to be operated effectively in parallel. The invention does not require operated valves or gear drives, and it provides apparatus which can be driven directly and the output of which will be closely proportional to its speed. Furthermore, it has a wide range of operation without critical conditions and gives high over-all adiabatic efficiency particularly under conditions requiring high pressure ratios. These results are all obtainable in accordance with the invention in apparatus constructed largely of parts which may be readily and inexpensively manufactured to the proper degree of accuracy without close tolerances.

Referring first to the embodiment of the invention shown in Figs. 1 to 3, and particularly to the structure shown to the left of the central plane A—A in Fig. 1, cylindrical wall member 20 and an outer cylindrical wall member 21 are concentrically arranged to form an annular cylinder chamber about a central passage, outer wall member 21 being provided with cooling fins 22 as shown. This annular cylinder chamber is in turn separated into a plurality of individual cylinders by wall members 25, which are radially arranged in circumferentially spaced relation between the concentric cylindrical wall members as shown particularly in Fig. 2. As shown, there are nine of these wall members 25, and they divide the annular cylinder chamber into nine parallel symmetrical cylinders 26 each having in transverse section the general configuration of a sector of a circular annulus. Wall members 25 are shown as held in position by engaging in suitable slots in the adjacent surfaces of the cylinder walls 20 and 21, and each wall member 25 is also provided, as shown, with a plurality of internal passages 27 parallel to the central passage of the apparatus, these passages 27 providing for cooling the walls by passing suitable coolant therethrough as will be described.

The above cylinder construction provides substantial advantages over conventional structures wherein the individual cylinders are circular in transverse section. In the latter type of construction only a limited number of circular cylinders can be provided within given diametral dimensions, and there will inevitably be substantial loss of useful space between and around adjacent cylinders, as can readily be appreciated by visualizing the design produced by drawing a series of small circles within a circular annulus. The present invention provides a construction wherein there is effectively a single annular cylinder chamber between walls 20 and 21 and makes possible the effective use of this entire cylinder chamber except for the comparatively negligible space occupied by radial walls 25. This construction has also substantial features of

economy of manufacture, since the individual parts which form the cylinders are of simple shape and readily manufactured to the proper degree of accuracy.

The outer heads for cylinders 26 are provided by a member 30 secured, as shown, to the outer end of wall member 21 and which includes a closed outer end portion 31 and a circular flange 32 which engages inner wall member 20 adjacent its outer end. Head 30 is provided with openings 33 which serve as intake passages for air from the outer atmosphere, and this air passes to the central passage formed by wall member 20, whence its further course is controlled by valve means to be described. A plurality of trough-like depressions 34 are provided on the inner side of head 30, there being one of these depressions 34 for each of cylinders 26 and each being adapted to register at its radially inner end with one of the corresponding apertures 35 in inner cylinder wall 20, each depression 34 and aperture 35 thus combining to provide a port for communication between the outer end of each cylinder 26 and the central passage of the apparatus, which ports serve alternately for both intake and discharge as will be described. Head 30 is also provided with slots radially arranged and suitably spaced to coincide with radial cylinder walls 25, as shown particularly in Figs. 2 and 4, and radially arranged wall portions 36 enclosing radial passages 37 which provide free communication to or from the ends of passages 27 in these walls 25. A screen 38 is provided for covering intake passages 33 to filter air taken into the apparatus.

The axially inner heads for cylinders 26 are provided by an annular member 40 which is slotted similarly to cylinder head 30 to coincide with the ends of radial wall members 25 and is formed on its surface adjacent cylinders 26 to provide a plurality of trough portions 41 similar to depressions 34 described above each adapted to register with one of the adjacent apertures 42 in inner cylinder wall 20 to provide a port for communication between the central passage and the axially inner end of each cylinder 26. Head member 40 is also formed with boss portions 43 for supporting the piston rods of the apparatus and is provided with a plurality of passages 44 through which coolant may be introduced to the passages 27 within wall members 25, the shape of these passages 44 being clearly shown in Fig. 3. In operation, coolant may be introduced into these radial cylinder walls 25 by positioning the device in an inlet air duct extending between the planes indicated generally at 45 and 46. With this arrangement, air will be directed into passages 44 and thence through passages 27 in each wall member 25 and this air can then exhaust to atmosphere through the outlets 37 at the outer end of the apparatus, as indicated by arrows 47 in Figs. 1, 3 and 4.

Each of cylinders 26 has a piston 50 mounted for reciprocating movement therein parallel to the central axis of the apparatus, and as shown particularly in Fig. 2, each of these pistons 50 is complementary in shape to the cylinder wherein it is mounted, having a circularly convex outer edge, a circularly concave inner edge, and plane side edges each parallel to its adjacent radial cylinder wall 25. Since as pointed out, cylinders 26 effectively provide a single annular cylinder chamber of substantially the maximum cross sectional area for apparatus of given diameter, the use of the complementarily shaped pistons in these sector-

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shaped cylinders provides maximum piston displacement for the given diametral dimensions, which as noted is substantially greater than can be obtained from apparatus of the same diametral dimensions using cylinders and pistons of circular or any other shape not formed directly by subdivision of the annular cylinder space.

Each of pistons 50 is secured, by means such as a nut and lock washer 51 to a piston rod 52 mounted for reciprocating movement in boss 43 of head member 40, suitable bushings 53 and packings being provided to permit free reciprocation without leakage from the cylinder. Each piston rod 52 is in turn secured to a bridge member 54 adapted for embracing contact through slipper bearing elements 55 with a slant or swash plate 55 mounted for rotation coaxially with the annular cylinder chamber within the central portion of the apparatus and enclosed by annular casing 57. As shown, both piston rod 52 and bridge 54 may be made substantially hollow to provide for lightening the total weight of the apparatus, and the resulting open end of the rod adjacent the bridge provides for convenient mounting of the socket mountings for bearing elements 56, as shown in Fig. 1.

As swash plate 55 rotates, it will cause each piston rod 52 and the piston 50 connected therewith to reciprocate in rotational sequence, and during such rotation slipper bearings 56 will pivot in their sockets to follow the varying presentation of the faces of the swash plate. Furthermore, since these pistons are of sector shape as described and are restrained by their adjacent complementarily formed cylinder walls against rotation about the axis of rods 52, means such as a pin 58 and key 59 may be provided to hold rod 52 and bridge 54 against rotation with respect to the piston, thus making possible the elimination of separate guide members for retaining the bridge in the proper alignment for continuous engagement with the rotating swash plate.

The mounting means for swash plate 55 includes cylindrical tube members 60 and 160 which are rotatably supported in bearings 61 and 161 carried by supporting members 62 and 162 secured to the inner rims of cylinder heads 40 and 140. Tube 60 has a flanged inner end which is bolted at 63 to swash plate 55. The similar cylindrical tube member 160 is also bolted at 63 to swash plate 55, and these tube members 60 and 160 together extend substantially the entire length of the apparatus and provide a continuous central passage indicated generally as 66. Swash plate 55, is connected through radial spokes 67 to an inner hub member 68 which in turn is splined or otherwise provided with a driving connection to the main drive shaft 70. Since spokes 67 and hub 68 are positioned within central passage 66, the spokes are preferably streamlined or made of similarly smooth shape to offer minimum resistance to the passage of air, and a streamlined nose piece 71 for the inner end of shaft 70 serves similarly to provide for reducing the resistance of the shaft and hub 68 to the flow of air through passage 66. The stiffness of spokes 67 can be selected to offset torsional resonance within the speed range of the engine, and also instead of being formed integrally with the swash plate the spokes may connect with an outer hub which in turn may be splined or otherwise placed in driving connection with the swash plate.

Drive shaft 70 leads to a suitable source of motive power, not shown, such as an engine within the casing shown fragmentarily at 75. The

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outer casing fragmentarily shown at 76 is adapted to be fixedly mounted with respect to the compressor, as shown, and forms with casing 75 a passage 77 continuous with central passage 66, through which the output of the apparatus is adapted to pass as will be explained. Casings 75 and 76 are shown as secured together through annularly disposed ribs 78 which should be of such design as to avoid offering undesirable resistance to the flow of air through passage 77.

To lubricate the swash plate and its associated moving parts, head member 40 may be provided at 80 with an inlet for lubricant, which may be supplied from the main engine pump, this inlet connecting with an annular conduit 81 from which lubricant may be jetted to the bearing surfaces of the slant as shown by arrow 85 in Fig. 1. An oil outlet 82 is provided in casing 57 and may be attached to a scavenge pump on the main engine.

When the apparatus is operated as described, each piston will make one complete reciprocatory cycle for each 360° of rotation of the swash plate, and during each half of its cycle it will act to force the air or other working fluid out through the port at the cylinder head towards which it is moving and simultaneously to exert suction on the port at the opposite cylinder head. The invention accordingly provides valve means for controlling the passage of fluid through these ports, and the embodiment thereof shown in Figs. 1 to 3 utilizes rotary valves operating to direct the output of each cylinder through ports into central passage 66 on both strokes of the piston and also to provide for communication from intake openings 33 to the ports whereon the pistons are exerting suction.

The valve means for control of intake to and discharge from cylinder 26 comprises a pair of generally cylindrical valve members 100 and 101 mounted on tube member 60 and provided with a cylindrical spacing piece 102. As illustrated, these valve members are identical and member 100 is shown in clearer detail in Fig. 5. The outer end of tube 60 is closed by a disk 103 bolted to valve member 101, thus closing this end of passage 66. Valve member 100 is provided with a radially extending projection 105 which is adapted for close engagement with the inner surface of inner cylinder wall 20 and includes a slot 106 adapted to register with port openings 35 in wall 20, and tube 60 is similarly provided with slots 107 adapted to register with slot 106. These slots serve to provide for discharge into passage 66 from each of cylinders 26 in rotation as the valve rotates, and the circumferential length of slot 106 depends upon the discharge pressure duty of the machine. Valve member 101 is provided with a similar radially extending projection 110 having a similar discharge slot 111 therein adapted to register with ports 42 in cylinder wall 20 and slots 112 in tube 60. In assembling the apparatus, valve members 100 and 101 will be so positioned that the projections 105 and 110 will lie approximately opposite each other with the slots 106 and 111 approximately at 180° rotation from each other. This construction leaves a space 115 which is annular adjacent spacing piece 102 and partially annular adjacent the projections 105 and 110 and which connects through head member 30 with the intake passages 33, thus providing for direct intake to each of cylinders 26 when the ports 35 and 42 are left open by rotation of valve members 100 and 101 with respect to cylinder wall 20.

With the valve structure as above described and shown, communication is provided between certain of cylinders 26 and the intake passages 33 through space 115 and ports 35 and 42, and between others of cylinders 26 and central passage 66 through slots 105 and ports 35 and through slot 111 and ports 42. Accordingly, the valve members 100 and 101 are so designed and constructed and so secured to tube 60 for properly timed rotation with swash plate 55, that there will be open communication between central passage 66 and the end ports of the cylinder 26 towards which the piston 50 therein is moving and open communication between the intake passages and the other end ports, i. e., the ports which the piston is moving away from and thus exerting suction on. Thus in Figs. 1 and 2 it is assumed that shaft 70 is rotating in clockwise direction as viewed in Fig. 3, with the piston 50 in cylinder 26a at the top in these views shown in approximately axially inner dead center position. The remaining pistons will therefore be at various positions between inner and outer dead center, as is indicated in Fig. 2 by showing in elevation the two pistons in cylinders 26b and 26c adjacent the uppermost piston, since these pistons will be at the right of the section line 2-2 in the position shown in Fig. 1, and the two pistons 26d and 26e in Fig. 2 will be out beyond this section line 2-2 in Fig. 1 so that only their piston rods 52 show in Fig. 2.

The operation of valve members 100 and 101 in controlling intake and discharge in the operation of the apparatus is shown most clearly in Fig. 3, wherein tube 60 and the valve members carried thereby are assumed to be rotating in clockwise direction. With the parts as shown in Fig. 3, the portion of the projection 105 including the trailing edge of slot 106 is shown as closing the port 42 from the uppermost cylinder 26a, which coincides with the view in Fig. 1 showing the piston 50 in this uppermost cylinder as being at substantially dead center position. At the same time, slot 106 is in register with the ports 42 of cylinders 26b and 26c, and it will accordingly be understood that the output from these cylinders passes through slot 106 and slots 107 into the central passage 66. Also, in order to accommodate changes in discharge pressure during operation, the leading edge of slot 106 is formed with a member 116 hinged at 117 to the adjacent portion of projection 105. This construction permits member 116 to pivot inwardly if the pressure within cylinder 26d becomes too great and so permits the cylinder to begin its discharge to central passage 66 before slot 106 is fully in register with the port 42 of the cylinder. Member 116 is also shown as provided with a suitable counterweight portion 118 and a pin and slot unit 119 serving as a stop to limit its pivotal movement.

In Fig. 3, port 42 of cylinder 26e is shown as closed similarly to cylinder 26a by the leading portion of projection 105. This cylinder 26e will be the next in rotation after cylinder 26d to discharge to central passage 66 as valve member 100 continues to rotate. The ports 42 of cylinders 26f, 26g, 26h and 26i are all shown as open to the passage 115 between the valve structure and cylinder wall 29, so that these ports 42 are serving as intake ports for these cylinders, with the air entering from intake passages 33 and annular passage 115. Fig. 3 also shows in dotted lines the position of slot 111 in the projection 110 on valve member 101, and as shown, this slot is in register with the ports 35 of cylinders 26f, 26g, and 26h.

Thus these three cylinders will be discharging to central passage 66 through their outer end ports at the same time that cylinders 26b, 26c and 26d discharge through their inner end ports, and as explained, these cylinders 26f, 26g and 26h together with cylinder 26i will at the same time be taking in air through their inner end ports as shown in Fig. 3.

As has already been pointed out, the invention makes practical the use of a double ended structure having a separate set of cylinders at each end of the apparatus with the centrally positioned swash plate operative to reciprocate the pistons of both sets of cylinders. The right hand portion of Fig. 1 illustrates such a construction, and the component parts thereof are to a considerable extent duplicates in structure and function of the corresponding parts already described in connection with the structure shown in the left in Fig. 1. Such parts are accordingly designated in Fig. 1 by reference characters produced by adding 100 to the reference character of the corresponding part at the left hand portion of the structure shown in Fig. 1, and specific description thereof is accordingly believed to be unnecessary.

Some structural modification of certain of the elements at the right in Fig. 1 is called for to provide for the discharge at this end of the apparatus and for convenient attachment to casing members 75 and 76. As shown, the member 130, which provides the outer heads for cylinders 126, is open at its outer end 131 corresponding to the closed end 31 of head member 30, and this opening is surrounded by an enlarged flange portion 137 to provide for convenient attachment, as by bolting, to casing member 76. Casing 76 is also provided as shown with an outer annular flange 139 adapted for bolting to the outer periphery of head member 130, and suitable apertures 139' are provided in this flange for the discharge of the air or other coolant utilized for cooling radial cylinder walls 125 through passages 127 and 144 as indicated by arrows 147.

The valve means for cylinders 126 are similar in construction, function and operation to the valve means for cylinders 26 just described. Valve member 200 may be identical in construction with valve members 100 and 101, but valve member 201 is somewhat modified in structure to provide for the desired discharge from the outer end of central passage 66. As shown in Fig. 1, valve member 201 includes an annular flange portion 203 which extends through cylinder head 130 and engages the inner rim of outer end 131 of head 130 adjacent casing 76. Spacing piece 202 is substantially the same as the corresponding member 102 at the opposite end of the apparatus, and it and the two valve members 200 and 201 are similarly carried by tube member 160, which includes slots registering with the slots in the projections 205 and 210 on valve members 200 and 201 in the same manner as explained in connection with the other valve members, these slots 212 for the outer end ports being shown in Fig. 1. Otherwise the construction at the right hand end of the apparatus as shown in Fig. 1 and its operation are substantially the same as that already described in connection with the opposite end of the apparatus, and no further detailed description is believed necessary.

The above construction provides a variety of advantageous features of the invention in addition to those already pointed out. In operation, for each 360° of rotation of the main shaft and swash plate, each piston will displace approxi-

mately twice the volume of its cylinder, and this output will all be delivered to the common central passage 66 and thence to passage 77. The total output of the apparatus will accordingly be closely proportional to the speed at which the shaft and swash plate are driven. In this connection it should be noted that this apparatus is readily adaptable for connection to sources of pressure fluid other than the outside atmosphere, such connections merely requiring mechanical modification of the intake and discharge passages. For example, the apparatus is highly satisfactory for use in an airplane, in which the ram effect in flight will serve to increase the pressure at which air is supplied to the intake passages. This same ram effect will also be useful for directing air as described into the intake passages 44 and 144 for coolant to be transmitted to the passages 27 and 127 in radial cylinder walls 25 and 125. It should also be noted that the directions of intake and discharge of the apparatus can be readily reversed by simple rotational and functional adjustments of the rotary valve members. The swash plate construction for reciprocating the pistons offers further advantages of overall compactness, light weight, simplicity of manufacture and efficiency in operation, and in addition it can readily be made of sufficient mass for accurately balancing the reciprocating members.

Figs. 6 to 8 illustrate packing means found satisfactory for providing tight sealing between the sides of each of the pistons shown in Figs. 1 to 3 and the inner walls of the cylinder wherein each of said pistons reciprocates. In Figs. 6 to 8, piston 240 has each of its sides grooved to receive packing material, there being two such grooves 241 in the outer and inner piston sides spaced axially with respect to each other and a single groove 242 in the plane piston sides, this groove 242 being spaced axially substantially intermediate grooves 241. Packing members 243, 244 and 245 of suitable material are adapted to engage in these grooves and are formed, as shown particularly in Figs. 7 and 8, so that the portions thereof adapted for engagement in each individual groove in the piston overlap at their ends to provide increased packing material at each corner where leakage would be most likely to occur. Each groove 241 and 242 also has mounted therein a sinuous metal spring 246 between the inner wall of the groove and the packing material, these springs being operative to urge the packing material outwardly from the slot into yielding engagement with the adjacent cylinder wall to increase the tightness of packing.

Fig. 9 shows a modified form of the packing means shown in Figs. 6 to 8. In Fig. 9, piston 247 has only a single groove in each side thereof, but these grooves are axially spaced with respect to each other and packing members 248 and 249 which overlap at the corners in the same manner as in the construction shown in Figs. 6 to 8. It will be seen that this arrangement also provides for increased thickness of packing material at each corner of the piston as opposed to the amount of packing material along the sides. Sinuous springs such as those shown at 246 in Fig. 6 may also be used with the construction shown in Fig. 9 to urge the packing material into the desired yielding engagement with the adjacent cylinder walls.

Fig. 10 illustrates a blower or compressor having structural and operational features and advantages similar to those just described in connection with Figs. 1 to 3 but embodying a modified

structure including a plurality of automatic poppet or plate type valves instead of rotary valves such as are shown in Figs. 1 to 3. In Fig. 10, inner and outer circular walls 250 and 251 form an annular cylinder chamber which may be separated by radial walls as described in connection with Figs. 1 to 3 into a plurality of parallel cylinders 252 arranged about a hollow central passage 253 equivalent to passage 66 in Fig. 1. Piston 254 corresponds to pistons 50 and is similarly mounted on piston rod 255 for reciprocating movement parallel to the axis of passage 253. Piston rod 255 is mounted by means of bushing 256 for sliding movement in an annular member 257 and is actuated through bridge 258, slipper bearings 259 and swash plate 260, the latter being shown as mounted for rotation with hollow shaft 261 supported in bearings 262 carried by a suitable seat 263 provided by an inner rim portion of member 257. The clearance between the slant shaft and member 257 is exaggerated in Fig. 10 for clarity, but in practice it may be only of the order of a few thousandths of an inch. If necessary more elaborate labyrinthine packings may be employed.

Member 257 is shown as having in cross-section the general configuration of a pair of annular concentric channel members and provides an annular chamber 264 opening inwardly into central passage 253 and a second annular chamber 265 open to the outside atmosphere. Member 257 also provides the axially inner end wall for each cylinder 252, this wall being provided with intake and discharge passages 266 and 267, respectively, which are in turn controlled by suitable poppet valves 268 and 269. Intake passages 266 communicate with chamber 265 and thence with the outer atmosphere, and this chamber is also shown as provided with a screen 270 for preventing dirt particles and the like from being drawn into the apparatus. Intake valve 268 is mounted on valve stem 271 for sliding movement with respect to intake passages 266 and is controlled by a suitable coil spring 272 normally urging it to closed position. Discharge valve 269 is mounted for sliding movement on valve stem 273 carried by member 257 and is similarly normally urged to closed position by coil spring 274.

The axially outer end wall for each cylinder 252 is formed by a member 275 which includes a central chamber 276 connecting directly with central passage 253 and an annular outer chamber 277 open to the atmosphere and shown as provided with a cover screen 278 similar to screen 270. Member 275 is provided with intake and discharge passages 279 and 280 for each cylinder 252 controlled by poppet valves 281 and 282 respectively. Intake passages 279 open into annular chamber 277, and valve 281 is mounted on valve stem 283 for sliding movement inwardly against spring 284. Discharge passages 280 open into central chamber 276 of member 275 and thence into central passage 253, and valve 282 is accordingly mounted for sliding movement on stem 285 against spring 286.

With the construction as described and shown in Fig. 10, as each piston 254 reciprocates in its cylinder 252, a cycle of intake and discharge similar to that described in connection with Figs. 1 to 3 will take place. Thus with piston 254 in the position shown in Fig. 10, discharge valve 282 at the outer end of cylinder 252 will be open as shown under pressure from the piston to permit passage of fluid from within the cylinder into chamber 276 and thence to central passage 253,

and intake valve 281 will be forced shut under the pressure from the piston. At the same time, the suction behind the piston will have resulted in drawing intake valve 268 open against its spring as shown to draw in air through channel 265, while the discharge valve 269 at the inner end of the cylinder has been held shut by this same suction effect from the piston. As swash plate 260 rotates from the position shown in Fig. 10, piston 254 will reverse its stroke and the reverse operation of valves will take place, with valves 269 and 281 opening and valves 268 and 282 being held closed until the piston reaches the end of its inward stroke and again begins its outward stroke. It will be understood that the structure shown in Fig. 10 may have a plurality of cylinders and pistons as described in connection with Figs. 1 to 3, including a second plurality of cylinders on the opposite side axially of swash plate 260, so that the net effect will be closely comparable to that in connection with that shown in Figs. 1 to 3. With this construction, the discharge from the cylinders passes through the center of the machine and through the central boss of the slant member towards the end at which discharge is desired as with the apparatus shown in Fig. 1. The packing means shown in Figs. 6 to 9 are also applicable to pistons 254 in the structure shown in Fig. 10.

While the forms of apparatus herein described constitute preferred embodiments of the invention, it is to be understood that the invention is not limited to these precise forms of apparatus, and that changes may be made therein without departing from the scope of the invention which is defined in the appended claims.

What is claimed is:

1. In a positive displacement pumping apparatus of the character described, the combination of inner and outer circular wall members of different diameters concentrically arranged and forming an annular cylinder chamber about a central passage, wall members radially arranged in said annular chamber and separating said chamber into a plurality of parallel cylinders circumferentially arranged about said central passage, each of said cylinders having in transverse section the general configuration of a sector of a circular annulus, a piston mounted in each of said cylinders for reciprocating movement parallel to said central passage, each said piston being substantially complementary in shape to the cylinder wherein it is mounted, and means for imparting reciprocating movement to said pistons.

2. In a positive displacement pumping apparatus of the character described, the combination of inner and outer circular wall members of different diameters concentrically arranged and forming an annular cylinder chamber about a central passage, wall members radially arranged in said annular chamber and separating said chamber into a plurality of parallel cylinders circumferentially arranged about said central passage, each of said cylinders having in transverse section the general configuration of a sector of a circular annulus, a piston mounted in each of said cylinders for reciprocating movement parallel to said central passage, each said piston being substantially complementary in shape to the cylinder wherein it is mounted, port means providing communication between each of said cylinders and said central passage, and between each of said cylinders and the exterior of said apparatus, means for imparting reciprocating

movement to said pistons, and valve means for controlling said port means to establish proper pumping relation in accordance with the direction of motion of said pistons.

3. In a positive displacement pumping apparatus of the character described, the combination of inner and outer circular wall members of different diameters concentrically arranged and forming an annular cylinder chamber about a central passage, wall members radially arranged in said annular chamber and separating said chamber into a plurality of parallel cylinders circumferentially arranged about said central passage, each of said cylinders having in transverse section the general configuration of a sector of a circular annulus, a piston mounted in each of said cylinders for reciprocating movement parallel to said central passage, each said piston being substantially complementary in shape to the cylinder wherein it is mounted, port means adjacent each end of each of said cylinders, means providing communication between said port means and said central passage, means providing communication between said port means and the exterior of said apparatus, means for imparting reciprocating movement to said pistons, and means including valve means for controlling communication to and from said port means to establish proper pumping relation in accordance with the direction of motion of said piston.

4. In a positive displacement pumping apparatus of the character described, the combination of inner and outer circular wall members of different diameters concentrically arranged and forming an annular cylinder chamber about a central passage, wall members radially arranged in said annular chamber and separating said chamber into a plurality of parallel cylinders circumferentially arranged about said central passage, each of said cylinders having in transverse section the general configuration of a sector of a circular annulus, a piston mounted in each of said cylinders for reciprocating movement parallel to said central passage, each said piston being substantially complementary in shape to the cylinder wherein it is mounted, port means adjacent each end of each of said cylinders, means providing communication between said port means and said central passage, means providing communication between said port means and the exterior of said apparatus, means for imparting reciprocating movement to said pistons, and means including valve means for controlling said port means to open communication between said central passage and the end port of each cylinder toward which the piston therein is moving and substantially simultaneously to close communication between said central passage and the other end port of each said cylinder.

5. In a positive displacement pumping apparatus of the character described, the combination of inner and outer circular wall members of different diameters concentrically arranged and forming an annular cylinder chamber about a central passage, wall members radially arranged in said annular chamber and separating said chamber into a plurality of parallel cylinders circumferentially arranged about said central passage, each of said cylinders having in transverse section the general configuration of a sector of a circular annulus, a piston mounted in each of said cylinders for reciprocating movement parallel to said central passage, each said piston being substantially complementary in shape to the cyl-

finder wherein it is mounted, port means adjacent each end of each of said cylinders, means providing communication between said port means and said central passage, means including a rotary member for imparting reciprocating movement to said pistons in rotational sequence, and means actuated by said rotary member and including valve means for controlling said port means operative to open communication between said central passage and the end port of each cylinder toward which the piston therein is moving, substantially simultaneously to close communication between said central passage and the other end port in each said cylinder and open communication between said other end port and an intake passage, and to reverse said operations when the direction of piston motion is reversed.

6. In a positive displacement pumping apparatus of the character described, the combination of inner and outer circular wall members of different diameters concentrically arranged and forming an annular cylinder chamber about a central passage, wall members radially arranged in said annular chamber and separating said chamber into a plurality of parallel cylinders circumferentially arranged about said central passage, each of said cylinders having in transverse section the general configuration of a sector of a circular annulus, means providing in each of said radial walls a plurality of passages for coolant substantially parallel to said central passage, means providing ports for intake and discharge of coolant at opposite ends of said passages, a piston mounted in each of said cylinders for reciprocating movement parallel to said central passage, each said piston being substantially complementary in shape to the cylinder wherein it is mounted, and means for imparting reciprocating movement to said pistons.

7. In a positive displacement pumping apparatus of the character described, the combination of inner and outer circular wall members of different diameters concentrically arranged and forming an annular cylinder chamber about a central passage, wall members radially arranged in said annular chamber and separating said chamber into a plurality of parallel cylinders circumferentially arranged about said central passage, each said cylinder having in transverse section the general configuration of a sector of a circular annulus, means providing in each of said radial walls a plurality of passages for coolant substantially parallel to said central passage, means providing ports for intake and discharge of coolant at opposite ends of said passages, a piston mounted in each said cylinder for reciprocating movement parallel to said central passage, each said piston being substantially complementary in shape to the cylinder wherein it is mounted, a swash plate mounted for rotation with a shaft substantially coaxial with said central passage, a piston rod fixedly connected with each of said pistons, a bridge member fixedly connected with each said piston rod and including portions adapted to embrace said swash plate, means for rotating said swash plate to impart reciprocating motion to said pistons, each said piston coacting with its adjacent cylinder walls to prevent rotation of said bridge means, port means providing communication between each of said cylinders and said central passage and between each of said cylinders and the outside atmosphere, and means for controlling said port means to establish proper pumping relation in accordance with the direction of motion of said pistons.

8. In a positive displacement pumping apparatus of the character described, the combination of inner and outer circular wall members of different diameters concentrically arranged and forming an annular cylinder chamber about a central passage, wall members radially arranged in said annular chamber and separating said chamber into a plurality of parallel cylinders circumferentially arranged about said central passage, each of said cylinders having in transverse section the general configuration of a sector of a circular annulus, a piston mounted in each of said cylinders for reciprocating movement parallel to said central passage, each said piston being substantially complementary in shape to the cylinder wherein it is mounted, means providing substantially air-tight engagement between the periphery of each said piston and the inner walls of the cylinder wherein it is mounted and including packing means positioned in a groove in each side of each said piston and yieldable means urging said packing means into contact with the adjacent cylinder wall, and means for imparting reciprocating movement to said pistons.

9. In a positive displacement pumping apparatus of the character described, the combination of inner and outer circular wall members of different diameters concentrically arranged and forming an annular cylinder chamber about a central passage, wall members radially arranged in said annular chamber and separating said chamber into a plurality of parallel cylinders circumferentially arranged about said central passage, each of said cylinders having in transverse section the general configuration of a sector of a circular annulus, a piston mounted in each of said cylinders for reciprocating movement parallel to said central passage, each said piston being substantially complementary in shape to the cylinder wherein it is mounted, means providing a groove in each side of each said piston, a packing member mounted in each said groove, sinuous spring means positioned in each said groove between the inner wall thereof and the packing member therein and operative to urge said packing member into yielding engagement with the adjacent wall of said cylinder, and means for imparting reciprocating movement to said pistons.

10. In a positive displacement pumping apparatus of the character described, the combination of inner and outer circular wall members of different diameters concentrically arranged and forming an annular cylinder chamber about a central passage, wall members radially arranged in said annular chamber and separating said chamber into a plurality of parallel cylinders circumferentially arranged about said central passage, each of said cylinders having in transverse section the general configuration of a sector of a circular annulus, a piston mounted in each of said cylinders for reciprocating movement parallel to said central passage, each said piston being substantially complementary in shape to the cylinder wherein it is mounted, means providing a groove in each side of each said piston, the grooves in adjacent piston sides being spaced axially with respect to each other and overlapping at their adjacent ends, a packing member mounted in each said groove with the ends thereof overlapping the adjacent ends of the packing members in adjacent grooves and providing increased packing material at each corner of said piston, yieldable means positioned in each said groove between the inner wall

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thereof and the packing member therein and operative to urge said packing member into yielding engagement with the adjacent wall of said cylinder and means for imparting reciprocating movement to said pistons.

11. In a positive displacement pumping apparatus of the character described, the combination of inner and outer circular wall members of different diameters concentrically arranged and forming an annular cylinder chamber about a central passage, wall members radially arranged in said annular chamber and separating said chamber into a plurality of parallel cylinders circumferentially arranged about said central passage, each of said cylinders having in transverse section the general configuration of a sector of a circular annulus, a piston mounted in each of said cylinders for reciprocating movement parallel to said central passage, each said piston being substantially complementary in shape to the cylinder wherein it is mounted, a swash plate mounted for rotation about an axis substantially colinear with the axis of said central passage, bridge means providing a reciprocable connection between each of said pistons and said swash plate, said bridge means being fixedly connected to each said piston, and means for rotating said swash plate to impart reciprocating motion to said pistons, each said piston coacting with its adjacent cylinder walls to prevent rotation of said bridge means.

12. In a positive displacement pumping apparatus of the character described, the combination of inner and outer circular wall members of different diameters concentrically arranged and forming an annular cylinder chamber about a central passage, wall members radially arranged in said annular chamber and separating said chamber into a plurality of parallel cylinders circumferentially arranged about said central passage, each said cylinder having in transverse section the general configuration of a sector of a circular annulus, a piston mounted in each said cylinder for reciprocating movement parallel to said central passage, each said piston being substantially complementary in shape to the cylinder wherein it is mounted, a swash plate mounted for rotation with a shaft substantially coaxial with said central passage, a piston rod fixedly connected with each of said pistons, a bridge member fixedly connected with each said piston rod and including portions adapted to embrace said swash plate, means for rotating said swash plate to impart reciprocating motion to said pistons, each said piston coacting with its adjacent cylinder walls to prevent rotation of said bridge means, port means providing communication between each of said cylinders and said central passage and between each of said cylinders and the outside atmosphere, and means for controlling said port means to establish proper pumping relation in accordance with the direction of motion of said pistons.

13. In a positive displacement pumping apparatus of the character described, the combination of inner and outer circular wall members of different diameters concentrically arranged and forming two parallel annular cylinder chambers about a central passage and spaced axially from each other, wall members radially arranged in each said annular chamber and separating said chambers into two groups of parallel cylinders circumferentially arranged about said central passage, each said cylinder having in transverse section the general configuration of a sector of a

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circular annulus, a piston mounted in each said cylinder for reciprocating movement parallel to said central passage, each said piston being substantially complementary in shape to the cylinder wherein it is mounted, a swash plate mounted for rotation with a shaft substantially coaxial with said central passage and extending outwardly into said space between said cylinder chambers, means including a piston rod and a bridge providing a connection between each piston in one said group of cylinders and a piston in the other said group of cylinders, each bridge including portions constructed for embracing contact with said swash plate, means for rotating said swash plate to impart reciprocating movement to said pistons, port means providing communication between each said cylinder and said central passage and between each said cylinder and the outside atmosphere, and valve means for controlling said port means to establish proper pumping relation in accordance with the direction of motion of said pistons.

14. In a positive displacement pumping apparatus of the character described, the combination of inner and outer circular wall members of different diameters concentrically arranged and forming two parallel annular cylinder chambers about a central passage and spaced axially from each other, wall members radially arranged in each said annular chamber and separating said chambers into two groups of parallel cylinders circumferentially arranged about said central passage, each said cylinder having in transverse section the general configuration of a sector of a circular annulus, a piston mounted in each said cylinder for reciprocating movement parallel to said central passage, each said piston being substantially complementary in shape to the cylinder wherein it is mounted, a swash plate mounted for rotation with a shaft substantially coaxial with said central passage and extending outwardly into said space between said cylinder chambers, said swash plate being provided with a passage therethrough adjacent its center and coinciding with said central passage, means including a piston rod and a bridge providing a connection between each piston in one said group of cylinders and a piston in the other said group of cylinders, each bridge including portions constructed for embracing contact with said swash plate, means for rotating said swash plate to impart reciprocating movement to said pistons, port means providing communication between each said cylinder and said central passage and between each said cylinder and the outside atmosphere, and valve means controlling said port means and operative in accordance with the direction of motion of said pistons to direct substantially the entire output of said cylinders into said central passage and to one end of said passage and apparatus.

15. In a positive displacement pumping apparatus of the character described, the combination of inner and outer circular wall members of different diameters concentrically arranged and forming two parallel annular cylinder chambers about a central passage and spaced axially from each other, circumferentially spaced wall members radially arranged in each said annular chamber and separating said chamber into two groups of parallel cylinders circumferentially arranged about said central passage, each said cylinder having in transverse section the general configuration of a sector of a circular annulus, a piston mounted in each said cylinder for

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reciprocating movement parallel to said central passage, each said piston being substantially complementary in shape to the cylinder wherein it is mounted, a swash plate mounted for rotation with a shaft substantially coaxial with said central passage and extending outwardly into said space between said cylinder chambers, means including a piston rod and a bridge providing a connection between each piston in one said group of cylinders and a piston in the other said group of cylinders, each bridge including portions constructed for embracing contact with said swash plate, means for rotating said swash plate to impart reciprocating movement to said pistons, port means adjacent each end of each said cylinder, means providing communication between said port means and said central passage and between said port means and the outside atmosphere, and rotary valve means mounted for rotation with said swash plate for controlling said port means and operative to open communication between said central passage and the end port of each cylinder toward which the piston therein is moving, substantially simultaneously to close communication between said central passage and the other end port in each said cylinder and open communication between said other end port and an intake passage, and to reverse said operations when the direction of piston motion is reversed.

16. In a positive displacement pumping apparatus of the character described, the combination of inner and outer circular wall members of different diameters concentrically arranged and forming two parallel annular cylinder chambers about a central passage and spaced axially from each other, wall members radially arranged in each said annular chamber and separating said chambers into two groups of parallel cylinders circumferentially arranged about said central passage, each said cylinder having in transverse section the general configuration of a sector of a circular annulus, a piston mounted in each said cylinder for reciprocating movement

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parallel to said central passage, each said piston being substantially complementary in shape to the cylinder wherein it is mounted, means providing a groove in each side of each said piston, a packing member mounted in each said groove, sinuous spring means positioned in each said groove between the inner wall thereof and the packing member therein and operative to urge said packing member into yielding engagement with the adjacent cylinder wall, a swash plate mounted for rotation with a shaft substantially coaxial with said central passage and extending outwardly into said space between said cylinder chambers, means including a piston rod and a bridge providing a connection between each piston in one said group of cylinders and a piston in the other said group of cylinders, each bridge including portions constructed for embracing contact with said swash plate, means for rotating said swash plate to impart reciprocating movement to said pistons, each piston coacting with said packing means and the adjacent cylinder walls to prevent rotation of the bridge connected therewith, port means providing communication between each said cylinder and said central passage and between each said cylinder and the outside atmosphere, and valve means for controlling said port means to establish proper pumping relation in accordance with the direction of motion of said pistons.

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