Aug. 14, 1945. N. HERZMARK 2,382,716

COMPRESSOR

Filed Feb. 10, 1943 4 Sheets-Sheet 1

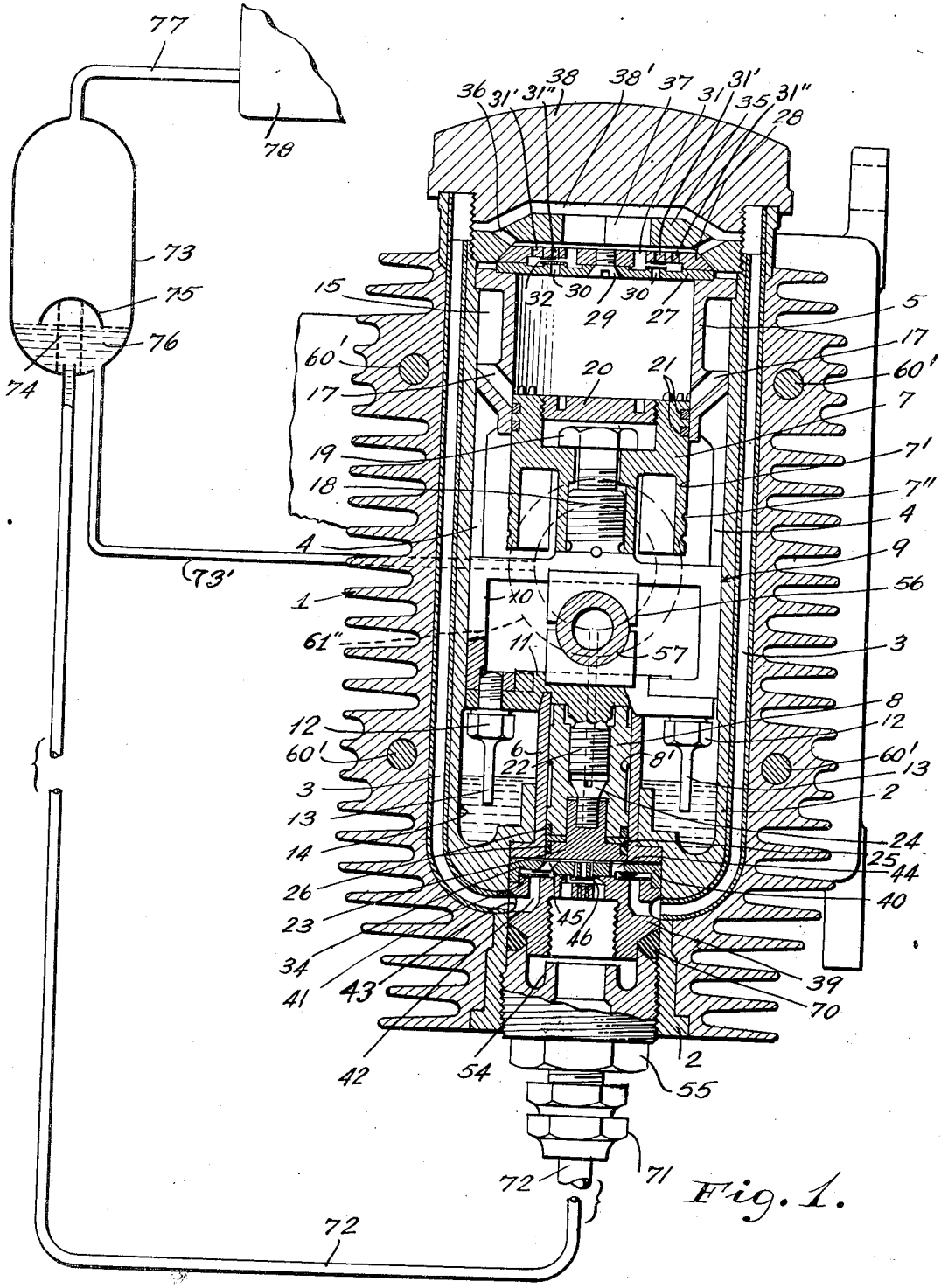


Fig. 1.

INVENTOR.
NICOLAS HERZMARK
BY
ATTORNEY

Aug. 14, 1945. N. HERZMARK 2,382,716

COMPRESSOR

Filed Feb. 10, 1943 4 Sheets-Sheet 2

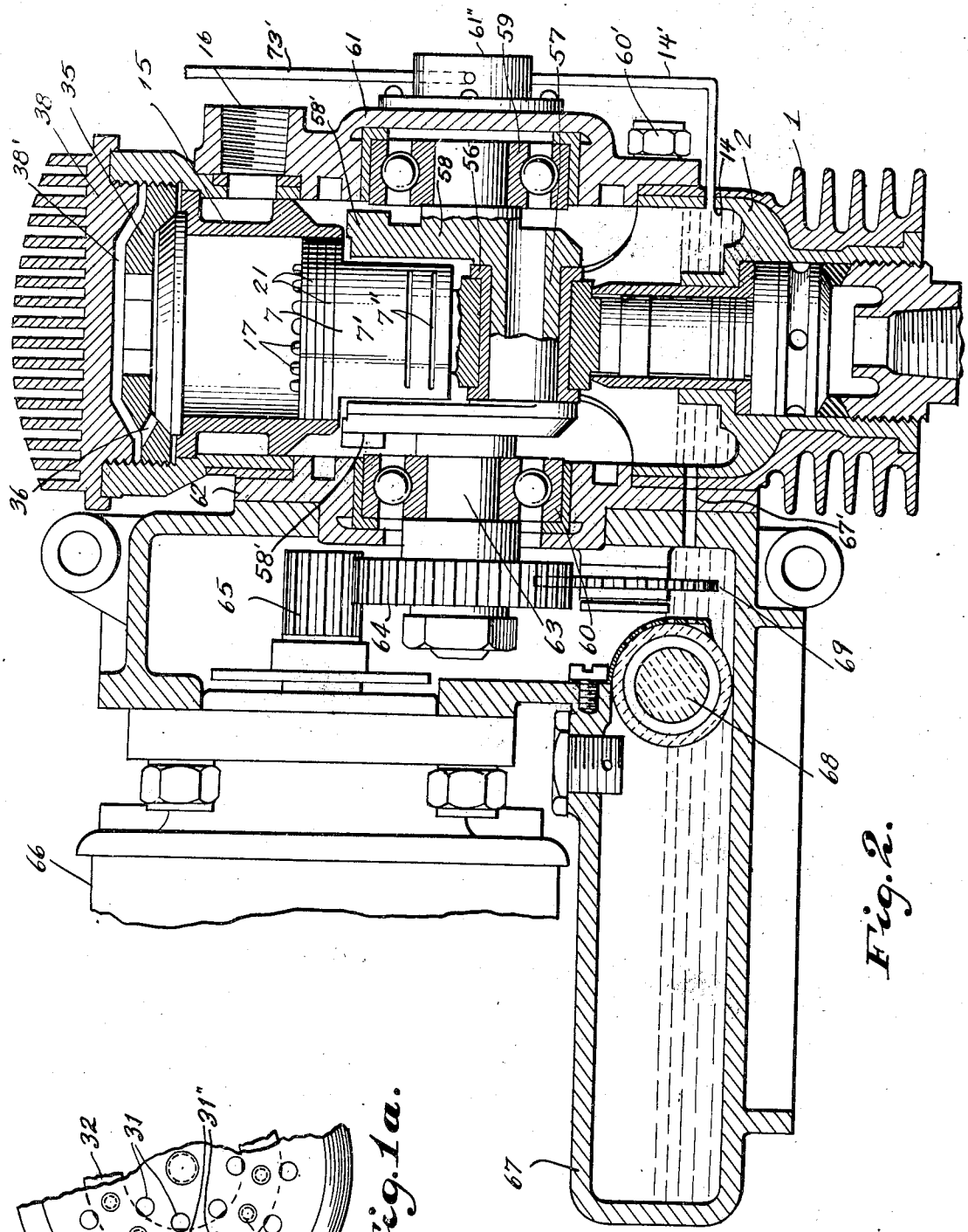


Fig. 2.

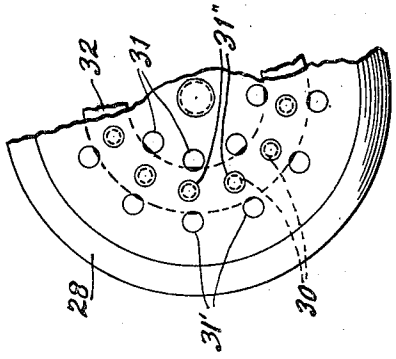


Fig. 1a.

INVENTOR.
NICOLAS HERZMARK
BY
Lawrence Klein
ATTORNEY

Aug. 14, 1945. N. HERZMARK 2,382,716

COMPRESSOR

Filed Feb. 10, 1943 4 Sheets-Sheet 3

Fig. 4.

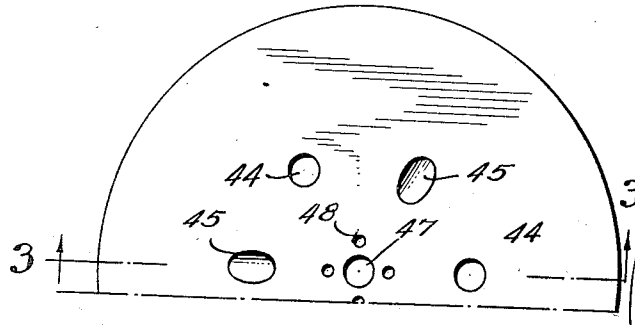


Fig. 6.

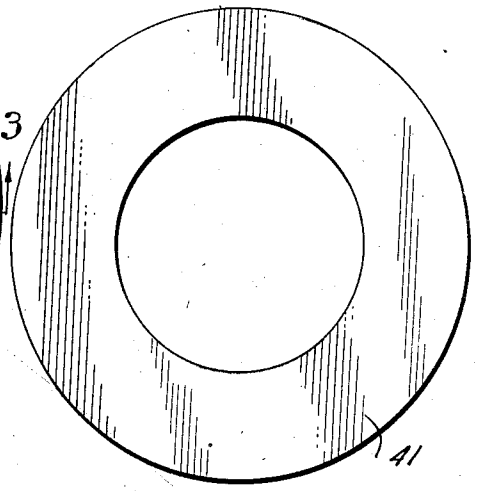


Fig. 3.

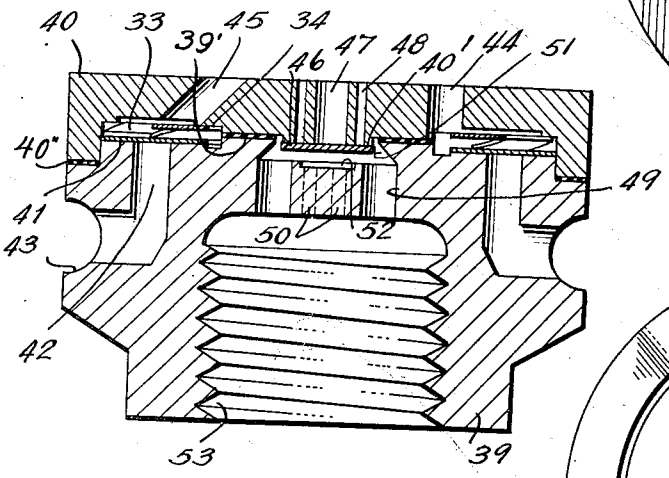


Fig. 7.

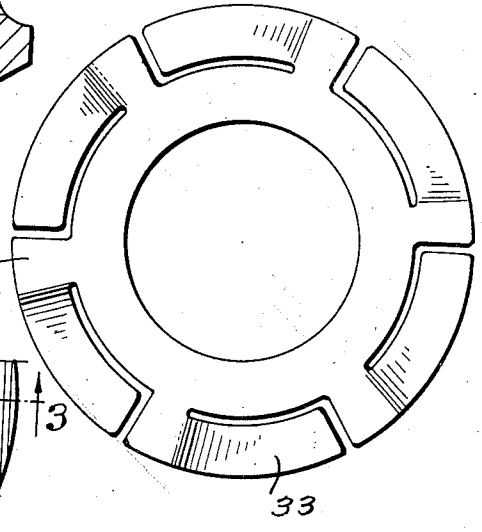


Fig. 5.

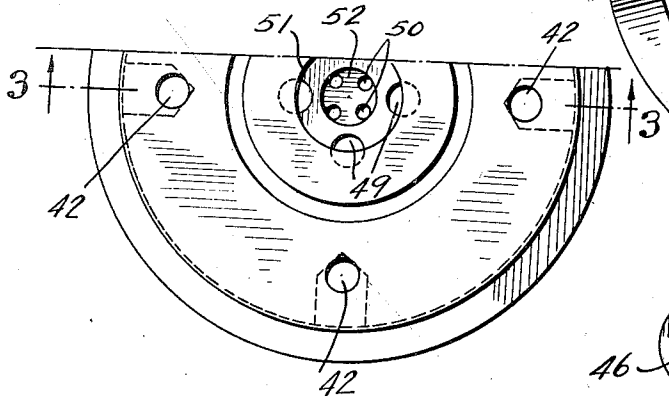
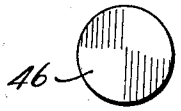


Fig. 8.



INVENTOR.
NICOLAS HERZMARK
BY
ATTORNEY

Aug. 14, 1945. N. HERZMARK 2,382,716

COMPRESSOR

Filed Feb. 10, 1943 4 Sheets-Sheet 4

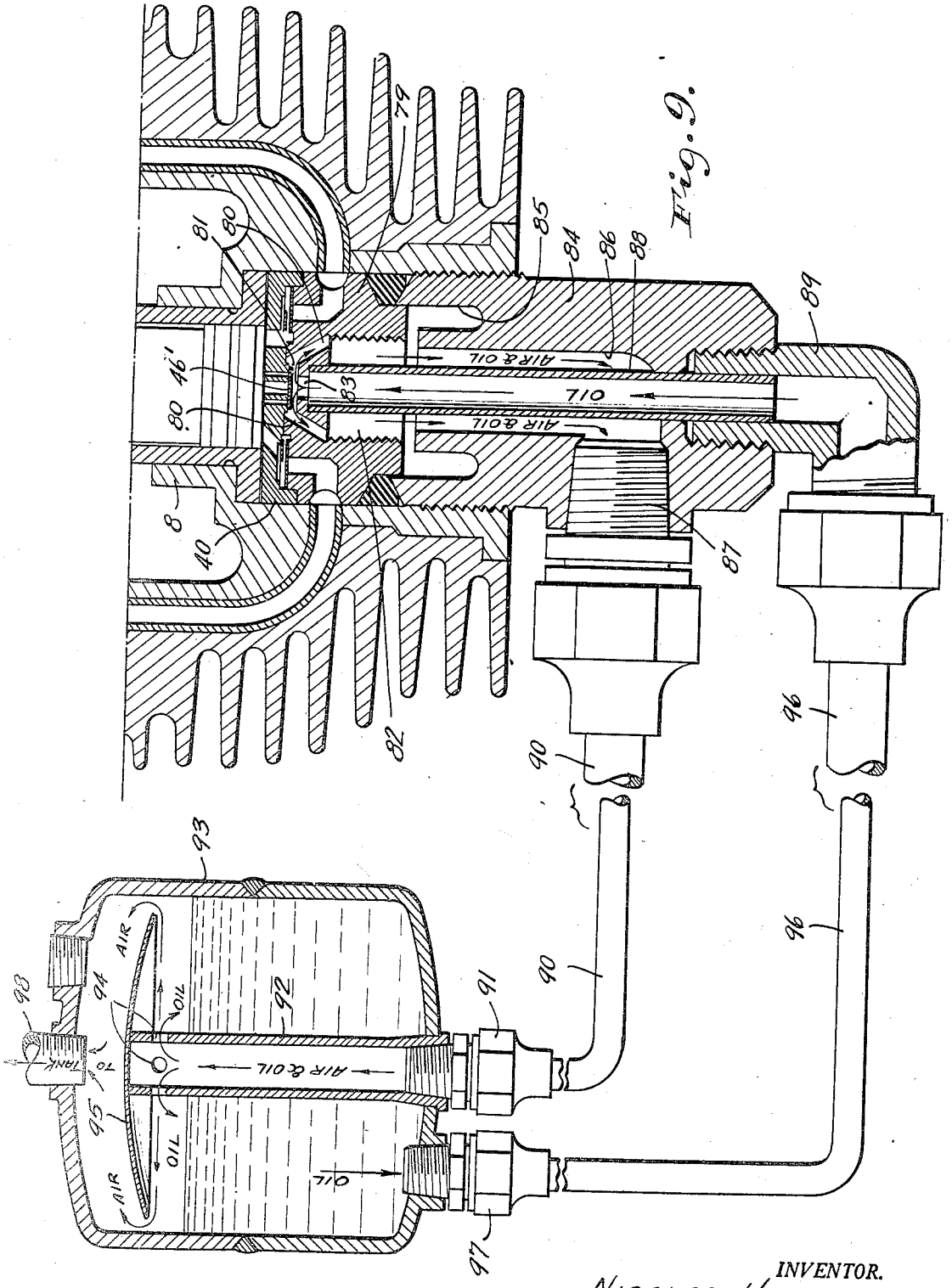


Fig. 9.

INVENTOR.
NICOLAS HERZMARK
BY
Rentzon & Klein
ATTORNEY

Patented Aug. 14, 1945

2,382,716

UNITED STATES PATENT OFFICE

2,382,716

COMPRESSOR

Nicolas Herzmark, New York, N. Y.

Application February 10, 1943, Serial No. 476,241

12 Claims. (Cl. 230—181)

This application is a continuation in part of my application for Compressors, Serial Number 449,038, filed June 29, 1942, now abandoned.

This invention relates to compressors generally, and especially to compressors for high pressures, particularly adapted for operation at high altitudes, and has for its object the provision of an improved compressor of this character.

The invention provides a gas compressor having at least two stages of compression, one being a high pressure stage and the other a relatively low pressure stage, means for introducing oil into the low pressure cylinder, and means for passing the oil along with the compressed gas from the low pressure stage to the high pressure stage and into contact with a valve member for the discharge port of the high pressure cylinder. Advantageously, the oil introduced into the low pressure cylinder is in an amount sufficient to fill the dead spaces and, when carried over to the high pressure stage, to form a body of oil in the discharge port for the high pressure cylinder wherein the oil contacts and protects the valve member from the high pressure hot gases.

The invention preferably provides a recess in which the valve member operates, a cavity on the discharge side of the valve member connected to the recess and means for maintaining cooling oil from the cavity in contact with the discharge side of the valve member. The discharge port for the high pressure cylinder may comprise a plurality of small openings for oil and at least one large opening for the flow of gas, and the valve member may be arranged to be pressed by fluid into seating contact with the small openings when the discharge port is closed with the result that the oil from the high pressure cylinder entering the small openings serves as a thermal barrier between the hot compressed gas and the valve member.

The foregoing and other important objects and advantages of the present invention will become more readily apparent from the following description, in connection with the accompanying drawings, wherein:

Fig. 1 is a vertical, partial cross-section through a two-stage compressor of my present invention, including a diagrammatical illustration in reduced form of its complement exterior features;

Fig. 1a is an enlarged, fragmental top view of the upper valve structure;

Fig. 2 is another partial, vertical cross section through my compressor, taken substantially at right angles to that shown in Fig. 1;

Fig. 3 is a detail vertical cross section through the valve retaining structure of the high pressure stage of my compressor, taken on lines 3—3 of Figs. 4 and 5;

Fig. 4 is a partial top view thereof;

Fig. 5 is a partial top view of the lower member of Fig. 3;

Fig. 6 is a plan view of an annular valve employed in the structure shown in Fig. 3;

Fig. 7 is a plan view of an annular spring member employed in the structure shown in Fig. 3;

Fig. 8 is a plan view of the discharge valve employed in my device; and

Fig. 9 is a fragmental cross section of a modified form of my device, partially in diagrammatical form.

Referring now specifically to Figs. 1 and 2, numeral 1 designates the body or casing of my compressor, equipped with air cooling ribs or fins, and preferably made of light cast material, such as aluminum or an alloy thereof. Within the casing is cast a body core 2, with which latter are previously cast or otherwise associated flattened inter-cooler tubes 3, serving as interstage communicating passages. These tubes connect the outlet ports of the low pressure stage with the intake ports of the high pressure stage, as will be explained presently.

In the body core 2 there are provided premachined cylindrically curved guides 4, and with the upper and lower ends of the body core are associated, respectively, low and high stage cylinders 5 and 6. These cylinders are aligned with one another. Operating within these cylinders are low pressure and high pressure pistons 7 and 8, respectively. Piston 7 is equipped with aprons 7', in which are provided oil retaining grooves 7''. The ends of grooves 7'' terminate short of the edges of the aprons 7', the grooves being designed to hold a measured amount of oil. Similarly high pressure piston 8 is equipped with oil retaining recesses 8'.

These pistons are also aligned and are joined with one another to form a substantially integral or one-piece structure, which structure includes a yoke-like cross head 9 joining the pistons. The ends of the cross head are cylindrically curved, and operate or slide within the similarly curved guides 4. The diameter of the cylindrical curvature of both the guides and of the cross head ends is substantially larger than the diameters of either of the two pistons. The cross head is composed of an upper, substantially C-shaped structure 10, and a lower flange 11, which latter is secured to upper structure 10 by bolts 12. From these bolts extend downwardly oil displacing dippers or

splashers 13, of a definite and predetermined displacement value, which are designed to plunge into an oil-filled basin 14, provided at the bottom of the body core and surrounding the high pressure cylinder.

Special attention is directed to the disposition of the low pressure cylinder above the high pressure cylinder, and the provision of the relatively large oil basin 14 surrounding the high pressure cylinder. This construction is chosen to minimize space losses, and to gain sufficient room for a substantial body of oil held in the basin.

Low pressure cylinder 5 is designed with an annular exterior channel 15, into which issues air intake opening 16. (See Fig. 2.) From channel 15 extend downwardly slanting and converging passages 17, which terminate with their lower ends in vertically elongated, oval ports. The upper halves of these ports extend above the top of the piston, when the latter is in its lowermost position, and form intake areas corresponding in breadth to the diameters of the passages, but are shorter in height than the diameters. Through this lowered height of the intake areas the idle port-closing movement of the piston during its upward stroke becomes shortened. This shortening in turn reduces the length of the entire piston assembly, and thereby the overall height of the compressor, since in reducing the movement of one piston, the stroke of the other piston becomes necessarily shortened also.

Although the resulting height reduction of the compressor may seem rather insignificant, it nevertheless constitutes an important part of the prime aims of the present invention, that is, compactness and lightness. The tendency towards these aims will be found emphasized throughout the ensuing specification, inasmuch as the device is designed for use in close quarters, such as in aircraft, where the factors of space saving and weight reduction are of paramount importance.

When piston 7 is in its downward position, it closes the lower oval end portions of passages 17, whereby tiny pockets or oil-retaining wells are formed, the purpose of which will become presently evident. Air entering at the end of the suction stroke of piston 7 through air inlet 16 into the annular space of channel 15, passes through passages 17 into the interior of the cylinder, wherein it is compressed after piston 7 has passed the upper ends of passages 17 in its upward movement.

The upper structure of cross head 9 terminates in a central extension 18 engaging low pressure piston 7, which is held against movement by stud 19, its head being disposed in a depression provided in piston 7. This depression is sealed by a removable closure 20. The upper end of low pressure piston 7 has the usual arrangement of piston rings 21, and it will be observed that in the downward position of the piston its major body portion below the rings, including aprons 7', clears cylinder 5, for the purpose of applying to the piston surface an adequate amount of lubricant.

The lower yoke portion or flange 11 has a threaded central extension 22 in engagement with high pressure piston body 3. At the lower end of that piston body is provided piston head 23, secured by flat-head screw 24. Between the piston body and piston head 23 is a piston ring spacer 25 separating piston rings 26.

Recessed at the upper end of low pressure cylinder body 5 is a low pressure valve structure consisting of two members, the lower member 27 constituting a valve seat or valve support, while the upper member 28 serves as valve housing and valve movement limiting means. Both members are joined by a flat-head screw 29, and possess substantially vertical air passages. In lower member 27 these passages, indicated at 30, are disposed along a circle and terminate at the top of the valve seat. In upper member 28 there are preferably arranged three concentric series of passages. The passages of the innermost series are indicated at 31; the passages of the outermost series are designated by numeral 31', and the passages in the central series are numbered 31''. (See Figs. 1 and 1a.) Passages 31 and 31' are disposed substantially above the inner and outer valve seat edges in member 27 and are offset relative to passages 30 of the lower member, whereas passages 31'' are preferably aligned with passages 30, and are disposed directly over the valve seat. This disposition of passages 31'' is of eminent importance, as will become presently evident. The arrangement of passages 31 and 31' is intended to provide for the least possible resistance to the escaping compressed air.

Resting upon the valve support is an annular valve 32, against which bear spring prongs 33 of spring washer 34, illustrated in detail in Figs. 3 and 7. While this spring washer is primarily intended for exerting pressure against annular valve 32, its function and operation is relied upon only for the initial or starting operation period of the compressor. Once pressure is built up in the system, the compressed fluid exerts, through the central row of passages 31'' in upper member 28, a sufficient force against the body of valve 32 to automatically press the valve against its seat, when piston 7 has reached its uppermost compression position and is about to start its suction stroke. Thus the closing, as well as the opening of valve 32 becomes effectively and exactly synchronized with the movements of piston 7, without reliance upon the spring action of washer 34 for closing the valve. As a matter of fact, the closing action of the valve, induced by the compressed fluid, is instantaneous and anticipates the closing function of the spring washer.

Members 27 and 28 of the valve structure are forcibly held against cylinder 5 by a threaded valve retaining or locking member 35, in engagement with the internal thread provided at the upper end of body core 2. Member 35 is spaced from the valve structure and has a plurality of inclined, peripherally disposed passages 36, and a central opening 37, designed for the reception of a wrench used for tightening member 35 against the valve structure.

Closing the upper end of the low pressure cylinder is a cylinder head 38, which also engages the threaded portion of the body core, but is spaced from locking member 35 at 38' to provide communication for passages 36 and central opening 37 with the upper ends of the interstage communicating tubes 3.

The valve structure of the high pressure stage consists of lower and upper members 39 and 40, both having valve seating or supporting surfaces and valve movement limiting means. These two members comprise two valve portions, an outer portion, housing the intake valve, and a central portion accommodating the discharge valve. Member 39 has an annular seat against which rests a ring-shaped valve 41. (See Fig. 3.) Below valve 41 are arranged inlet ports 42, having vertical and horizontal passages, the latter extending into annular groove 43 in lower member 39, into which

groove issue the curved lower ends of inter-communicating tubes 3.

These tubes, shown clearly in Fig. 1, are indicated as having been cast into the material of the body core 2, and are uniformly spaced from each other over their entire length by the body core. This body core is then machined, and the whole unit, including tubes 3, is then cast into the outer, finned casing. The tubes are preferably parallel over their entire length except for their lower termini, which are gently curved towards annular groove 43 of lower valve member 39. The interior portions of tubes 3 are removed at their upper termini to provide communication with passage 38' beneath low pressure cylinder head 38.

Although body core 2 and tubes 3 are shown to be united by a simple casting procedure, I have found it advantageous to braze, weld or hard solder the tube bodies to the body core, especially at their termini, thus precluding possible leakage between the body core and the ends of the tubing, which leakage would negate compression at high values.

Upper member 40 of the high pressure valve structure is recessed sufficiently to accommodate an annular spring member 34, identical with that explained in connection with the low pressure valve arrangement. Prongs 33 of spring washer 34 bear against the upper surface of ring valve 41. The spring washers employed in both the low and the high pressure valve structures serve merely for the purpose of facilitating the initial operation of the device. Once pressure is built up in both pressure stages, the function of the spring washers becomes of secondary importance.

It will be observed that upper member 40 has alternately disposed vertical and oblique passages 44 and 45, respectively, leading into the high pressure cylinder. The oblique passages are primarily designed to facilitate the seating of ring valve 41 by the pressure created within the high pressure cylinder. Thus the initial valve closing action by spring washers 34 is taken over by the high pressure surges against annular valves 41, positively forcing the valve against its seat. This seating is facilitated by the presence of lubricating oil, which latter serves as sealing medium.

At the center portion of members 39 and 40 is located the discharge port of the high pressure cylinder. Member 40 has a central extension 40' (see Fig. 3), providing a ground seat for a disc valve 46, shown in detail in Fig. 8. The body of member 40, above extension 40', possesses a relatively large central discharge port 47 and a plurality of peripherally disposed, relatively smaller passages 48. Lower member 39 is provided at its center with generously dimensioned outer vertical passages 49, and smaller interior passages 50. There exists a distinct relation between the areas of discharge port 47 and its surrounding passages 48 in upper member 40, and the large openings 49 and the smaller central openings 50 provided in lower member 39. The combined discharge areas in the upper member are much smaller than those of the openings in the lower member. I have determined that the outlet areas of the lower member should be at least three times as large as the high pressure discharge areas of member 40. This proportion is subject to an upward or downward adjustment, however, depending upon the factors of capacity, pressure, speed, temperature, altitude and other conditions, at which the compressor is to operate. The top center portion of member 39 is deeply recessed at 51. The upper periphery of the recess passes through the vertical centers of passages 49. Concentric with recess 51 is a smaller, shallow recess 52, within which lie the top ends of small passages 50. Within the space created between valve seat extension 40' and the bottom surface of recess 51, disc valve 46 operates. It may be considered a "floating" valve, and its operation may be well compared with vibration.

In the course of experimentation with valve disc 46 and ring valves 32 and 41, I have found that there must be maintained a certain relation between the thicknesses and weights of these valve elements. All of the valve elements must be thin and light in weight so as to possess a relatively small amount of inertia to facilitate their vibratory operation in synchronization with the pistons. I have determined that best results were obtained by making all valves of practically a uniform weight. Thus disc valve 46 should approximately weigh as much or as little as either one of the ring valves 32 and 41. This requirement is achieved by fabricating the ring valves from material which is of about half the thinness of the material from which disc 46 is made. (See Fig. 3.)

The mass of the valve members 32, 41 and 46 is preferably such that they will open and close, without spring pressure, at least as rapidly as thirty times per second when subjected to the relatively high air pressure developed by the compression stroke of the pistons 7 and 8.

Within the lower body of member 39 there is provided a threaded, relatively large opening 53, which communicates with a generously dimensioned well 54, arranged in discharge bushing 55. Particular attention is directed to the relatively large high pressure discharge apertures in member 39, and the unusual spaciousness provided below valve 46, both in member 39 as well as in discharge bushing 55. These spacious cavities are designed to be constantly filled with a relatively large body of a cooling medium, which is to be kept in unrestricted, direct and constant contact with floating disc valve 46, for the purpose of facilitating a rapid heat transfer from the valve disc to the medium.

Within the yoke of cross head 9 there is slidably mounted a yoke bearing 56, in which is journaled the hollow crank 57 of crankshaft 58, the latter being provided with spaced counterbalances or counterweights 58'. (See Fig. 2.) Crankshaft 58 is journaled in bearings 59 and 60, which latter are mounted in bearing plates 61 and 62, respectively. These plates are secured to outer casing 1 by means of bolts 60'. One end 63 of the crankshaft extends beyond bearing 62 for the reception of gear 64, which is driven by pinion 65 from motor 66. Below the motor there is provided an oil basin 67, in communication with oil basin 14 through passage 67'. Basin 67 is equipped with a heater 68. Within the oil basin 67 operates an oiling gear 69, in operative engagement with and adapted to lubricate gear 64 and pinion 65.

Attention is directed to the arrangement of piston 7, and especially to its skirts or aprons 7', and their relation to counterweights 58', which construction may be clearly observed by consulting Fig. 2. It will be seen that the piston body is cut away to provide spare-outs of just a sufficient space for facilitating the operation therein of the counterweights, which latter extend closely to the lower end of the low pressure cylinder. Thus, while the counterweights extend so-to-

speak into the piston body, aprons 7' of the piston project into the space between the counterweights of the crank. In this manner a considerable reduction in height of the entire device is accomplished, without the loss of the essential guide areas for the piston, provided by aprons 7'.

Counterweights 58' are designed for very accurately balancing the entire piston structure, including the crank-shaft, in order to eliminate even the slightest vibration. A coin placed edgewise on top of the operating compressor will remain standing, indicating that the entire operative assembly is perfectly balanced.

From the foregoing allusion to the shortness of the piston assembly, it becomes readily evident that leverages between the crank and the connecting members to the pistons are reduced to a minimum. Additionally the aprons provided with the low-pressure piston afford generous bearing surfaces. The combined features of shortness in the piston structure and the provision of the aprons, in conjunction with the cross-head guides, prevent ovalization of the pistons. In other words side play is substantially completely eliminated.

Referring again to Fig. 1, and especially to discharge bushing 55, the latter is threaded and engages the lower interiorly threaded end of body core 2, and secures therein, by means of compression gasket 70 bearing against lower member 39, the entire high pressure valve structure. With discharge bushing 55 is connected by way of fitting 71 a discharge pipe 72, shown in reduced dimension at the left-hand side of Fig. 1, the upper end of which pipe or conduit terminates in a trap 73. This trap is intended to be disposed a sufficient distance above the compressor, although its position is not so shown in the drawing. Discharge pipe 72, as well as the lower portion of trap 73, is completely filled with a cooling medium, constituting a relatively high liquid column. Thus the liquid fills the cavities within the high pressure discharge end of the compressor, and exerts a certain pressure against valve 46. This cooling medium may be in the form of oil or any other suitable matter which will facilitate a ready passage therethrough of the compressed fluid discharging from the high pressure compressor end. Conduit 72, secured at the bottom end of trap 73, is surrounded by a member 74 adapted to break up the compressed air entering the trap. Member 74 may be in the form of a perforated pipe or a screen, on top of which is arranged an inverted bowl or mushroom 75, extending with its lower edge towards the body of cooling medium 76 retained in the trap. From the top end of the trap extends a conduit 77, leading into air reservoir indicated at 78.

In Fig. 1 is a shown a single pipe system leading from the discharge port of the high pressure cylinder. In order to provide a satisfactory circulation of the heated cooling medium in upward direction, and of the cooled medium in downward direction, conduit 72 must be designed of a sufficiently large area to readily facilitate such fluid exchange.

I have also shown trap 73 to be disposed above check valve 46, to provide a relatively tall column of oil under sufficient pressure to maintain a large body of oil in constant contact with the valve. Nevertheless similar results may be obtained by placing a partially oil-filled trap below the compressor, and connecting it by an arrangement of inner and outer conduits with the latter, whereby oil will be also maintained in contact with the valve, due to the pressure in the system. Such arrangement being obvious, its structure is not illustrated.

Referring now specifically to the device illustrated in Fig. 9, this modification constitutes an alternate form of the lower compressor structure, a modified arrangement of the trap or separator, as well as a different mode of connecting the latter with the compressor.

Attention is directed to the modified form of the valve body, wherein lower member 79 is provided with outwardly inclined outer passages 80, connecting the valve retaining compartment 81 with threaded cavity 82 of member 79. There is also provided at the center of this member, within the arrangement of passages 80, a single opening 83.

The closing structure of the lower compressor end is changed, in that for the formerly employed closing bushing 55 there is substituted a closing body 84. The latter is equipped with a deep well 85 for the retention of a substantial body of a cooling medium. At the center of body 84 is provided a passage 86, terminating sidewise in a threaded opening for the reception of tube union 87. Through the center of passage 86 extends tubing 88, the upper end of which terminates beneath central opening 83, while its lower end is held within elbow tube union 89, secured at the bottom of body 84.

Extending from union 87 is a conduit 90, which is directed upwards for a substantial distance above valve retaining compartment or valve chamber 81, and connects by means of union 91 with a pipe or tube 92 projecting centrally into trap or separator 93. Tube 92 is provided with openings 94 beneath a mushroomed deflector 95, the latter extending towards the periphery of trap or separator 93.

Connected with elbow union 89 is conduit 96, which also extends in upward direction and is associated by means of union 97 with the bottom end of separator 95. At the top of the separator or trap there is provided a tube connection 98, leading to the air storage tank, not shown.

Particular attention is directed to floating check valve 46', which in this modified form serves two purposes, although its so-to-speak vibratory movement is also limited in a similar manner to that shown in Fig. 1. During the upward stroke of piston 8 the valve closes the discharge port in upper valve structure member 40, while during the downward stroke of the piston it opens the discharge port and closes opening 83 in lower member 79.

A large portion of the interior of trap 93 is filled with a cooling medium, such as oil, which cooling medium also fills both conduits 96 and 90. First conduit 96 becomes filled and conveys the cooling medium into central tube 88, extending through passage 86 within closing body 84. While valve 46' is in its elevated position, oil can freely pass from central tubing 88 through port 83 and passages 80 into cavity 82, and from there into well 85 and into the space within passage 86 surrounding tube 88. Thus a relatively large body of cooling medium fills the interior of member 79 and of closing body 84.

During the discharge period of the compressed fluid, valve 46' is moved over central opening 83 and closes it. Thus the body of cool oil within central tube 88 is trapped and is prevented from issuing through port 83. The trapped oil, being under static pressure, is forced into direct and

intimate contact with the major portion of the bottom surface of valve 46', thereby rapidly and effectively cooling it, while its upper surface is exposed to the heat of the issuing compressed air.

As the hot air strikes the relatively cool valve body, it receives a substantial initial cooling. From there the compressed fluid is directed through the large body of the cooling medium, which completely fills inclined passages 80, cavity 82 and passage 86 of member 84. In addition to passing through this body of cooling medium, the fluid is forced through the relatively tall column of cooling medium contained in conduit 90.

As the compressed fluid leaves the high compression cylinder and is discharged into the cooling medium, it enters a space under a lesser pressure than that imparted thereto by high pressure piston 8. In consequence thereof the tiny bubbles, passing through the cooling medium gradually expand and partially displace some of the cooling medium. The latter not only absorbs whatever heat the bubbles still retain, but becoming heated itself, rises with the air into central pipe 92 of separator 93. As the volume of both air and oil increases, both are discharged through pipe openings 94 under mushroom 95, the air escaping into the reservoir, while the cooling medium reverts into the outer portion surrounding pipe 92. During this separation the cooling medium, coming in contact with the relatively large, substantially cold surface of the separator, becomes very substantially cooled and descends in its now cool state through conduit 96 into tube 88.

Compared with the construction of Figures 1 and 2, the modified form shown in Fig. 9 provides for a more effective, relatively rapid circulation of the cooling medium, while the latter is kept under constant static pressure, due to the high column at which it is maintained. Thus a positive contact between the cool medium and the major part of the bottom surface of floating valve 46' is always assured. In consequence of the improved manner of oil circulation, the modified structure provides for a greater cooling efficiency.

Another advantage of this construction resides in the fact that the compressed fluid, issuing from the discharge port, is more positively prevented from displacing the cooling medium or pushing it out of contact with floating valve 46'. The two-pipe arrangement also facilitates a quick pressure-equalization within the entire system after the completion of each pressure stroke, whereby the circulating movement of the cooling medium therein becomes more uniform and steady. In consequence of this improved circulation the temperature of the cooling medium within tube 88 is relatively very low. As a result, the hot compressed air striking against valve disc 46' can not heat the latter above the coolness imparted to the disc by the body of oil in tube 88. On the contrary, the disc rapidly absorbs the heat from the air, quickly transfers it to the cool oil, and thus cools the air. Hence the high cooling efficiency of the device.

Referring again to Figs. 2, 1, and 3, it will be observed that bearing plate 61 is provided with a central aperture, through which extends a shaft 61' of a metering pump 61'', attached to the outer face of the plate. Shaft 61' is operatively but removably connected with crankshaft 58. Also the compressor shown in Fig. 9 is intended to be equipped with such a metering pump.

This pump, which may be conveniently placed and driven anywhere and which may be of any suitable design to dispense measured amounts of oil, is intended to deliver oil through conduits 73' and 14' from oil reservoir or trap 73 to basin 14. The amount of oil thus transferred during each operating cycle of the compressor corresponds in volume to that of high-pressure discharge passages 47 and 48, clearly illustrated in Fig. 3.

The amount of oil filling the "dead spaces" of these passages corresponds to the amount of surplus oil delivered from basin 14, by means of dippers 13 and grooves 7'', to the head of piston 7. During each operating cycle, this surplus oil becomes discharged, together with high-pressure air, into cavity 53, and augments the amount of oil in conduit 72 and trap 73. The continuous delivery of oil by dippers 13 and its discharge through passages 47 and 48 would soon empty basin 14. Therefore this oil must be replaced. Pump 61'' is designed to maintain the oil in basin 14 at a constant level.

In the detail drawing of the high-pressure valve structure shown in Fig. 3, attention is directed to packing elements 39' and 40'' between members 39 and 40 of the valve structure. Similar packing elements are intended to be provided between members 27 and 28 of the low-pressure valve structure.

These packing elements are preferably in the form of laminae, and upon their thicknesses depend the heights of the valve chambers wherein the respective valves operate. The heights of the chambers govern the movements of the valves. The greater the height, the longer is the movement of the valve, and vice versa.

The length of the valve movements has a direct relation to the speed at which the compressor is to operate, and to the necessary synchronization in operation between the valves and the pistons. The valve operation must not lag after that of the piston. Thus, for example, when low-pressure piston 7 has completed its compression stroke and commences its suction movement, valve 32 must be in closing position. Similarly, when high-pressure piston 8 has completed its suction stroke and commences its pressure stroke, valve 41 must be closed. Even the slightest lag in the valve movements, or non-synchronization with the piston movement, will result in gross inefficiency of the device.

By adjusting the thickness of the packing between the members of the valve structures the movement of the valves may be regulated for different compressor speeds. For low speeds the valve movements may be longer, and therefore slower, while for higher speeds the valve movements have to be proportionately shorter and faster. By increasing or decreasing the thicknesses of the packings, the height of the valve chambers and the movements of the valves will be increased and decreased, respectively; invertly, the speeds of the valve movements will be decreased and increased, respectively.

Operation

Referring to Figures 1 and 2, when low pressure piston 7 moves downwards, air enters through inlet passage 16 into annular recess 15 of the low pressure cylinder, and is drawn in through converging passages 17 into the cylinder interior. At the same time dippers 13 descend into the oil held in well 14 and cause the oil to splash upwards, which oil deposits upon aprons 7' of piston 7, whereby a certain amount of lubricant

is made available for transfer into the cylinder. The oil, filling retainer grooves 7'' of the piston aprons, is elevated into the cylinder and remains in passages 17. During the suction stroke of the piston the oil is caused to spread over the piston head in a relatively thin film, but of a sufficient volume for the purposes stated below. Because it is impossible to so design a piston which would completely displace the interior of a cylinder under all conditions and at all temperatures, and since it is equally impossible to completely eliminate essential cavities, such as passages leading from the cylinder, the oil brought into the latter, in accordance with my method, is employed to compensate for the unavoidable inadequacy of piston design in filling all spaces and cavities, thereby eliminating "dead" space.

Figuratively as well as actually, the non-compressible oil placed on top of the piston, according to my method, constitutes a "dead"-space-filling liquid extension of the solid piston. As a result the degree of fluid-compression efficiency of my device is very high. Such high compression efficiency is particularly essential when rarified fluids are being handled, such as air at high altitudes.

A very important and a decidedly essential feature of the present invention resides in the employment of a non-compressible medium, such as oil, not only for lubricating the different working parts of the device, but for performing certain specific major functions in a specific manner for rendering the compressor a most efficient instrument of its kind, especially when considering its ultimate purpose, i. e., the quick, positive and sustained delivery of compressed fluid at pressures in the neighborhood of one thousand pounds or over, at high altitudes.

These major functions, which will hereinafter be more fully explained by examples and otherwise, may be divided into three principal groups. The first group deals with the total displacement of compressed fluid from all "dead spaces" within the cavities of both the low and high pressure cylinders; the second group concerns the synchronization of all valve movements with those of the pistons by the use of "oil plugs" directed against the bodies of the valves, and by means of which "oil plugs" an instantaneous opening and closing or sealing of the valves is effected through the force of compressed fluid in the system, whereby any lag in the valve movements is effectively eliminated, in consequence whereof the efficiency of the device is raised; and the final group deals with the cooling of the entire device through the employment of a combination of two cooling instrumentalities, one being a freely floating, highly heat-conductive valve element at the discharge port of the compressor, the other being a heat-absorbing fluid medium in motion, in constant contact with that valve element, whereby the latter is being effectively cooled for the purpose of producing an overall cooling of the entire compressor structure. Through this arrangement the compressor is kept at normal working temperatures and assures continuity and efficiency in operation.

Referring now to the first group concerning displacement of compressed fluid from "dead spaces" by the use of oil, attention is directed to Figure 1, and especially to oil basin 14, the oil therein, plungers 13, skirts 7', skirt grooves 7'', converging intake passages 17 in the cylinder, the head of piston 7, the valve structure on top of cylinder 5, the ports in the valve structure, the communicating passages 3 connecting the low pressure valve structure with the high pressure valve structure, the high pressure valve structure and especially its passages therein, the high pressure discharge apertures 47 and 48 and disc valve 46.

During each operation cycle of the compressor, plungers 13, dipping into the oil basin 14, will displace or splash a certain amount of oil which will reach the aprons 7'. A certain amount of lubricating oil will adhere to the surface of the aprons, but a small amount of oil will be retained in grooves 7''. This oil passes into passages 17, and is transferred to the piston head.

The delivery of oil displaced by plungers 13 continues until a sufficient quantity of oil is deposited on top of the low pressure piston to fill passages 30 and other cavities within the cylinder. Once these "dead spaces" are completely filled with oil, all air within the cylinder may now be fully compressed within, and totally expelled from the cylinder. As the small delivery of oil, splashed by plungers 13 onto the aprons, continues still further and augments the oil already held in the cylinder, the oil will gradually enter into and fill passages 31' and 31'', from which passages it will eventually overflow and pass, together with the compressed air, through communicating passages 3, into the ports of the high pressure valve structure.

With each compression movement of the low pressure piston, and the simultaneous suction movement of the high pressure piston, the oil will completely fill the valve chamber of the high pressure valve structure, as well as its passages 42, 44 and 45. Any surplus of oil within the high pressure cylinder will be forced out through high pressure discharge port 47 and capillary passages 48. (See Fig. 3.)

The oil in these passages forms "oil plugs." The highly compressed air leaving the high pressure cylinder will exert pressure through these "oil plugs" against valve 46, and thus unseat or open the latter. Through the continuous but minute oil supply delivered by plungers 13 to, successively, the low and high pressure valve structures, all "dead spaces" of both cylinders become completely filled with oil and remain thus filled, with the exception of discharge port 47 and capillaries 48. The amount of oil in these passages is equivalent to the required volume of oil delivered by plungers 13 during each operating cycle of the compressor. As has been said before, the rather minute quantity of oil, temporarily held in and being discharged from these passages, is the only amount of oil which leaves the compressor cylinders.

The importance of the use of oil for the displacement of compressed fluid from "dead spaces" in both cylinders, may be best explained by an example. I shall first deal with low pressure cylinder 5. Assume for a moment that the compressor is to operate at a high altitude, and that the rarification of air is one-tenth of the density of air at sea level, and that the low pressure piston effects a normal compression in the proportion of ten to one by its solid body. Thus at a rarification of the air at one-tenth of its normal density, the piston completing its compression stroke would compress the trapped air to one atmosphere, or the normal density of air at sea level. There would be an insufficient pressure created to effect the opening of annular valve 32. Consequently the compressor would simply idle without delivering any compressed

air whatsoever. At higher altitudes, and the consequent greater rarification of air, this condition would be amplified.

The use of oil on top of the piston assures a complete displacement of every particle of compressed air, which latter is pushed past valve 32 and into tubes 3 towards the high pressure cylinder. It is of great importance, however, that the quantity of oil employed for the displacement of air from the so-called "dead spaces" corresponds exactly to the volume of the oil discharged during each operating cycle through the high pressure discharge openings. Therefore the oil must be measured and should not be too much in excess of the volume, corresponding to that capable of being held in the discharge passages.

For this reason grooves 7'' in aprons 7' are made of a certain capacity to retain a certain measured amount of oil. For the same reason dippers or plungers 13 must be designed to displace a sufficient amount of oil which will fill gooves 7'', and also lubricate aprons 7' sufficiently to reduce friction. Yet the oil splashed upwards by plungers 13 must not be in excess.

From the above explanation of the displacement of compressed air in the first stage, by filling the "dead spaces" of that stage, it becomes quite evident that unless such "dead spaces" are completely filled, the low pressure cylinder will not operate efficiently. It would be illogical to perfect the operation of the low pressure unit without also enhancing the efficiency of the high pressure stage by the same method of air displacement through oil.

It is the intention of the present invention, therefore, to utilize the oil, first brought into the low pressure cylinder, for displacing air from the "dead spaces" thereof, to serve the same effective purpose in the high pressure cylinder. Obviously, the successive operations of the pistons, following their initial movement, will cause successive uniform oil admissions into the low pressure cylinder, until all of its "dead spaces" are filled. The following admissions will form excesses of oil over the amount required for one dead-space-filling. As stated, these excess amounts of oil are relatively very small, and therefore are easily ejected through any of the valve ports.

The air in the low pressure cylinder being on top of the oil, it is expelled through ports 30, as it lifts circular valve 32 against the tension of spring member 34. Air compressed in the first stage is brought through flattened tubes 3 towards the high pressure cylinder, the piston of which is in its uppermost position, creating suction. The primary air lifts high pressure ring valve 41, passing through ports 44 and 45 into high pressure cylinder 6, whereupon valve 41 closes and traps the air in the cylinder. During the downward stroke of the pistons, the high pressure piston will now compress the pre-compressed air to a higher pressure value, say to 1,000 pounds, the proportion between the low pressure and high pressure cylinders ranging, depending upon different requirements, from 1 to 5, to 1 to 8, or higher. The pressure in reservoir 78 being lower than the pressure created in cylinder 6, valve 46, formerly held against the valve seat in member 40 by the pressure in the air reservoir, now opens and releases the compressed air.

It has been stated previously, that the measured amount of oil carried by grooves 7'' into low pressure cylinder 5 corresponds substantially to the volume of discharge passages 47 and 48 in the high pressure valve structure, and that such measured amount of oil is transferred to the top of the first-stage piston during each cycle of operation. What actually takes place may be described in the following manner.

At the initial stroke of piston 7, oil is splashed by dippers 13 onto the piston aprons. During the following compression stroke of the piston a part of the oil retained in the upper grooves 7'' of the aprons is deposited in the pockets formed at the lower ends of passages 17, while the oil adhering to the apron surfaces is partially scraped off by the lower end of cylinder 5, leaving but thin oil films to be carried into the cylinder for lubrication during the compression stroke of piston 7.

When the piston is about to complete its downward movement and clears the upper ends of passages 17, the suction thus created causes the inrushing air to sweep the oil, accumulated in these passages, over the piston head. During the next following series of compression strokes, the oil on top of the piston will completely fill all "dead spaces," whereby all of the compressed air is expelled from the cylinder. The oil, however, remains on top of the piston.

With each downward movement of the piston, a new measured amount of oil is deposited in grooves 7'' and is carried during the compression stroke into the pockets of passages 17. The moment piston 7 clears the upper ends of the passages in its downward movement, the newly supplied oil is sucked into the cylinder and augments the first oil deposit remaining on top of the piston.

At this point attention may be directed to the fact that oil delivered in excess of the dead-space-filling requirement in the low pressure cylinder not only lifts ring valve 32, but also serves as seal between the ring valve and its seat. In addition, the oil expelled into and retained in ports 31'' forms oil plugs, against which the compressed air, forced from the low pressure cylinder into the communicating spaces between the two stages, exerts a sufficient pressure to instantly seat the valve, when piston 7 commences its downward stroke.

A very similar oil and valve action takes place in the valve structure of the high pressure stage. As stated, also in that stage the complete filling of all "dead spaces," and the consequent expulsion of all highly compressed air from the cylinder is absolutely necessary, in order to produce the high degree of compression, say of 1000 pounds, at high altitudes and in rarified atmospheres. Oil in the valve chamber, housing ring valve 41, not only enhances the seal between the valve and its seat, but fills all "dead spaces." That part of the oil which enters oblique ports 45 functions as liquid plugs for instantaneously seating the ring valve by the force of compressed air during the downward stroke of the piston 8. The surplus oil between the piston and upper member 40 of the valve structure is expelled, through discharge port 47 and capillary passages 48, against disc element 46, and forms an oil film over its top surface. Because of this film formation, the hot, compressed air is prevented not only from ever coming into direct contact with the bare metal surface of the disc element, but the latter is thus kept in free suspension between two oil bodies, i. e., the film at its upper surface, and the oil held in constant

contact with its lower face by the pressure of the oil column in the cooling system.

The oil film on top of disc valve **46** also serves as a seal between the disc and its seat, provided at faced extension **40'** of member **40**. A large portion of the surplus oil, gathering during sustained operation of the compressor on top of disc **46**, is forced off the latter by the discharges of compressed air, while additional oil is removed by the forceful closing of the disc against its seat, when piston **8** commences its upward stroke. Thus only a thin film remains at the top surface of the disc. The removed oil surplus mixes with the oil of the cooling system.

The moment high pressure piston **8** has reached its extreme low position and has discharged the highly compressed air from cylinder **6**, an equilibrium of pressure immediately takes place in that portion of the system extending below valve **46**, and which system includes the conduits leading to the separator or air trap and the air reservoir. At the moment piston **8** commences its upward or suction stroke and creates a partial rarification within cylinder **6**, the pressure in the exterior system will instantly close valve **46**. During the equilibrium period, just prior to the upward stroke of piston **8**, valve **46** will actually freely float between the oil films covering both the top and bottom surfaces of the valve.

Due to the high compression created in cylinder **6**, the temperature rises considerably. Valve **46** is directly exposed to the resulting compression heat. One of the main purposes of the present invention is to reduce the usually excessive heat created in high pressure valve compressors, since high temperatures render difficult sustained operation and often cause a complete break-down. For this reason special attential has been given to the high pressure stage and particularly to the design of the floating discharge check valve in the present structure. Disc **46** is intended to not only fulfill its primary purpose of an effective check valve, but constitutes the "heart" of the cooling system of the present device, being solely responsible for the high efficiency thereof.

One of the essential additional pre-requisites for a sustained, efficient operation of the device resides in the necessity of maintaining all valves employed in the compressor immaculately clean. This applies equally to the high pressure discharge valve, which is subject to high temperatures, as well as to both ring valves **41** and **32**. When exposed to heat for extended periods of time, the valves are subject to becoming coated by a crust of cooked or coked oil used for lubrication or cooling. Even the slightest crust formation upon the surfaces of any of the valves or their valve seats, will cause failure in operation of the compressor. The cooling effects produced in the present cooling system are sufficient to maintain the entire device at a relatively low temperature, that is, at a temperature low enough to prevent crusting of the valve surfaces by excessively heated oil.

Another very important factor affecting the efficient operation of the compressor is the complete and exact synchronization of the movements of all the valves with those of the pistons. Due to the rather high speeds at which the device is designed to operate, dependency upon spring action for closing or opening valves would be futile. As a matter of fact it has been found that springs cannot operate dependably at high speeds and consequently induce irregular valve movements. This applies especially to valve **46**. A spring tried with that valve actually prevented synchronization of the valve movement with that of the piston. As has been stated previously, the movements of all the valves amount to a high vibration, which, when impaired by the action of springs, will cause a lag in operation and compression failure.

I have found, after a good deal of experimentations and tests lasting for many months, that disc valve **46**, as well as ring valves **41**, must possess certain definite physical properties in order to serve their intended purpose. The valves must be of relatively thin construction, light in weight, and in addition must possess great strength and hardness, high resiliency, high heat conductivity and permanency as to their retention of the shapes given to them. As stated before, they are not only to serve as check valves, as nearly perfect as is humanly possible, but they are designed also to fulfill the task of rapidly absorbing, conducting and propagating, as well as rapidly transferring heat to their immediate surroundings. In the course of my experimentation I have found that the most suitable material for the production of these valves is a specially treated beryllium-copper composition.

The special treatment to which the beryllium-copper valves are subjected is covered by a copending application. However the result of such treatment imparts to the valves the above recited essential physical properties. I especially direct attention to four of these essential properties required, i. e. resiliency, toughness, hardness and the inherent tendency to retain the shape originally imparted to the valve, its absolute flatness.

In the foregoing description it has been pointed out that oil is being used not only for lubricating purposes and the displacement of "dead spaces," but also to improve the sealing function of the valves against their seats. Assume now that the device operates not in a directly vertical position, but is somewhat inclined. As a result some of the oil will flow towards one portion of the valve seats, whereas another portion thereof may only be covered by a very thin oil film. Since it is required, however, that the closing of the valves be effected instantaneously over their entire seating surface, the larger quantity of oil in contact with that one portion of the valve seat has to be quickly pressed out of the way, in order to prevent leakage. Due to the resiliency, toughness, hardness and shape retaining quality of the valve, the displacement of the larger oil body actually becomes instantaneous, the moment any point of the valve body is subjected to pressure, irrespective of the place or places against which such pressure is applied. Thus all valves will function in the aforesaid manner only when they are treated to possess and to maintain their above stated essential properties.

Referring again to check valve **46**, I repeat its essential physical properties. It is highly heat conductive, readily absorbs and rapidly propagates heat to its entire body, and in turn quickly transfers its heat to the relatively large volume of cooling medium retained in cavity **53**, well **54** and in the interior of bushing **55**. Thus, the combined cooling means employed, will maintain the valve in a state of coolness, in spite of the fact that one face of the valve is directly exposed to high compression temperatures. When the hot, compressed air contacts the cool valve, its temperature becomes considerably lowered.

As the compressed air passes over the valve, it forms bubbles which are forced through the body

of the cooling medium in the cavities just mentioned. Since the cooling medium also fills conduit 72 and the lower portion of trap 73, the air is being forced to travel through the entire height of the fluid column. The heat of the compressed air bubbles is transferred to the cooling medium, and because the body of the latter is many times greater than the tiny air bubbles, the heat transfer does not materially raise the temperature of the cooling medium. In addition, the cooling medium forming a tall column, its temporarily heated portion is caused to rise with the air bubbles to the top, where the medium becomes cooled through large surface contact within the trap. The cooled portion of the medium reverts into the hollow discharge end of the compressor.

As the bubbles of the compressed air reach the body of the cooling medium within the trap and penetrate to the upper surface of the medium, they rapidly expand and burst, due to the difference between the lower pressure within the trap and the higher pressure of the compressed fluid in the bubbles, and thereby rid themselves of the medium formerly entrapping them. Thus the air becomes pure and dry.

In the above described manner the discharge end of the high pressure cylinder, which in previous similar devices has been subjected to terrific heat, is kept cool to such a low degree that the presently achieved temperature favorably compares with normal working temperatures of factory machinery. Thus, for instance, I have found that when using light grade lubricating oil of a relatively low fire test, with a flash point not exceeding 240 degrees Fahrenheit, the compression heat does not in the least deteriorate or otherwise adversely affect the physical and lubricating properties of the oil. The highest temperature recorded at the discharge end of the high pressure cylinder amounted to less than 220 degrees Fahrenheit during a test period of several months. The average temperature maintained was far below this highest recorded temperature.

From the foregoing it becomes clearly evident that the present device and the method employed therein effect an unprecedented reduction of the usual compression temperature at the high pressure stage, and consequently the overall efficiency of the compressor is raised to what has been found to be approximately 82%.

In addition to the above achievement, the present invention possesses numerous other advantages, one of which being the elimination of what is known as "dead" spaces within cylinders. As is well known, even the slightest heat expansion of the cylinder will cause an increase in the volume intended to be displaced by the piston. This additionally created space must be filled, in order to prevent compression losses. The lubricant transferred from without to within the cylinder fills such spaces and virtually forms a fluid continuation of the piston body.

Attention is also called to the valve structures employed at the cylinder ends, and especially to the interior arrangement of these valve structures. It has been explained previously that the members of the valve structure are provided with valve seating and valve limiting means, and special emphasis is now placed upon the limiting means. The movement of the valve is very slight, and more or less amounts to a rapid vibration. This may be readily understood when it is considered that the compressor operates at approximately 4,000 R. P. M. Consequently the stroke of the valve annulus, as well as of the discharge disc, must be defined within close limits.

In the foregoing description I have dealt with relatively specific structures as shown in the accompanying drawings. Similarly I have specifically mentioned various features relationg to the physical properties and to the employment of the annular and disc-shaped valves used in the device. Moreover I have shown and described specific means for transferring lubricant to the heads of the pistons, and employing that lubricant for displacing compressed fluids. Furthermore I have in many other ways described specific structural details of my compressor, and have referred to them specifically in explaining the underlying, broad principle of my invention designed to effect heat reduction, both at the high pressure fluid discharge, as well as at other parts of the device, which heat reductions are instrumental in maintaining the entire mechanism at a practical, low working temperature.

Consequently, all specific features specifically described are to be considered as having been employed for no other purpose except that to render the principle of my invention more readily understandable. Therefore, neither the illustrations nor the description thereof are intended to in any way limit my invention, and I reserve for myself the right to make improvements and changes therein if and when they may become advisable or necessary, without departing from the broad principle, scope and intent of my invent, as expressed in the annexed claims.

I claim:

1. In gas compressing apparatus having at least two stages of compression, one being a high pressure stage and the other a relatively low pressure stage and each having a cylinder and a piston, the improvement which comprises means for introducing oil into the low pressure cylinder, an inlet port for the high pressure cylinder, conduit means for passing the oil along with the compressed gas from the low pressure cylinder through the inlet port into the high pressure cylinder, discharge-port means for the high pressure cylinder, a valve member for opening and closing the discharge-port means, a space on the discharge side of the valve member into which the oil and compressed gas are passed when the discharge-port means is open, and means for maintaining a cooling oil in the space and in contact with the discharge-side of the valve member, whereby oil from the high pressure cylinder discharged through the discharge-port means contacts the valve member on the compression side and the cooling oil in the space contacts the valve member on the discharge side.

2. In gas compressing apparatus having at least two stages of compression, one being a high pressure stage and the other a relatively low pressure stage and each having a cylinder and a piston, the improvement which comprises means for introducing oil into the low pressure cylinder under the action of its piston, an inlet port for the high pressure cylinder, conduit means for passing the oil along with the compressed gas from the low pressure cylinder through the inlet port into the high pressure cylinder, a discharge port comprising a plurality of port openings for the high pressure cylinder, a floating valve-member arranged to close the discharge port on the suction stroke of the high pressure piston, the oil in the high pressure cylinder serving to contact the compression side of the floating valve-member and

protect it from the hot compressed gas, and means for maintaining a body of cooling oil in contact with the discharge-side of the valve member.

3. In gas compressing apparatus having at least two stages of compression, one being a high pressure stage and the other a relatively low pressure stage and each having a cylinder and a piston, the improvement which comprises means for passing oil into the low pressure cylinder, means for passing compressed gas and the oil from the low pressure cylinder into the high pressure cylinder during the operation of the low pressure piston, the oil entering the low and the high pressure cylinders being sufficient to fill any dead spaces which may be present and displace the gas undergoing compression, discharge-port means from the high pressure cylinder, a valve member for the discharge-port means, the oil entering the high pressure cylinder being sufficient to enter the space in the discharge-port means and to contact the compression side of the valve member, and means for supplying a cooling oil in contact with another side of the valve member.

4. In gas compressing apparatus having at least two stages of compression, one being a high pressure stage and the other a relatively low pressure stage and each having a cylinder and piston, the improvement which comprises means for introducing oil into the low pressure cylinder under the operation of its piston, a valve-controlled conduit connecting the cylinders, means for passing compressed gas and oil through the valve-controlled conduit and into the high pressure cylinder, a discharge valve means for the high pressure cylinder comprising a low member having a valve seat, an upper member serving as a seat for the high pressure cylinder and having a discharge-port means therein, a floating thin lightweight valve member in a recess between the upper and lower members, a valve-seating surface on the upper member against which the valve member closes the discharge-port means, said discharge-port means being arranged to receive oil during the operation of the high pressure piston which serves as a protecting barrier between the compressed gas and the valve member, a cavity on the discharge side of the valve member in communication with the recess, and means for maintaining oil in the cavity, whereby the valve member is coated with oil on both sides.

5. In gas compressing apparatus having at least two stages of compression, one being a high pressure stage and the other a relatively low pressure stage and each having a cylinder and a piston, the improvement which comprises means on the low pressure piston for introducing a small quantity of oil into the low pressure cylinder during the operation of its piston to fill dead spaces in the cylinder with oil, means to pass compressed gas and oil into the high pressure cylinder, discharge-port means for the high pressure cylinder, the oil being sufficient to fill the dead spaces in the high pressure cylinder and to enter the discharge-port means, and a valve member for the discharge-port means which contacts the oil in the discharge-port means and is thereby kept out of destructive contact with the hot compressed gases during compression.

6. In gas compressing apparatus having at least two stages of compression, one being a high pressure stage and the other a relatively low pressure stage and each having a cylinder and a piston, the improvement which comprises groove means on the low pressure piston to carry oil into the low pressure cylinder, means in the low pressure cylinder for introducing sufficient oil into the low pressure cylinder during the suction stroke of its piston to fill dead spaces in the cylinder with oil, conduit means for the passage of compressed gas and the oil from the low pressure cylinder into the high pressure cylinder, discharge-port means for the high pressure cylinder, the amount of oil entering the high pressure cylinder being at least sufficient to fill the dead spaces therein and to enter the discharge-port means, a recess embracing the discharge-port means, a valve member operating in the recess to close and open the discharge-port means, the oil in the discharge-port means serving as a thermal barrier between the hot compressed gas and the valve member.

7. In gas compressing apparatus having at least two stages of compression, one being a high pressure stage and the other a relatively low pressure stage and each having a cylinder and a piston, the improvement which comprises means on the low pressure piston to carry oil into the low pressure cylinder, means in the low pressure cylinder for introducing oil into the low pressure cylinder during the suction stroke of its piston sufficient to fill dead spaces therein with oil, conduit means for the passage of compressed gas and oil from the low pressure cylinder into the high pressure cylinder, a discharge port for the high pressure cylinder comprising a plurality of small openings, a recess embracing the small openings, a valve member in the recess arranged to be pressed by fluid into seating contact to close the openings, the oil from the high pressure cylinder entering the openings and serving as a thermal barrier between the hot compressed gas and the valve member, and means for maintaining cooling oil in contact with a surface of the valve member.

8. In gas compressing apparatus having at least two stages of compression, one being a high pressure stage and the other a relatively low pressure stage and each having a cylinder and a piston, the improvement which comprises groove means on the low pressure piston to deposit oil on the low pressure cylinder wall, means in the low pressure cylinder for carrying the deposited oil into the low pressure cylinder during the suction stroke of its piston sufficient to fill dead spaces therein with oil, conduit means for the passage of compressed gas and oil from the low pressure cylinder into the high pressure cylinder, a discharge port for the high pressure cylinder comprising a plurality of small openings, the amount of oil entering the high pressure cylinder being at least sufficient to enter the openings of the discharge port, a recess embracing the small openings, a conduit for cooling oil entering the recess, a valve seat for closing the small openings and another valve seat for closing the conduit, a thin flat valve member in the recess which is pressed into contact with the valve seat for the small openings on the suction stroke of the high pressure piston and into seating contact with the seat for the conduit on the compression stroke of the high pressure piston, and means for forcing cooling oil through the conduit into contact with the valve member when the valve member is moved from the seat closing the conduit.

9. In gas compressing apparatus having at least two stages of compression, one being a high pressure stage and the other a relatively low pressure stage and each having a cylinder and a piston, the improvement which comprises discharge-port means for the high pressure cylinder, means for flowing successively from the low pressure cylinder to the high pressure cylinder and along with the

compressed gas a sufficient quantity of lubricating oil to fill the dead spaces in the cylinders, and to provide a body of oil in the discharge-port means during the compression stroke of the high pressure piston, and a thin lightweight floating valve member for opening and closing the discharge-port means which is contacted with and protected by the oil in the discharge-port means.

10. In gas compressing apparatus having at least two stages of compression, one being a high pressure stage and the other a relatively low pressure stage and each having a cylinder and a piston, the improvement which comprises means for flowing successively from the low pressure cylinder to the high pressure cylinder along with the compressed gas a sufficient quantity of lubricating oil to fill dead spaces in the cylinders, an upper member serving as the head of the high pressure cylinder, discharge-port means in the upper member, the oil entering the high pressure cylinder being at least sufficient to provide a body of oil in the discharge-port means during the compression stroke of the high pressure piston, a lower member having a cavity therein and in operative engagement with the upper member, a recess between the upper and lower members and embracing the discharge-port means, a thin flat floating valve member in the recess, a seat on the upper member engaged by the valve member to close the discharge-port means, the oil in the discharge-port means serving as a thermal barrier protecting the valve member from the hot compressed gas, a seat on the lower member engaged by the valve member when the discharge-port means is open, and means for introducing cooling oil through the recess and into contact with a surface of the valve member to aid in cooling the valve member.

11. In a gas compressor having at least two stages of compression, one being a high pressure stage and the other a relatively low pressure stage and each having a cylinder and a piston, the improvement which comprises a connecting rod for each piston connected to the crank of a common crankshaft, and spaced counterweights connected to the crankshaft for balancing the pistons, said low pressure piston having two diametrically opposite clearance cuts and two diametrically opposite depending aprons, the aprons extending between said counterweights and said counterweights passing through the clearance cuts during rotation of the crankshaft.

12. In a gas compressor having at least two stages of compression, one being a high pressure stage and the other a relatively low pressure stage and each having a cylinder and a piston, the improvement which comprises at least one inlet port in the wall of the low pressure cylinder, means on the exterior of the low pressure piston for carrying lubricating oil into contact with edge-portions of the inlet port whereby oil is scraped from the piston and enters the inlet port, the oil scraped into the inlet port being sucked into the low pressure cylinder during the suction stroke of the low pressure cylinder wherein it fills dead spaces therein, means for passing the compressed gas and oil from the low pressure cylinder into the high pressure cylinder, a discharge valve for the high pressure cylinder, and means for passing the oil from the high pressure cylinder into contact with the valve.

NICOLAS HERZMARK.