Aug. 17, 1965 | A. A. DROS | 3,200,582

HOT-GAS RECIPROCATING MACHINE

Filed Nov. 4, 1963 | 6 Sheets-Sheet 1

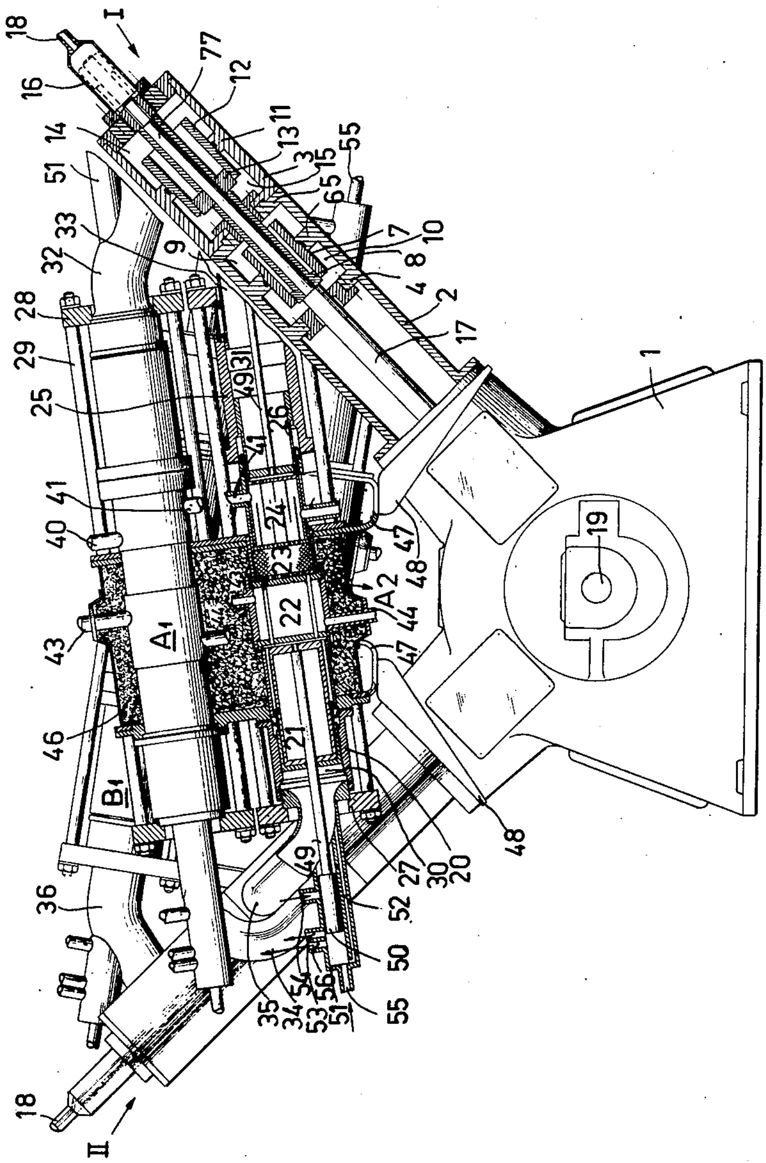

FIG. 1

INVENTOR.
ALBERT A. DROS

BY Frank R. Jifani
AGENT

HOT-GAS RECIPROCATING MACHINE

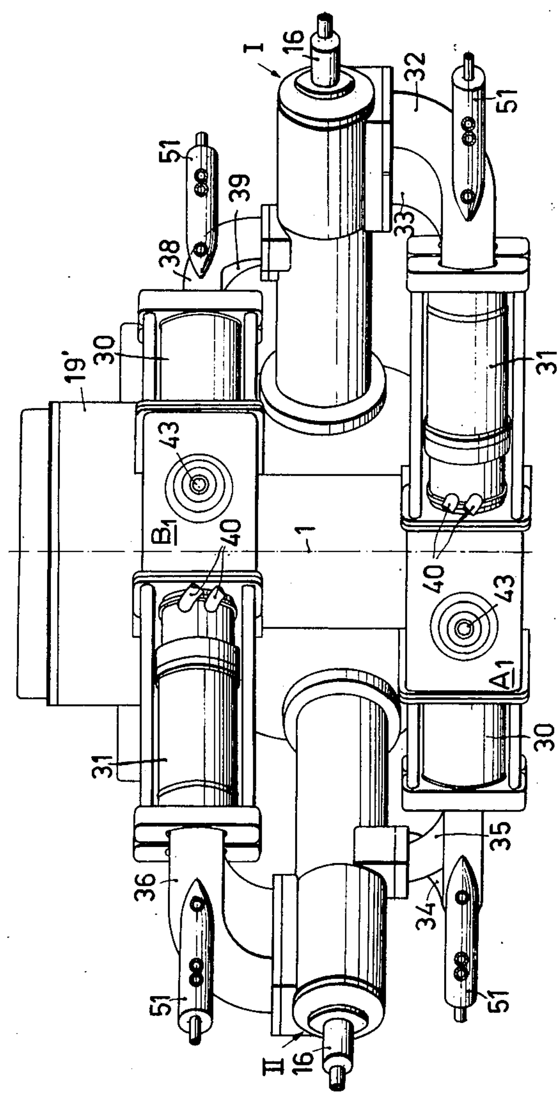

FIG. 2

INVENTOR.
ALBERT A. DROS

BY

Frank R. Jifani

AGENT

Aug. 17, 1965 A. A. DROS 3,200,582

HOT-GAS RECIPROCATING MACHINE

Filed Nov. 4, 1963 6 Sheets-Sheet 3

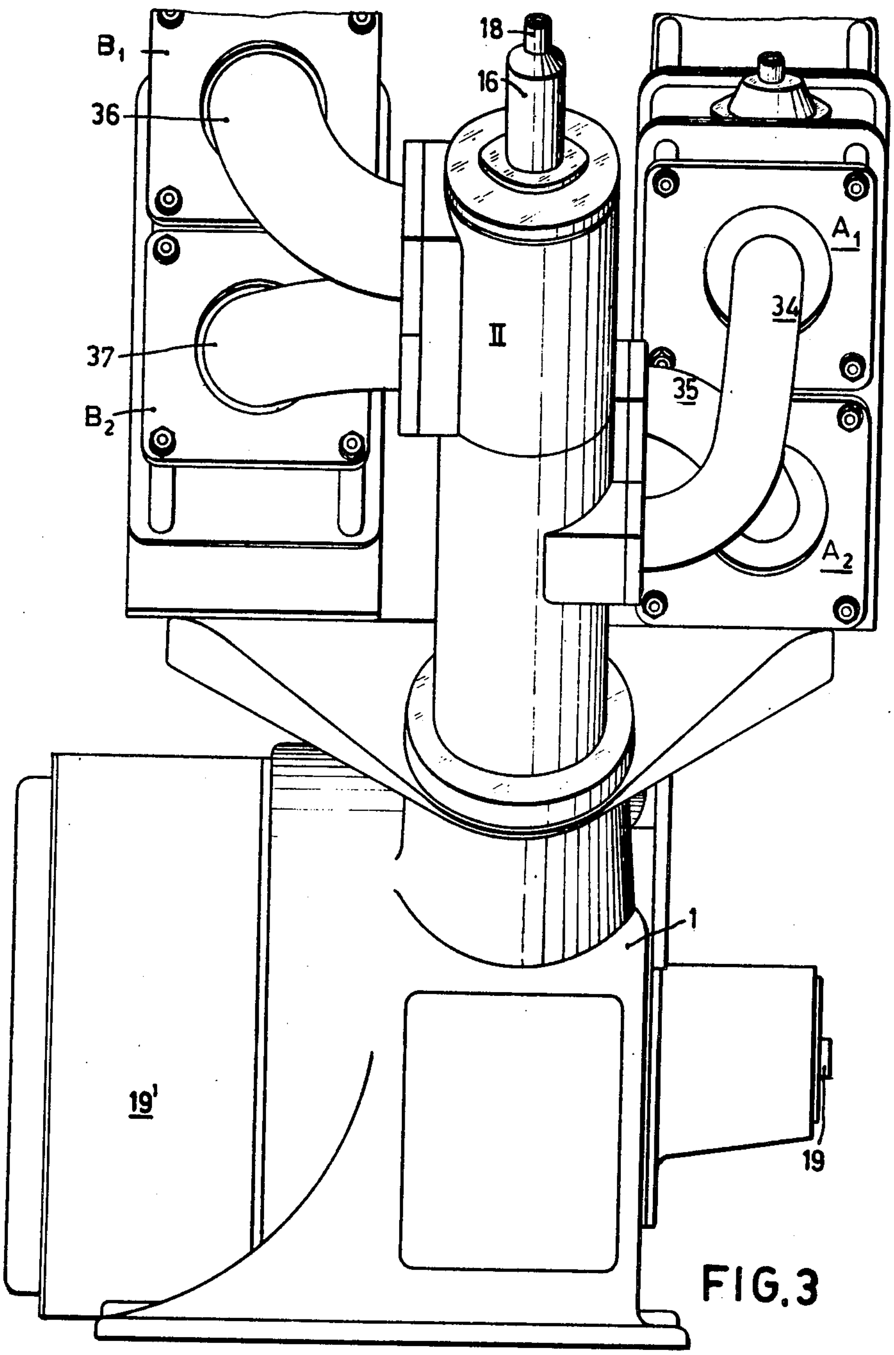

FIG.3

INVENTOR.

ALBERT A. DROS

BY

Frank R. Jifari

AGENT

Aug. 17, 1965 A. A. DROS 3,200,582

HOT-GAS RECIPROCATING MACHINE

Filed Nov. 4, 1963 6 Sheets-Sheet 4

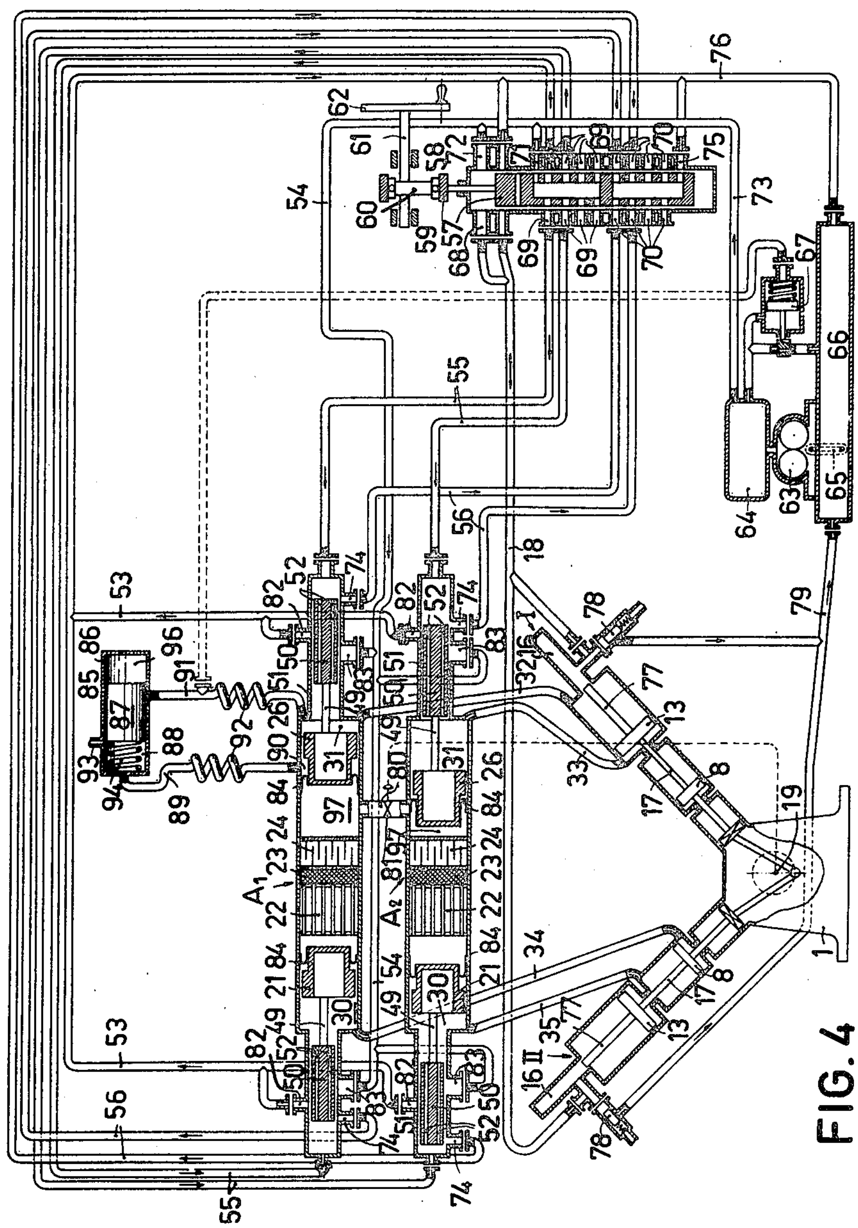

FIG. 4

INVENTOR.

ALBERT A. DROS

BY

Frank R. Jifari

AGENT

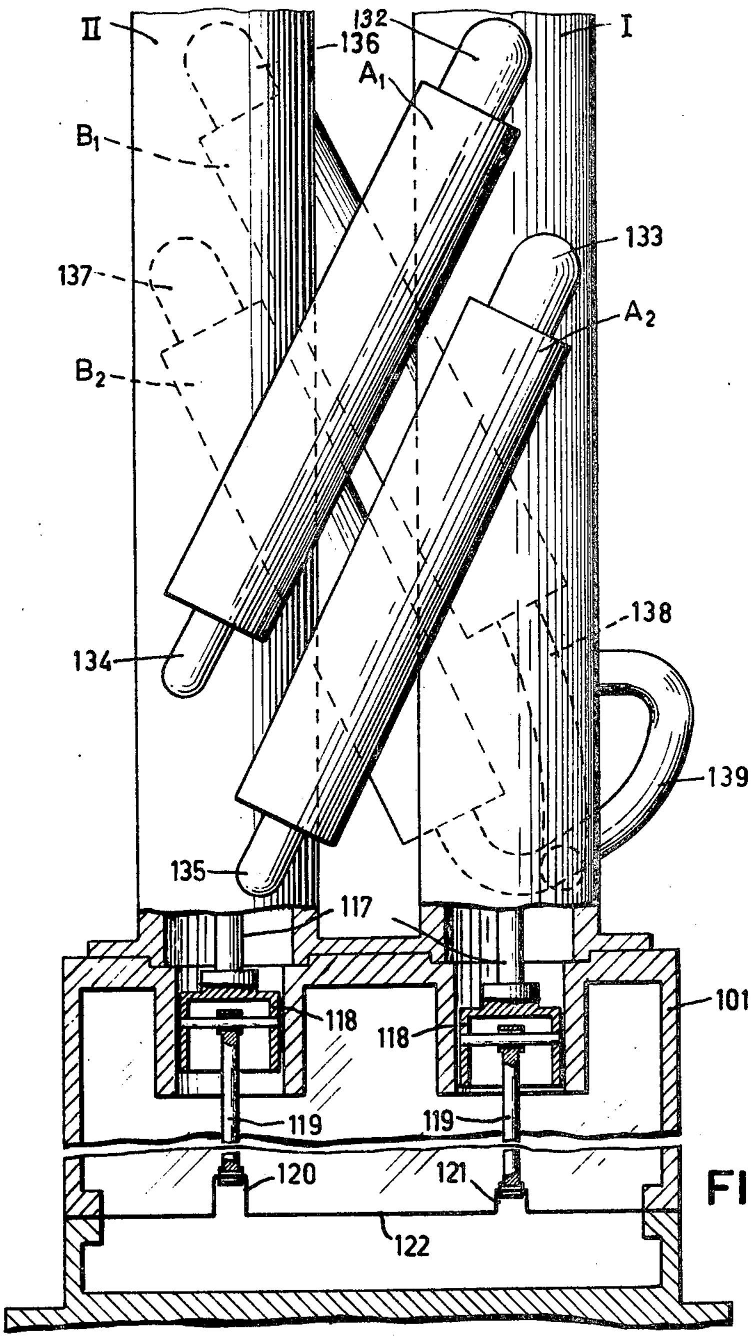

FIG. 5

INVENTOR.
ALBERT A. DROS
BY
Frank R. Jifani
AGENT

HOT-GAS RECIPROCATING MACHINE

Filed Nov. 4, 1963 6 Sheets-Sheet 6

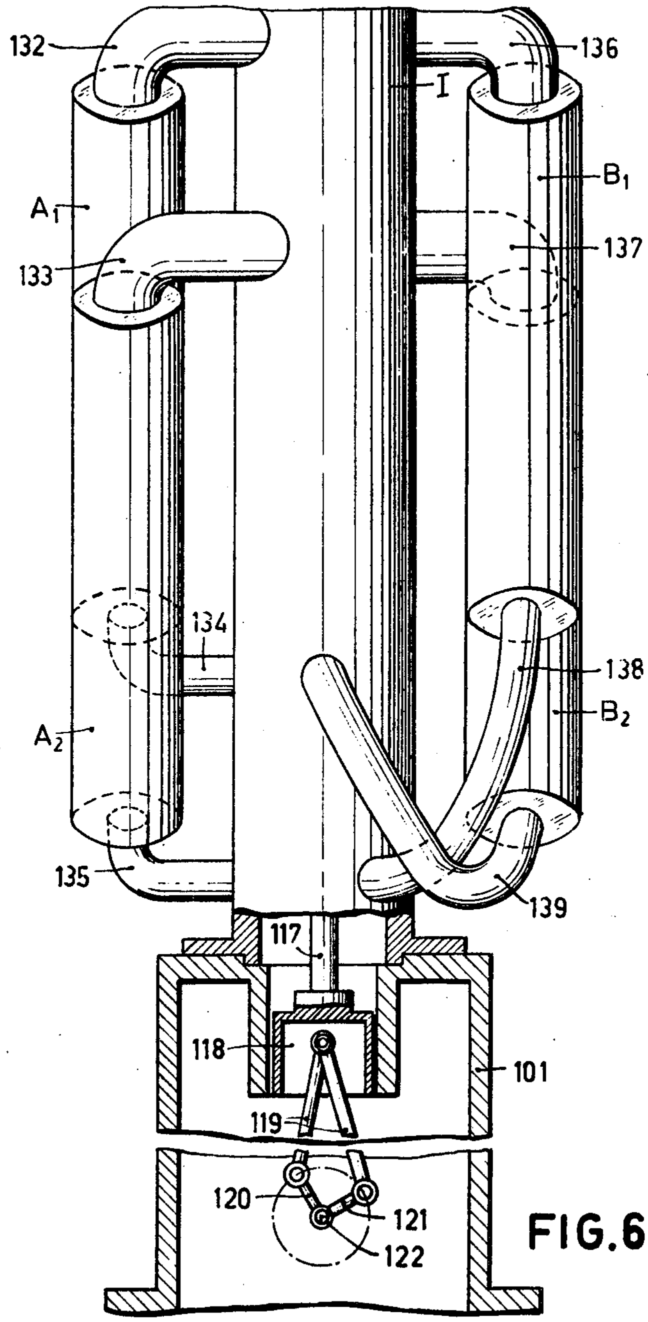

FIG. 6

INVENTOR.
ALBERT A. DROS
BY
Frank R. Jufari
AGENT

3,200,582
HOT-GAS RECIPROCATING MACHINE

Albert August Dros, Emmasingel, Eindhoven, Netherlands, assignor to North American Philips Company, Inc., New York, N.Y., a corporation of Delaware

Filed Nov. 4, 1963, Ser. No. 320,982
Claims priority, application Netherlands, Nov. 26, 1962, 285,957
9 Claims. (Cl. 60—24)

The invention relates to a hot-gas reciprocating machine, particularly a cold-gas refrigerator, comprising one or more compression spaces of variable volume, communicating with one or more expansion spaces also of variable volume, said spaces having, in operation of the machine, different mean temperatures, whilst the connection between the spaces includes regenerators, through which a medium can flow to and fro between the said spaces, whilst the machine comprises piston-like bodies adapted to move with a phase difference for varying the volumes of the expansion space and of the compression space, said piston-like bodies being coupled with a driving gear.

In the scope of the present invention the term "hot-gas reciprocating machine" is to denote not only a hot-gas engine but also a cold-gas refrigerator and a heat pump operating on the reverse hot-gas engine principle. For the sake of simplicity the unit in which the thermodynamic cycle is performed is termed hereinafter the cooling unit.

In known machines of the kind set forth the piston-like bodies varying the volumes of the compression space and of the expansion space are connected via piston rods, connecting rods, yokes, toothed wheels and the like with the driving gear. The construction of the driving gear with these machines is further complicated by the requirement that for a satisfactory operation of said machine the movements of the piston-like bodies should have a phase difference of about 90°. Hitherto this brought about complicated structures with many points of rotation subjected to wear, all of these structures comprising a great number of the aforesaid component parts.

In order to mitigate these disadvantages it has been proposed to establish the coupling between the driving gear and the piston-like bodies by means of fluid columns movable in ducts, so that power can be transferred by said fluid columns from the driving gear to the relevant piston-like bodies and/or conversely. The term "coupling" is to be understood in this connection to mean not only a fixed connection between the pistons and the driving gear but also a member which controls the movement of the pistons in accordance with the movement of the driving gear or conversely. In this way a simple coupling between the driving gear and the relevant pistons is obtained.

The invention has for its object to provide a further improvement of a hot-gas reciprocating machine with the coupling described above between the pistons and the driving gear and is characterized in that the machine comprises at least two pump units, each of which comprises a pair of double-acting pistons adapted to reciprocate in closed, fluid-filled cylinders and in that the machine comprises furthermore at least two pairs of cooling units, each comprising a compression piston, adapted to reciprocate in a cylinder, a cooler, a regenerator, a freezer or heater and an expansion piston adapted to reciprocate in a cylinder, whilst each of the spaces of one pair of cooling units positioned, on the side remote from the working space of the expansion pistons associated with said space, communicates with one of the spaces on either side of one of the pistons of the first pump unit and each of the spaces positioned, on the side remote from the working space

of the compression piston associated with said space, communicates with one of the spaces on either side of one of the pistons of the second pump unit, whilst each of the spaces of the other pair of cooling units positioned, on the side remote from the working space of the expansion piston associated with said space, communicates with one of the spaces on either side of the other piston of the second pump unit and each of the spaces positioned on the side remote from the working space of the compression piston associated with said space, communicates with one of the spaces on either side of the other piston of the first pump unit.

An advantage of said machine consists in that with each pump unit the spaces on either side of one of the double-acting pistons communicate with the spaces on the side of the compression pistons of a pair of cooling units remote from the working space, whereas the spaces on either side of the other double-acting piston of said pump unit communicate with the spaces on the side remote from the working space, of the expansion pistons of the other pair of cooling units. It is thus ensured that the variation of forces on the pump rod, during the movement of the rod in one direction, is substantially identical to the variation of forces on the pump rod during the movement of said rod in the other direction. As a result the load on the driving gear is as uniform as possible. A further advantage of said arrangement is that the energy released during the expansion of the working medium in one pair of cooling units via the fluid columns and one double-acting piston of a pump unit, is directly transferred to the other double-acting piston of said pump unit, said energy being again transferred via the fluid columns to the compression pistons. The efficiency of the machine is thus extremely furthered.

Although the pump units and the pairs of cooling units may be arranged relatively to each other in an arbitrary manner, an advantageous and compact construction of a hot-gas reciprocating machine is obtained by an arrangement of the units in accordance with the invention, which is characterized in that the pump units are pairwise arranged in a V and are connected with a common crank shaft, whereas each of the cooling units is arranged substantially between planes intersecting in the centre line of the crank shaft and determined by the centre lines of the pump units, and in that in a projection to a plane at right angles to the centre line of the crank shaft the centre lines of the two pump units and the centre line of each cooling unit form a triangle.

An advantageous embodiment of the hot-gas reciprocating machine described above is characterized in accordance with the invention, in that one pair of cooling units is arranged between the two pump units so that the spaces on the side remote from the working space of the compression pistons associated with said cooling units are orientated towards the first pump unit communicating with said space, whilst the spaces, on the side of the expansion pistons of said cooling units remote from the working space, are orientated towards the second pump unit associated with said space, whereas the other pair of cooling units is arranged between the two pump units so that the spaces on the side of the compression pistons associated with said cooling units remote from the working space are orientated towards the second pump unit communicating with said space and the spaces on the side of the expansion pistons associated with said cooling units remote from the working space are orientated towards the first pump unit communicating with said space. Thus a compact structure of a hot-gas reciprocating machine is obtained, which occupies little space and in which only comparatively small quantities of fluid are required due to the short lines of connection between the fluid-filled spaces in the pump units and the cooling units. It will be obvious that this is advantageous on account of the quantities of fluid to be displaced in the machine.

A further compact, advantageous hot-gas reciprocating machine embodying the invention is characterized in that the pump units are arranged parallel to each other and in that with two pump units one pair of cooling units communicating with said pump units is disposed in a plane extending parallel to and in front of the plane of the pump units, whereas the other pair of cooling units associated with said pump units is disposed in a plane extending parallel to and behind the plane of the pump units and the cooling units are arranged in their respective planes so that, in a projection to the plane of the pump units, the centre lines of the cooling units of one pair intersect the centre lines of the cooling units of the other pair.

A further advantageous hot-gas reciprocating machine embodying the invention has the feature that in each cooling unit each piston is connected with a control-slide, which is displaced during the movement of the piston associated with it along a wall portion of the fluid-filled spaces on the side remote from the working space in said space, whilst in the wall portion controlled by said slide at least one fluid inlet and one fluid outlet are provided, said openings being arranged so that the fluid inlet duct is released, when the piston moves beyond its extreme, prescribed position, whereas the fluid outlet duct is released, when the piston occupies its deepest position in the cooling unit.

By using the control-slide according to the invention structurally simple means ensure that the extreme positions of the pistons are always the same. This has the advantage that the pistons cannot come into contact with the cylinder boundaries, which might give rise to breakage, whilst, in addition, since the extreme positions are fixed, the volume variations of the working spaces are the same, so that also the pressure variation in said spaces does not change.

An advantageous hot-gas reciprocating machine embodying the invention is characterized in that the cylinder of each cooling unit, in which a piston is adapted to move, terminates in a further cylindrical part, in which the piston-like control-slide is adapted to move, whilst the machine comprises one or more ducts establishing a communication between the spaces on either side of the control-slide, whilst the fluid inlet duct and the fluid-outlet duct join the wall of the further cylindrical part.

In order to start the hot-gas reciprocating machine according to the invention the pistons must occupy given positions in the cooling units, which positions correspond with the pistons of the pistons of the pump units at the instant concerned. In order to move the piston-like bodies into the correct positions, the hot-gas reciprocating machine according to the invention has the feature that each of the fluid-filled spaces in each cooling unit communicates with a further fluid-supply duct, the passage of which is blocked during the operation of the machine, whereas at the position of the control-slide the opens out a further fluid-outlet duct, the passage of which can be released when the machine is prepared for a start, whilst the openings of the fluid-outlet ducts are disposed so that they are free when the relevant piston occupies its starting position.

In order to move the pump pistons into their starting positions which correspond, as a matter of course, with the aforesaid starting positions of the pistons of the cooling units, the hot-gas reciprocating machine according to the invention is characterized in that the interconnected pistons of each of the pump units are furthermore connected with a further piston-like body located in line with their centre line, said body being adapted to reciprocate in a closed cylinder, whilst in the space above said piston-like body there opens a fluid-inlet duct, by which compressed fluid can be inserted into said space, so that the pistons of the pump units occupy their starting positions.

A further advantageous hot-gas reciprocating machine embodying the invention is characterized in that the machine comprises a pump device, the pump duct of which can be caused to communicate by way of a control-member with the various fluid-supply ducts of the machine, whilst there is furthermore provided a fluid container, with which can communicate fluid-outlet ducts of the machine via a control-member.

The invention will be described more fully with reference to the drawing, which is given by way of example.

FIGS. 1, 2 and 3 show partly in a sectional view and in three orthognal elevations a hot-gas reciprocating machine formed by a cold-gas refrigerator. FIG. 4 shows diagrammatically a gold-gas refrigerator with the associated control-device, whilst for clarity only one pair of cooling units is shown.

FIGS. 5 and 6 show diagrammatically two different views of a gold-gas refrigerator, in which the pump units are arranged parallel to each other.

Referring to FIGS. 1, 2 and 3, reference numeral 1 designates a crank casing, on which the pump units I and II are arranged in a V. The machine comprises furthermore two pairs of cooling units A_1, A_2 and B_1, B_2, which communicate by ducts with the pump units.

The pump units I and II comprise each a housing constructed from two portions 2 and 3. In the portion 2 the partitions 4 and 5 form a closed space, which is subdivided by the partition 6, the cylinder 7 and the movable piston 8 into two spaces 9 and 10. In the portion 3 a closed space is formed, which is subdivided by the partition 11, the cylinder 12 and the piston 13, movable in the former, into the separated spaces 14 and 15. With the portion 3 communicates a further cylindrical portion 16, in which the end 77 of the pump rod 17 with the pistons 8 and 13 is adapted to reciprocate. In the cylindrical portion 16 opens out a supply duct 18. The pump rod 17 is connected via a crank driving mechanism housed in the crank casing 1 with the crank shaft 19, which is coupled in turn with an engine 19'.

The cooling units A_1, A_2 and B_1, B_2 comprise each a cylinder 20, in which the expansion piston 21 is adapted to reciprocate. Each cooling unit comprises furthermore a freezer 22, a regenerator 23, a cooler 24 and a cylinder 25, in which the compression piston 26 is adapted to reciprocate. End plates 27, 28 are interconnected by rods 29. These rods 29 are so constructed as to absorb the forces on the cooling units.

The space 30, on the side of the expansion piston 21 remote from the working space, is filled with fluid and the space 31 on the side of the compression piston 26 remote from the working space is also filled with fluid. The space 31 of each of the cooling units A_1 and A_2 communicates via duct 32 with the space 14 of the pump unit I, whereas the space 31 of the cooling unit A_2 communicates via a duct 33 with the space 15 of the pump unit I. The space 30 of the cooling unit A_1 communicates by way of a duct 34 with the space 10 of the pump unit II, whereas the space 30 of the cooling unit A_2 communicates via a duct 35 with the space 9 of the pump unit II. It will appear therefrom that, whereas the ducts 32 and 33 are parallel to each other, the ducts 34 and 35 cross each other. The purpose thereof is to obtain the desired phase difference between the compression pistons and the expansion pistons of the cooling units concerned.

The relevant, fluid-filled spaces of the pair of cooling units B communicate in a similar manner with the spaces of the pump units, the arrangement of said cooling units being, however, such that the fluid-filled spaces 31 are orientated towards the pump unit II, whereas the fluid-filled spaces 30 are orientated towards the pump unit I. The space 31 of the cooling unit B_1 communicates via a duct 36 with the space 14 of the pump unit II and the space 31 of the cooling unit B_2 communicates via a duct 37 with the space 15 of the pump unit II. The ducts 36 and 37 are again parallel to each other. The space 30 of the cooling unit B_1 communicates via a duct 38 with the space 9 of the pump unit I and the space 30 of the cooling unit B_2 communicates via a duct 39 with the space 10 of the pump unit I. From the drawing it will be seen that the ducts 38 and 39 are also parallel to each other.

The cooling units A_1, A_2, B_2, B_1 are furthermore provided with a supply duct 40 and an outlet duct 41 for cooling water. It will be apparent that, if desired, two or more coolers may be interconnected, so that they are traversed in series by the coolant.

The freezers 22 of each cooling unit are all provided with an inlet 43 and an outlet 44 for the medium to be cooled. Also the freezers may, if desired, be interconnected so that they are traversed in series by the medium to be cooled.

The regenerator 23, the freezer 22 and adjacent parts of each cooling unit are surrounded by insulating material 46. The cooling units are furthermore provided, for reinforcing the structure, with plates 47, accommodating the cooling units pairwise and being secured to supports 48, which are connected with the crank casing 1.

The compression pistons 26 and the expansion pistons 21 of all cooling units are provided with a piston rod 49. Each of these piston rods 49 supports a plunger-shaped control-slide 50, which is movable in a cylindrical portion 51, which is in open communication at one end with the connecting duct concerned between the fluid spaces in the cooling units and the fluid spaces in the pump units. The other side of the cylindrical portion 51 communicates through a duct 52 also freely with the said connecting duct. With the cylindrical portion 51 communicates a fluid-outlet duct 53. The opening of the fluid-outlet duct 53 in the portion 51 is disposed so that it can be released by the control-slide 50, when the relevant piston connected with said slide occupies its deepest position in the cooling unit. With the cylindrical portion 51 communicates furthermore a fluid-inlet duct 54, the opening of which in the cylindrical portion 51 is disposed so that it is released when the piston concerned passes beyond its outermost, prescribed position. With the cylindrical portion 51 communicate a further fluid-supply duct 55 and a further fluid-outlet duct 56, the passages of which are blocked in the operational condition of the machine.

The operation of the machine will now be described with reference to FIG. 4, in which the hot-gas reciprocating machine of FIGS. 1, 2 and 3 is shown diagrammatically. Corresponding structural parts are designated in FIG. 4 by the same references as in FIGS. 1, 2 and 3. It should furthermore be noted that for the sake of clarity only one pair of cooling units i.e. A_1 and A_2 is shown in FIG. 4, the various pistons being shown in their positions occupied when the machine is started.

The control-member not shown in FIGS. 1, 2 and 3 comprises, as is shown in FIG. 4, a control-slide 57, by means of which a number of ports can be closed or released. The control-slide 57 is connected by a rod 58 with a ring 59, in which an eccentric disc 60, seated on a shaft 61, is adapted to turn. The shaft 61 is provided with a hand wheel 62. The machine comprises furthermore an oil pump 63, the pump duct of which opens out in a buffer space 64. The oil suction duct 65 opens out in the reservoir 66. By means of an automatic control-valve 67 the pressure in the buffer space is kept constant.

The machine operates as follows:

In order to start the machine the hand wheel 62 moves via the eccentric disc 60 the control-slide 57 into a position in which the port 68 is open. The control-slide 57 is arranged so that, when the port 68 is open, also the ports 69 and 70 are free. In this position of the slide 57 also the ports 71 and 72 are free. Thus in this position of the slide 57 oil can flow out of the buffer space 64 via the duct 73 through the port 71 towards the ports 69 and through the latter into the oil inlet ducts 55. Thus compressed oil arrives via the ducts 52 in the spaces 31 and 30 of the cooling units, so that each of the pistons 26 and 21 are urged into their cooling units. When the control-slide 50 occupies a position in which the openings 74 of the fluid-outlet ducts 56 are free, the fluid can flow via the ports 70 and the port 75 into the fluid-outlet duct 76.

The duct 76 opens out in the reservoir 66. Thus the pistons 21 and 26 are prevented from penetrating further into the cooling units. They then occupy their starting positions. At the same time oil can flow out of the buffer space 64 through the duct 73 and the ports 72 and 68 into the duct 18. Consequently, compressed oil is introduced into the space 16 of the pump units. Thus the portion 77 of the pump rod 17 is subjected to pressure in the direction of the crank shaft, so that the pistons of the pump units are compelled to occupy the positions shown in FIG. 4. If, after the pistons of each pump unit have taken up their aforesaid positions, a further quantity of oil is supplied to the space 16, the valve 78 is opened during the pressure increase of the oil, so that oil flows out of the space 16 via the duct 79 towards the reservoir 66. The machine is then ready for starting.

For starting the machine first the hand wheel 62 is actuated so that the control-slide 57 closes the ports 68, 69, 70, 71, 72 and 75. Then the motor driving the crank shaft 19 is caused to rotate. The pump pistons 8 and 13 are also set moving so that the fluid columns cause the pistons 21 and 26 of the cooling units to move. When the machine starts, the working spaces of the two cooling units of each pair communicate via a connecting duct 80, including a variable valve 81, freely with each other, so that the machine starts without load. Afterwards, in accordance with the speed of the crank shaft, the control-valve 81 in the connecting duct 80 is closed, so that the machine starts producing cold according to the Sterling cycle.

The fluid leaking out of the system results in that the pistons 21 and 26 are urged excessively outwardly by the gas pressure in the working space. This is avoided by providing in the portion 51 accommodating the control-slide 50 a port 83, which is released, when the relevant piston passes beyond its extreme, prescribed position. The port 83 communicates with the fluid supply duct 54, so that fluid can flow from the fluid pump into the space 31 or 30, when the control-slide 50 releases the port 83. Thus, the stroke of the piston concerned is limited on the outer side and the fluid leaking away during the stroke is recovered.

If for some reason the pistons 21 or 26 of the cooling units should penetrate too far into the cooling units, the control-slide 50 releases a port 82, so that fluid can flow via the ducts 53 towards the reservoir 66. Thus the pressure in the spaces 30 or 31 cannot rise further, so that the piston concerned 21 or 26 will not further penetrate into the cooling units. The extreme inner positions of the pistons 21 and 26 are thus fixed.

The seal between the compression pistons and the expansion pistons and the surrounding cylinders in the cooling units is formed by rolling diaphragms 84. In order to keep the desired pressure difference constant with each of these rolling diaphragms, there are provided control members 85. Each of these control-members comprises a cylinder 86, in which a plunger 87 is adapted to reciprocate. The space 88 on one side of the plunger 87 communicates via a duct 89 with the space 90 beneath the rolling diaphragm 84. The fluid-filled space 31, on the side of the piston 26, remote from the working space, communicates via a duct 91 with cylinder 86. The ducts 89 and 91 include helices 92, which ensure that rapid pressure variations in the spaces 90 and 31 are damped, so that they do not occur in the cylinder 86. With the cylinder 86 communicates furthermore a fluid outlet duct 93 and there is provided a helix

94, by which the desired pressure difference on the plunger 87 is adjusted.

The control-member 85 operates as follows. The intention is to maintain a constant pressure difference on the rolling diaphragm 85, i.e. between the working space and the space 90 beneath the rolling diaphragm. Since the pressure of the gas in the working space and the pressure of the fluid in the space 31 are substantially equal to each other, it is sufficient to maintain a constant pressure difference between the spaces 31 and 90.

The piston 26 travels with a fair amount of clearance in its cylinder so that, since the pressure in the space 31 exceeds the pressure in the space 90, fluid flows towards the space 90. If no further steps were taken, the pressures in the spaces 31 and 90 would soon become equal to each other. However, the fluid fed to the space 90 now flows via the duct 89 to the space 88 in the cylinder 86. The helix 94 is chosen so that with the correct pressure difference the plunger 87 partly releases the opening of the duct 93. Thus the fluid fed to the space 88 can flow via the duct 93 out of said space.

It is thus achieved that the fluid in the space 90 is constantly replaced by freshly supplied fluid. This has the advantage that the gas diffusing across the rolling diaphragm is removed from the space 90 with the fluid conducted away.

If for some reason the equilibrium in the pressure difference between the spaces 90 and 31 is disturbed, the following occurs. If the pressure in the working space 97, and hence also in the space 31 increases beyond the value corresponding to the desired pressure difference, said pressure will be imparted via the duct 91 and the slot between the plunger 87 and the cylinder 86 to the space 96. Thus the energy equilibrium on the plunger 87 is disturbed. The plunger 87 moves to the left, so that the duct 93 is closed to a greater extent. Consequently, a smaller quantity of fluid can flow away from the spaces 90 and 88, so that the pressure in said spaces increases. When the correct pressure difference is restored, the plunger 87 re-occupies its initial position and the fluid is again permitted to flow.

The fluid leaking away through the fluid outlet duct 93, similarly to the fluid leaking away from the device in another manner, is replenished during each stroke, since the opening 83 of the fluid supply duct 54 is released.

FIG. 4 shows for the sake of clarity only one control-mechanism 85; however, in practice, all rolling diaphragms are provided with such a control-mechanism.

FIGS. 5 and 6 show diagrammatically a hot-gas reciprocating machine, formed by a cold-gas refrigerator, in two elevations; the pump units I and II are arranged parallel to each other on a crank casing 101. The pistons of each of these pump units are connected by means of piston rods 117, universal joints 118, connecting rods 119 with cranks 121 and 120 respectively of the crank shaft 122 accommodated in the crank casing 101. The cranks 120 and 121 are turned through 90° relatively to each other in order to obtain the desired phase difference between the pistons moving in the cooling units. The machine comprises again two pairs of cooling units A_1, A_2 and B_1, B_2. Said cooling units and the pump units I and II may be constructed in the same manner as the corresponding units described with reference to FIGS. 1, 2 and 3.

From the drawing it will be seen that the cooling units A_1 and A_2 are located in a plane located in front of the plane of the pump units I and II and parallel thereto, whereas the cooling units B_1 and B_2 are disposed in a plane located behind the plane of the pump units. The centre lines of the cooling units A_1 and A_2 cross the centre lines of the cooling units B_1 and B_2.

The cooling units A_1 and A_2 communicate on one side via ducts 132 and 133 respectively with the pump unit I and on the other side via ducts 134 and 135 respectively with the pump unit II. The ducts 132, 133 and 134, 135 extend pairwise parallel to each other.

The cooling units B_1 and B_2 communicate on one side via ducts 136 and 137 respectively with the pump unit II and on the other side via ducts 138 and 139 respectively with the pump unit I, whereas the ducts 136 and 137 are substantially parallel to each other and the ducts 138 and 139 are arranged crosswise. Thus the correct phase difference between the pistons moving in the various cooling units is obtained.

The advantage of the machine illustrated in FIGS. 5 and 6 is that the length thereof, i.e. the distance between the centre lines of the pump units is small as compared with other arrangements of pump units and cooling units. This may be useful in places where space is a problem.

Although the drawing shows only two pump units parallel to each other, it will be obvious that the machine may be extended with further pump units without any difficulty.

From the drawing it will also appear that with the construction of a hot-gas reciprocating machine according to the invention there is, in practice, a great freedom with respect to the arrangement of the various units relative to each other.

Although four cooling units are shown in the drawing, it will be obvious that it is possible, without any difficulty, if the conditions require it, to omit one or more of the cooling units.

What is claimed is:

1. A hot-gas reciprocating apparatus comprising at least two pairs of units in each of which a working medium performs a thermodynamic cycle, each unit having a compression space of variable volume and an expansion space of variable volume, means connecting said compression space with said expansion space, said connecting means including a cooler, regenerator and a heat exchanger, said spaces having relatively different mean temperatures, said working medium adapted to flow alternately in said spaces and through said cooler, regenerator and heat exchanger, a cylinder housing piston-like elements, said piston-like elements being adapted to move with a relative phase difference in order to vary the volumes of said compression and expansion spaces, a driving gear, said piston-like elements being coupled to said driving gear, at least two pump units, each of said pump units comprising two closed, fluid-filled cylinders, a pair of double-acting pistons being a compression piston and an expansion piston adapted to move in said fluid-filled cylinders whereas in the first pair of units each of the spaces positioned on the side of the associated expansion piston remote from said expansion space communicates with one of the spaces on either side of one of the pistons of the first pump unit, and each of the spaces positioned on the side of the associated compression piston remote from said compression space communicates with one of the spaces on either side of one of the pistons of the second pump unit, and in that of the second pair of units in which the thermo-dynamic cycle is performed each of the spaces being positioned on the side of the associated expansion piston remote from said expansion space communicates with one of the spaces on either side of the other piston of the second pump unit, and each of the spaces positioned on the side of the associated compression piston remote from said compression space communicates with one of the spaces on either side of the other piston of said first pump unit.

2. A hot-gas reciprocating apparatus as claimed in claim 1, further comprising a common crank shaft for said pump units and wherein the pump units are arranged pairwise in the form of a V and are connected with said common crank shaft, and in that each of the units in which the thermo-dynamic cycle is performed is arranged substantially between planes intersecting the center line of the crank shaft and going through the center lines of the pump units so that in a projection to a plane at right

angles to the center line of the crank shaft, the center lines of the two pump units and the center line of each unit in which the thermo-dynamic cycle is performed form a triangle.

3. A hot-gas reciprocating apparatus as claimed in claim **1**, wherein one pair of units in which the thermo-dynamic cycle is performed is arranged between the two pump units so that the spaces, on the side of compression pistons remote from said compression space, are orientated towards the first pump unit communicating with said spaces, while the spaces, on the side of the expansion pistons remote from said expansion space, are orientated towards the second pump unit communicating with said spaces and in that the other pair of units in which the thermo-dynamic cycle is performed is arranged between the two pump units so that the spaces, on the side of the compression pistons remote from said compression space, are orientated towards the second pump unit communicating with said spaces, whereas the spaces, on the side of the expansion pistons remote from said expansion space, are orientated towards the first pump unit communicating with said spaces.

4. A hot-gas reciprocating apparatus comprising at least two pairs of units in which a working medium performs a thermo-dynamic cycle, each unit having a compression space of variable volume and an expansion space of variable volume, means connecting said compression space with said expansion space, said connecting means including a cooler, regenerator and a heat exchanger, said spaces having relatively different mean temperatures, said working medium adapted to flow alternately in said spaces and through said cooler, regenerator and heat exchanger, a cylinder housing piston-like elements, said piston-like elements being adapted to move with a relative phase difference in order to vary the volumes of said compression and expansion spaces, a driving gear, said piston-like elements being coupled to said driving gear, at least two pump units arranged parallel to each other, each of said pump units comprising two closed, fluid-filled cylinders, a pair of double-acting pistons being a compression piston and an expansion piston adapted to move in said fluid-filled cylinders whereas in the first pair of units each of the spaces positioned on the side of the associated expansion piston remote from said expansion space communicates with one of the spaces on either side of one of the pistons of the first pump unit, and each of the spaces positioned on the side of the associated compression piston remote from said compression space communicates with one of the spaces on either side of one of the pistons of the second pump unit, and in that of the second pair of units in which the thermo-dynamic cycle is performed each of the spaces being positioned on the side of the associated expansion piston remote from said expansion space communicates with one of the spaces on either side of the other piston of the second pump unit, and each of the spaces positioned on the side of the associated compression piston remote from said compression space communicates with one of the spaces on either side of the other piston of said first pump unit, one of the pair of units in which the thermo-dynamic cycle is performed communicating with said pump units being arranged in a plane extending parallel to and in front of the plane of said pump units and the other pair of units in which said thermo-dynamic cycle is performed communicating with said pump units and being arranged in a plane extending parallel to and behind the plane of said pump units, and said units in which said thermo-dynamic cycle is performed being arranged in their respective planes so that in a projection through the plane of said pump units the center lines of one pair of said units in which said thermo-dynamic cycle is performed intersect the center lines of said relevant units of the other pair.

5. A hot-gas reciprocating apparatus comprising at least two pairs of units in which a working medium performs a thermo-dynamic cycle, each unit having a compression space of variable volume and an expansion space of variable volume, means connecting said compression space with said expansion space, said connecting means including a cooler, regenerator and a heat exchanger, said spaces having relatively different mean temperatures, said working medium adapted to flow alternately in said spaces and through said cooler, regenerator and heat exchanger, a cylinder housing piston-like elements, said piston-like elements being adapted to move with a relative phase difference in order to vary the volumes of said compression and expansion spaces, a driving gear, said piston-like elements being coupled to said driving gear, at least two pump units arranged parallel to each other, each of said pump units comprising two closed, fluid-filled cylinders, a pair of double-acting pistons being a compression piston and an expansion piston adapted to move in said fluid-filled cylinders whereas in the first pair of units each of the spaces positioned on the side of the associated expansion piston remote from said expansion space communicates with one of the spaces on either side of one of the pistons of the first pump unit, and each of the spaces positioned on the side of the associated compression piston remote from said compression space communicates with one of the spaces on either side of one of the pistons of the second pump unit, and in that of the second pair of units in which the thermo-dynamic cycle is performed each of the spaces being positioned on the side of the associated expansion piston remote from said expansion space communicates with one of the spaces on either side of the other piston of the second pump unit, and each of the spaces positioned on the side of the associated compression piston remote from said compression space communicates with one of the spaces on either side of the other piston of said first pump unit, plural control slides, each piston in each unit in which said thermo-dynamic cycle is performed being connected to one of said control slides, the latter being displaced upon movement of an associated piston along a portion of said fluid-filled space on the side of said piston remote from said expansion space, and at least one fluid inlet and at least one fluid outlet in said portion of said fluid-filled space, said inlet and outlet openings being so arranged that said inlet is opened when the piston passes to its outermost predetermined position and the outlet is opened when the piston occupies its innermost predetermined position in said unit in which a thermo-dynamic cycle is performed.

6. A hot-gas reciprocating apparatus as claimed in claim **5**, wherein each of the pistons adapted to reciprocate in the cylinder of each unit in which the thermo-dynamic cycle is performed further comprises another cylindrical part constituting said control-slide which is adapted to move in a further cylindrical part of each of the cylinders is in which said piston-like elements are moveable and in that the apparatus comprises at least one duct interconnecting the two spaces on either side of the control-slide and in that the inlet duct and the outlet duct are in contact with the wall of said other cylindrical part.

7. A hot-gas reciprocating apparatus as claimed in claim **5** further comprising a fluid supply duct and wherein each of the fluid-filled spaces in each unit in which the thermo-dynamic cycle is performed communicates with said fluid supply duct, the passage of which is blocked in operation of the apparatus, whereas at the location of the control-slide a further fluid outlet duct opens out, the passage of which is also blocked in the operation of the apparatus and in that the passages of said ducts can be released when the apparatus is prepared for starting and in that the openings of the outlet ducts are arranged so that they are uncovered when the relevant piston occupies its starting position.

8. A hot-gas reciprocating apparatus as claimed in claim **7** further comprising a closed cylinder, a further piston-like body adapted to move therein, and wherein the interconnected pistons of each of the pump units are furthermore connected with said piston-like body located substantially in their center lines, and in that the space above said piston-like body communicates with said fluid supply duct through which compressed fluid can be introduced into said space whereby the pistons of the pump units are driven in their starting positions.

9. A hot-gas reciprocating apparatus as claimed in claim 1 further comprising a control member, a plurality of fluid supply ducts and outlet ducts, a pump device having a pump duct, which can be caused to communicate through said control member with said fluid supply ducts of the apparatus, and in that there is furthermore provided a fluid reservoir, with which the fluid outlet ducts of said apparatus can be caused to communicate through said control member.

References Cited by the Examiner

UNITED STATES PATENTS

2,484,392	10/49	Van Heeckeren	62—6 X
2,567,637	9/51	De Brey et al.	60—24
2,590,519	3/52	Du Pré	60—24
2,616,245	11/52	Van Weenen	60—24
2,616,248	11/52	De Brey et al.	60—24
2,657,528	11/53	Jonkers et al.	60—24
2,657,552	11/53	Jonkers et al.	60—24 X
2,664,699	1/54	Kohler	60—24
2,771,751	11/56	Jonkers et al.	62—6 X
3,117,414	1/64	Daniels et al.	60—24

JULIUS E. WEST, *Primary Examiner.*

EDGAR W. GEOGHEGAN, *Examiner.*