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Gärtner

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[45] **June 17, 1975**

[54] **APPARATUS FOR CONTROLLING THE POWER OF A HOT-GAS PISTON ENGINE**

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[52] **U.S. Cl.** **60/521**

[51] **Int. Cl.** **F03g 7/06**; F25b 9/00

[58] **Field of Search** 60/516, 517, 518, 521, 60/522, 526

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Assistant Examiner—H. Burks, Sr.

[57] **ABSTRACT**

An apparatus for controlling the power of a hot gas piston engine is disclosed, the latter having at least one cylinder which is divided into a hot space and a cold space by a movable piston. A working fluid container is connected on one hand to the hot space by a conduit, and on the other hand to the cold space in such a way that flow between the cold space and the container may be prevented selectively in either or both directions, whereby the mass of working fluid in the cylinder may be increased or decreased, thus increasing or decreasing the power output of the engine.

9 Claims, 13 Drawing Figures

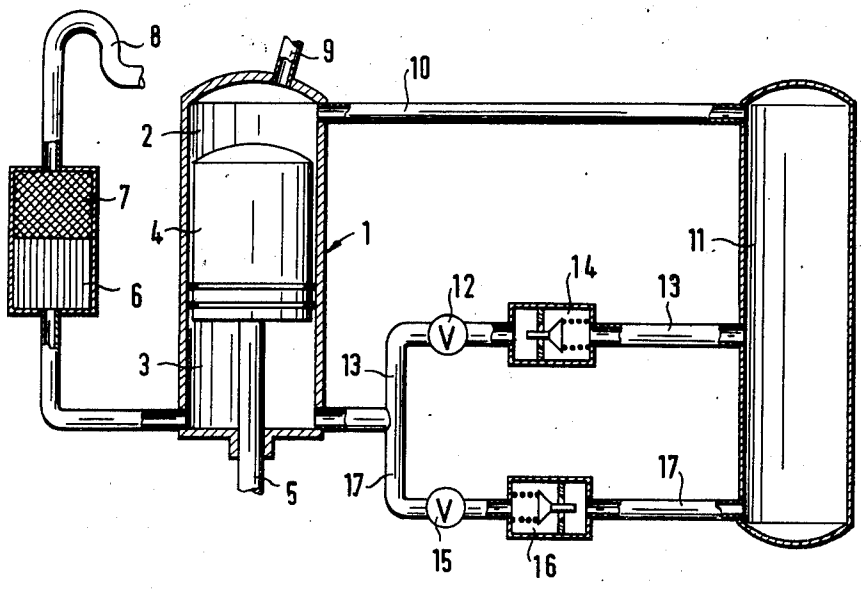


Fig.1

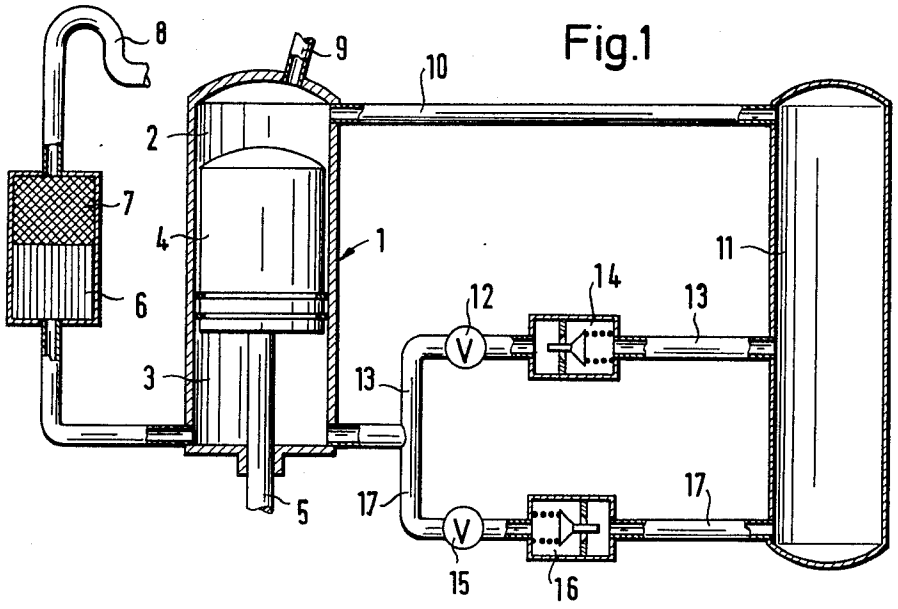
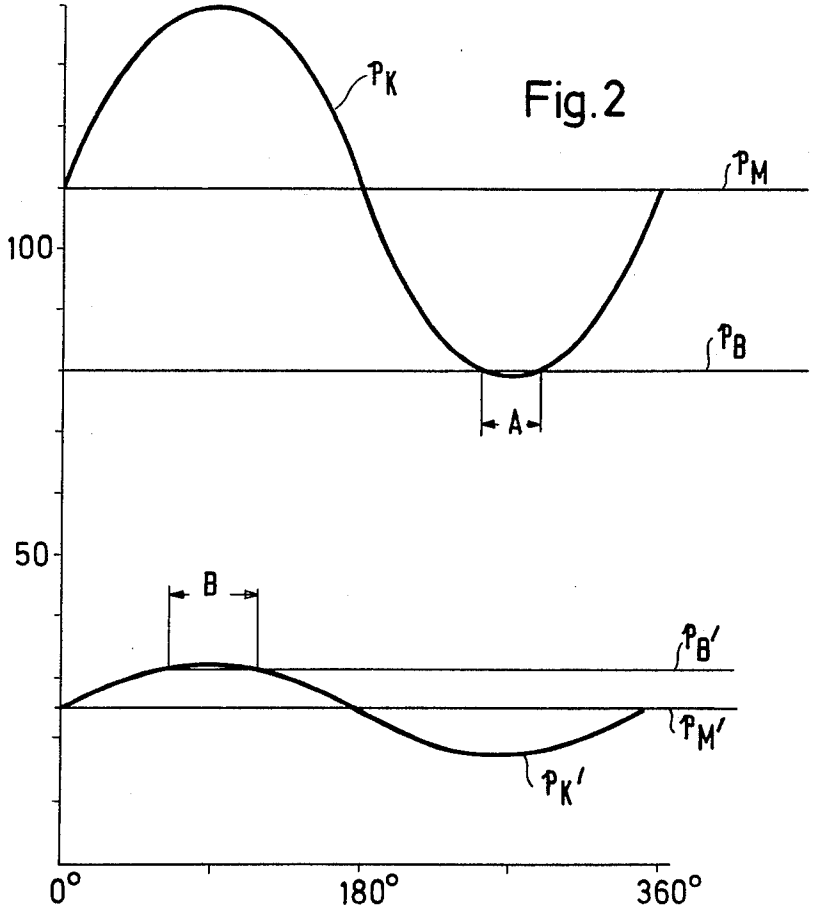

8
9
10
2
7
4
1
11
12
14
13
6
3
13
17
17
5
V
15
16

Fig.2


p_K
p_M
100
p_B
A
50
B
$p_{B'}$
$p_{M'}$
$p_{K'}$
0°
180°
360°

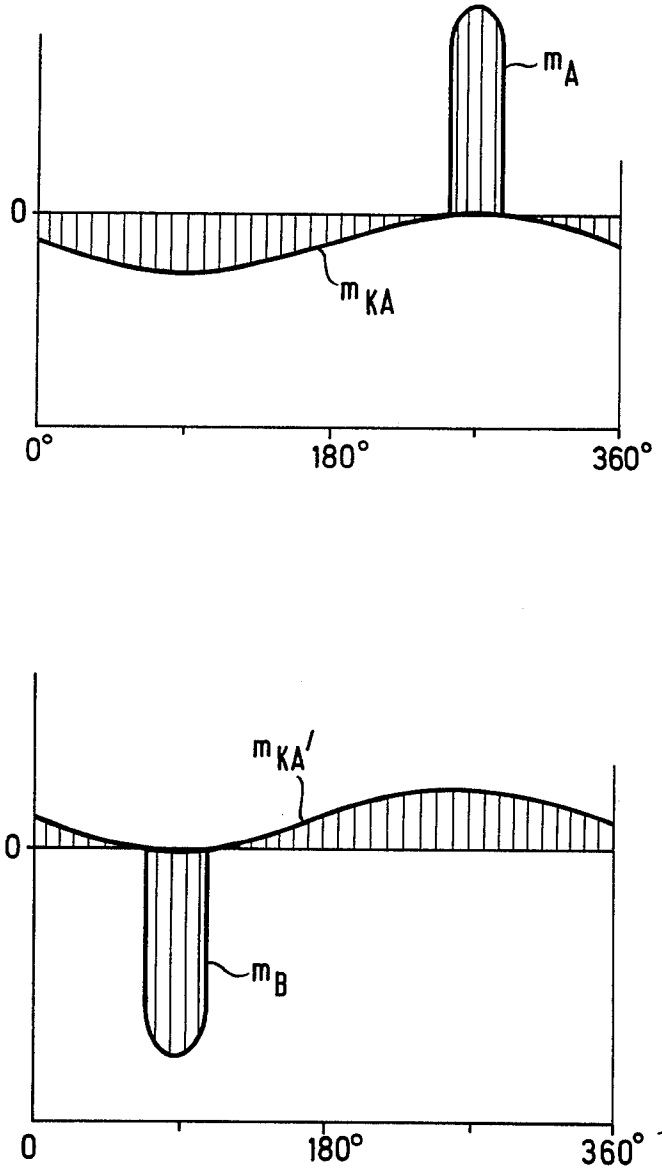


Fig.3

Fig.4

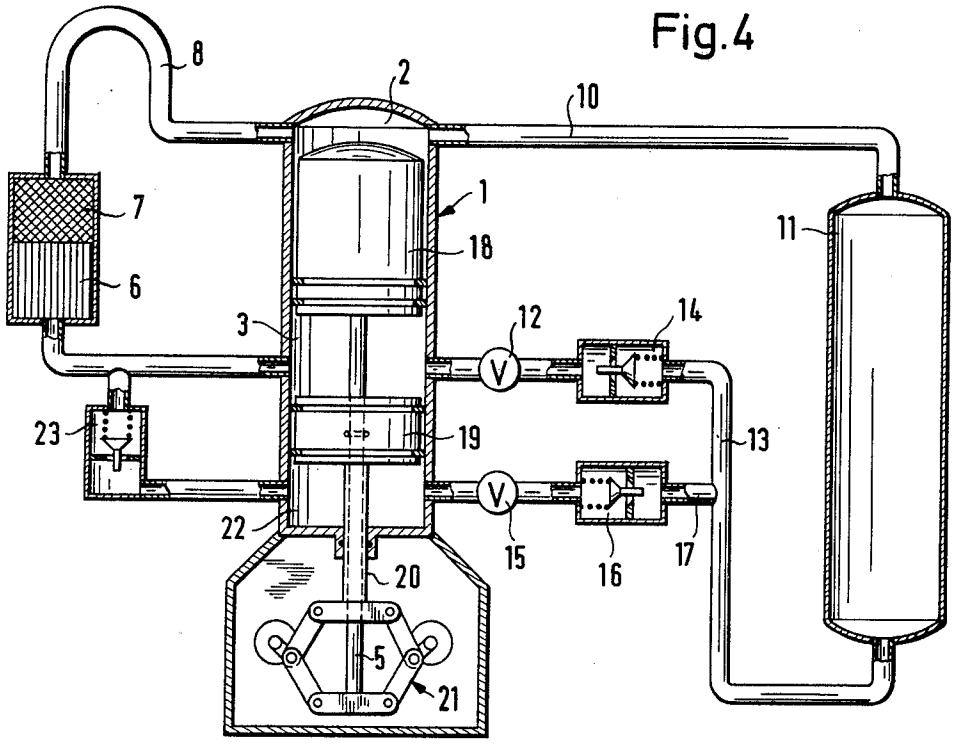
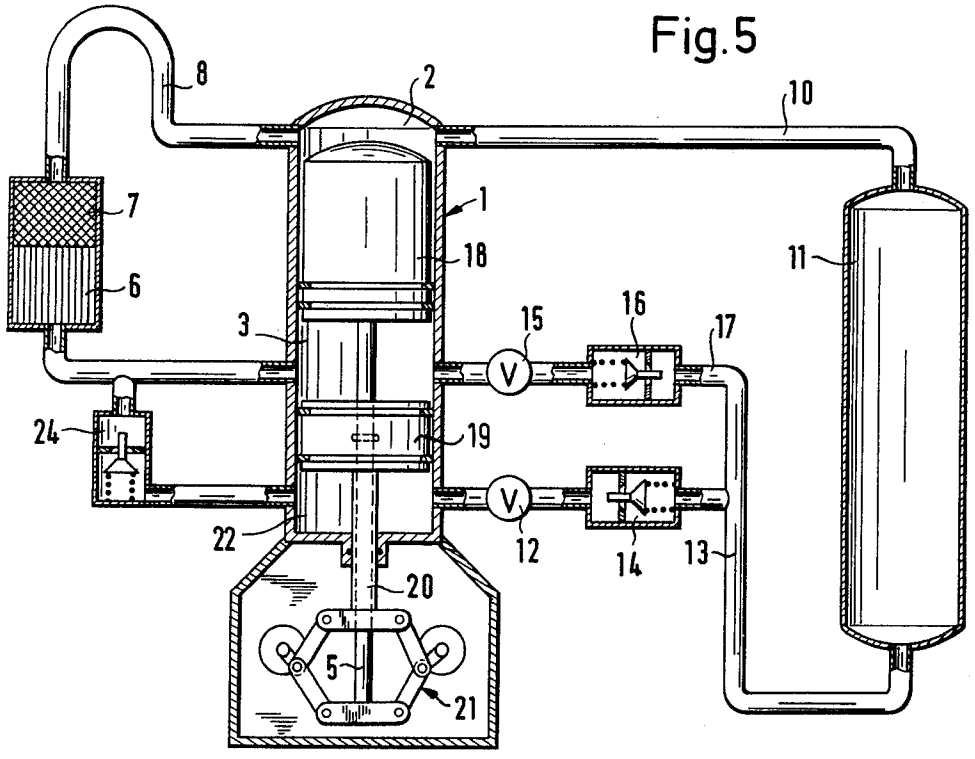

8
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7
1
11
18
6
3
12
14
V
23
19
13
V
22
15
16
17
20
5
21

Fig.5


8
2
10
7
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18
6
3
15
16
17
V
24
19
V
22
12
14
13
20
5
21

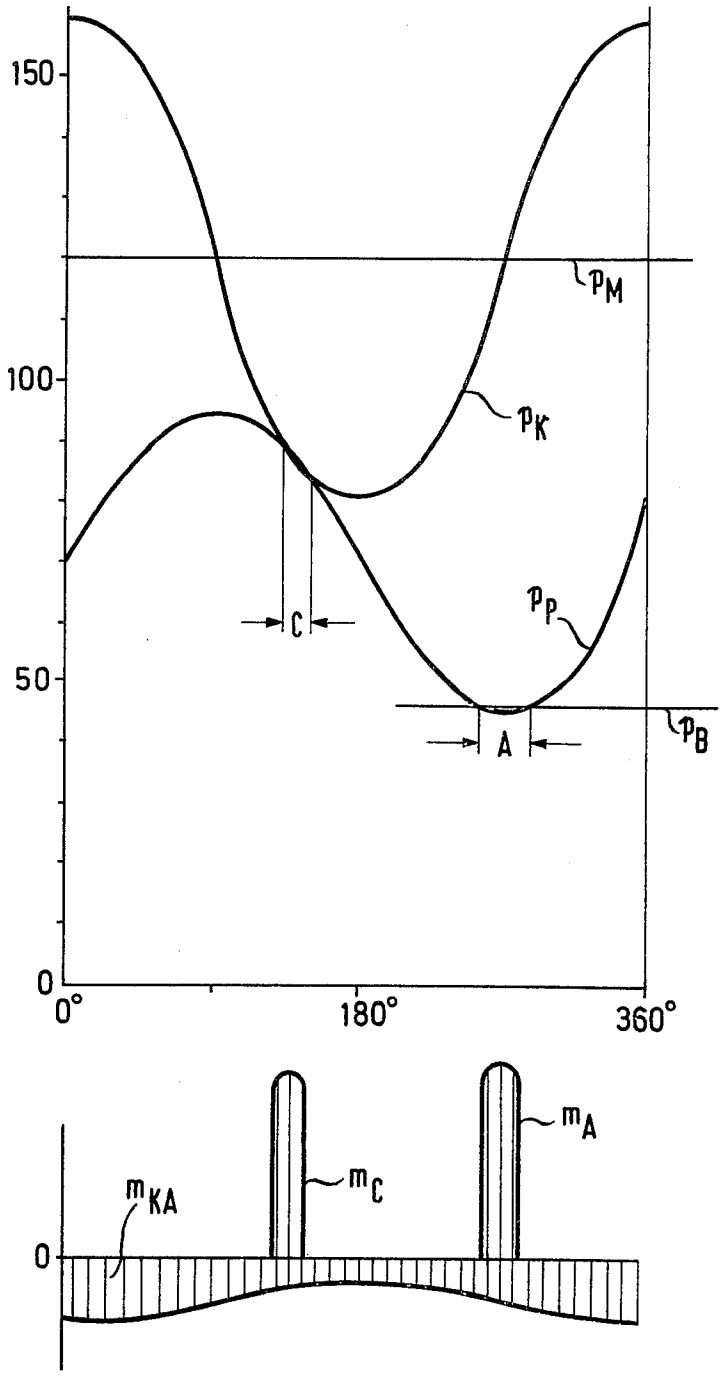


Fig.6

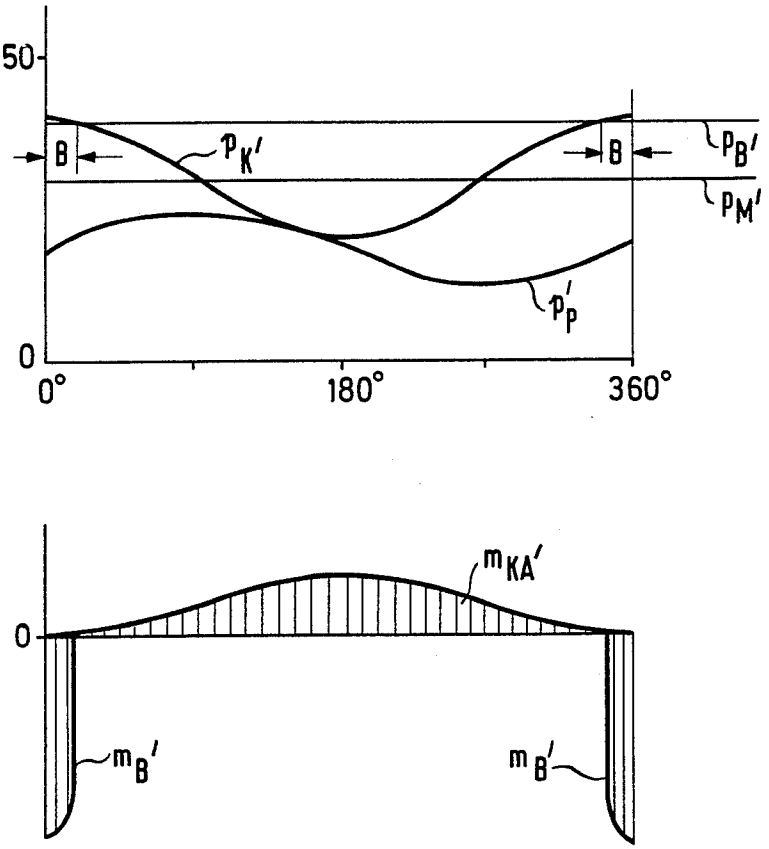


Fig.7

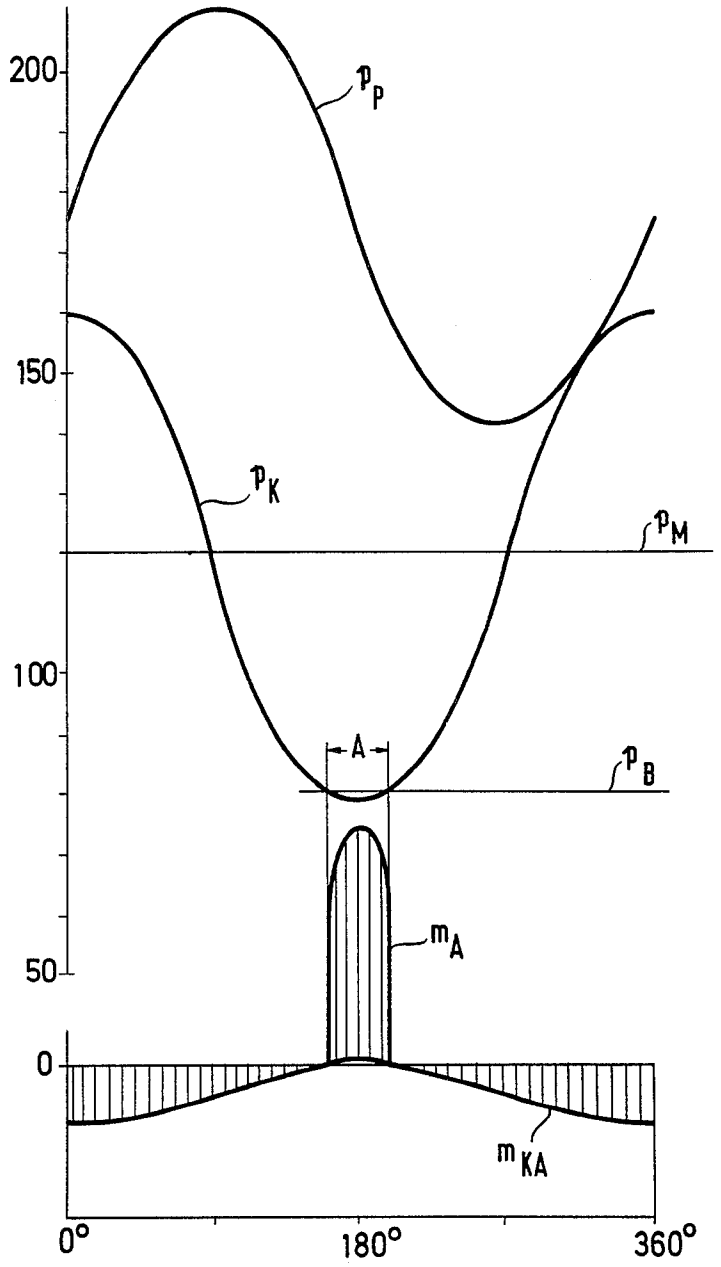


Fig.8

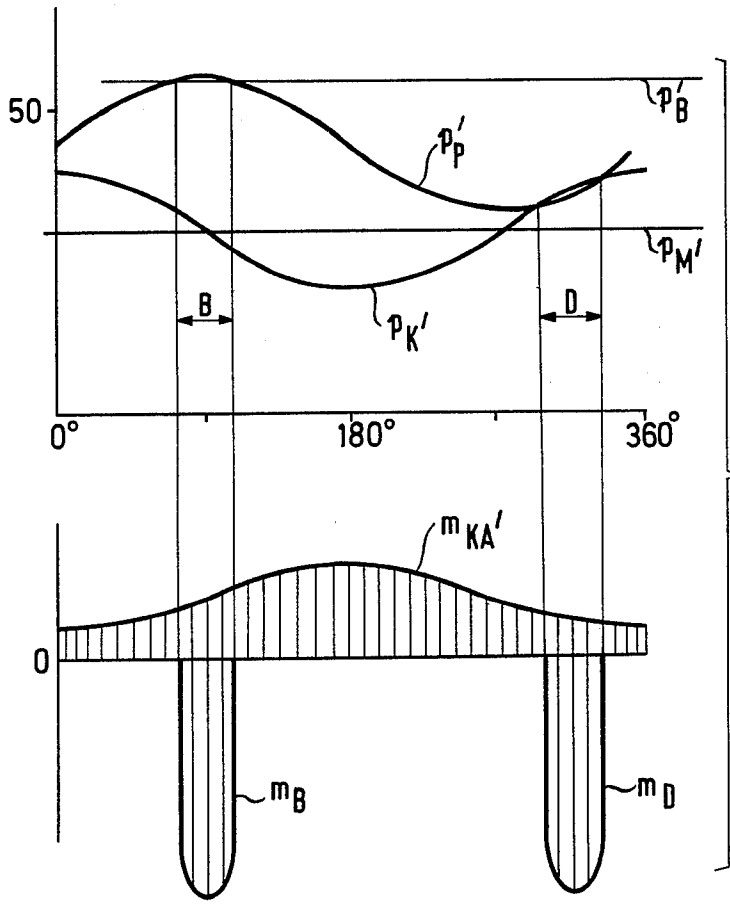


Fig.9

Fig. 10

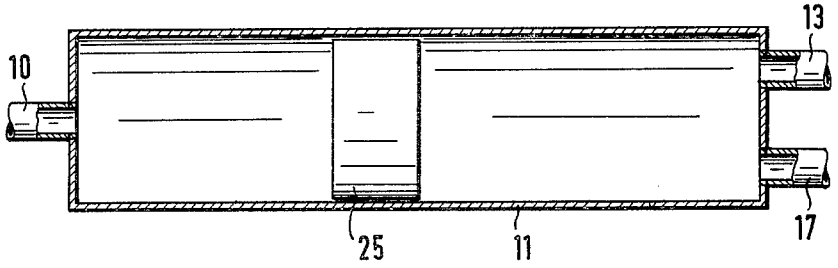


Fig. 11

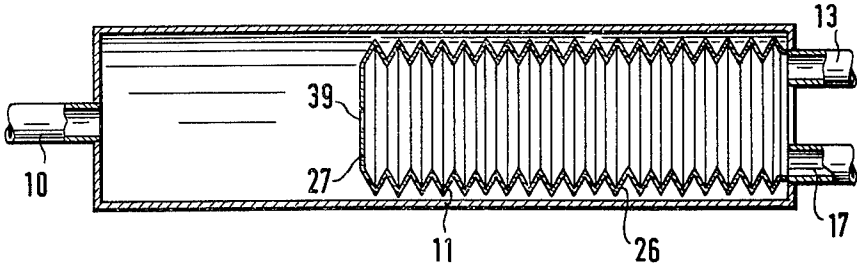
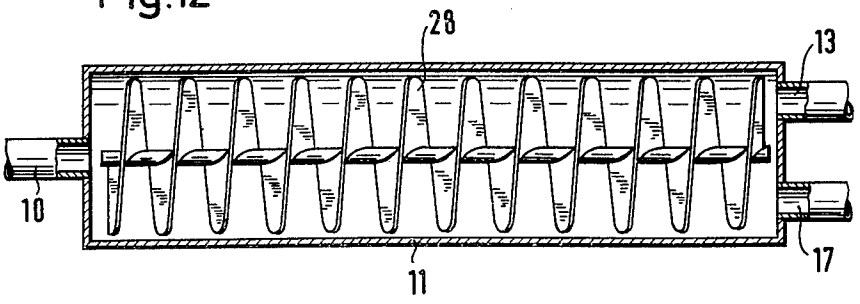


Fig. 12



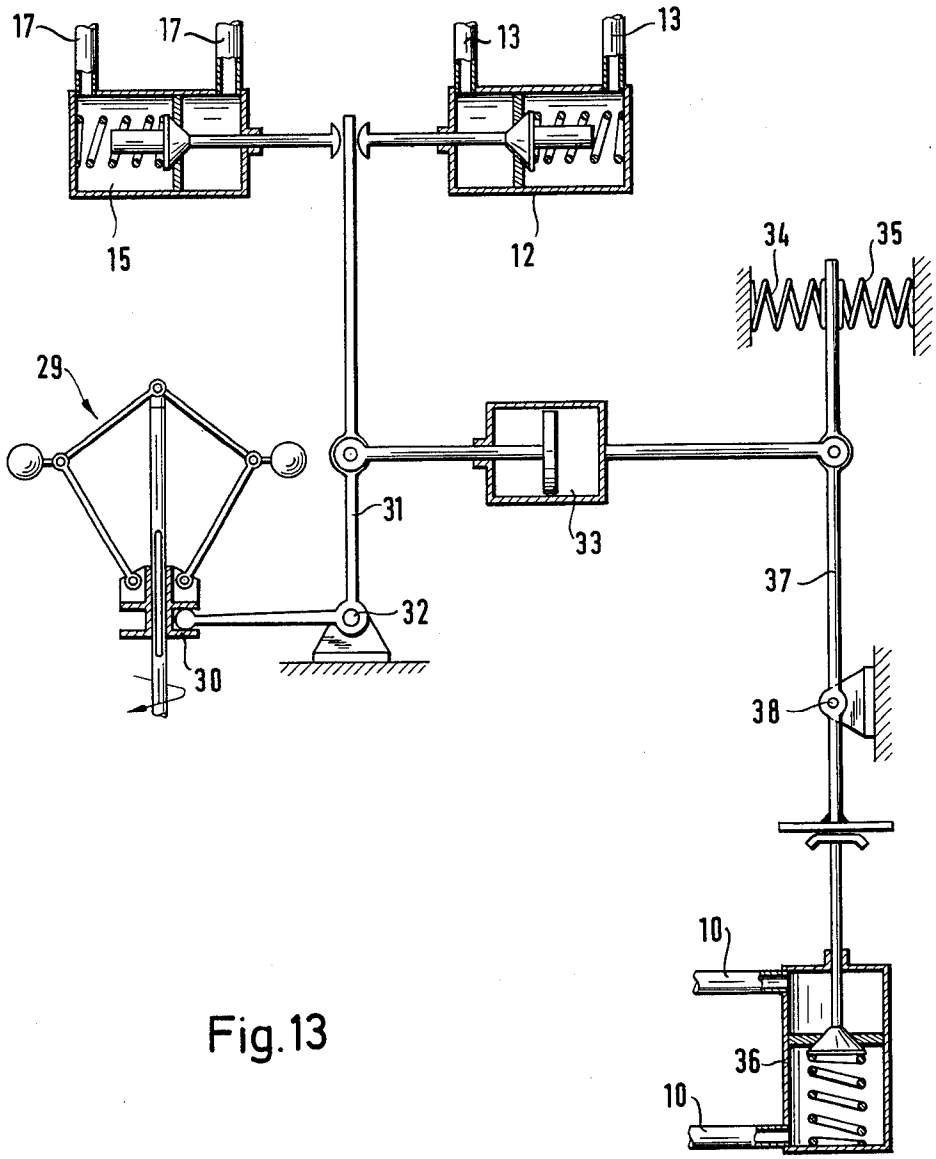


Fig.13

APPARATUS FOR CONTROLLING THE POWER OF A HOT-GAS PISTON ENGINE

The invention relates to an apparatus for controlling the power of a hot-gas piston engine having a hot chamber and a cold chamber per cylinder, these being separated from one another and adapted to be alternately reduced and enlarged in size by a piston movable in the said cylinder, the hot chamber being connected with the cold chamber of the same engine cylinder or another cylinder operating in a phase-displaced manner, by way of a path of flow which comprises in series one after the other a heater, a regenerator and a cooling device.

The control method hitherto used in hot-gas piston engines of the type specified is described for example in the German publication MTZ, Vol. 29 (1968) on pages 290–291. To control power, the mean pressure prevailing in the working chambers of the hot-gas engine is so modified that a high pressure is present in the chambers at high power and a low pressure at low power. Varying the pressure level is carried out by means of a compressor driven by the engine and pumping the working medium in the case of power reduction into a supply container which is under high pressure.

A compressor of this kind has to meet very high standards. It must have a high pressure ratio, must operate without lubrication of the piston and must be sealed hermetically against gases, such as helium. These requirements can be met only with difficulty and if they are met at all only at great expense.

When increasing power, with the known control method the working medium is made to flow from the supply container into the working chambers, so that the mean pressure in these chambers rises quickly. Thus, the mass of gas which has participated in the working process of the engine is modified, whereas the entire mass of gas situated in the working chambers and in the supply container remains unaltered. The pumping of the working medium out of the working chambers by the compressor takes place relatively slowly, so that it is necessary to adopt the remedy of so-called short-circuit control, which in fact reacts quickly enough but reduces the efficiency of the machine to nil during the short-circuit periods. This property and the relatively expensive control compressor are the disadvantages which the present invention sets out to obviate.

According to the invention this object is achieved in a hot-gas piston engine of the type mentioned initially in that the hot chamber is connected by way of a restricting or throttling conduit with a container whose interior can be connected selectively with the cold chamber by way of one of two non-return valves. For increasing the engine power the container interior is connected with the cold chamber through the agency of one non-return valve, which allows a flow from the hot chamber by way of the container into the cold chamber, whereas to reduce the engine power the container interior is connected with the cold chamber by way of the other non-return valve, which allows a flow from the cold chamber by way of the container into the hot chamber.

The control arrangement according to the invention makes use, like the aforesaid known control method, of the efficiency-neutral principle of modifying the mass of gas which participates in the working process of the engine, the entire mass of gas remaining constant. With high power, a large mass of gas is situated in the working chambers of the engine and a small mass of gas in the container, whereas at low power, a small mass of gas is in the working chambers and a large mass of gas in the container.

Suitable measures for carrying this principle into effect, which are used according to the invention, comprise varying of the temperature and/or pressure in the container. To modify the temperature, the varying temperatures in the cold and the hot chambers are used, and for modifying the pressure, the periodically varying pressure in the working chambers of the engine are used, the temperature influencing the gas density in the container in the desired sense.

When flow takes place from the hot chamber by way of the container into the cold chamber, the heat passing into the container from the hot chamber increases the container pressure, and at the same time brings about an expansion of the gas in the container. As a result, gas is displaced from the container into the cold chamber, and also the pressure in the working chambers of the engine, and thus the mass of gas participating in the working process, are increased, whereas the gas density and thus the mass of the gas remaining in the container are reduced.

If flow takes place from the cold chamber into the hot chamber, again by way of the container, the hot container content is displaced into the hot chamber, and cold gas flows in after, so that the container pressure drops. As a result, the pressure in the working chambers of the engine falls also, and thus the gas mass participating in the working process is reduced.

Since the temperature in the hot and cold chambers are maintained at values necessary for carrying out the known Stirling process, by heat-exchange elements: heater, regenerator and cooling device, a pressure increase in the working chambers means an increase in the mass of gas participating in the working process, while a pressure drop in the working chambers means a reduction in the participating gas mass.

In the container the conditions are reversed in the sense that a pressure increase is the result of a temperature rise or a gas density drop on the part of the container contents. The gas mass in the container is therefore reduced when there is a pressure increase, and increased when there is a pressure drop, cooling and increasing of the gas density.

With hot-gas piston engines having a buffer chamber, the latter can advantageously be included in the control arrangement according to the invention. In the constructional form of a hot-gas piston engine wherein the hot chamber is connected with the cold chamber of the same cylinder by way of the heater, the regenerator and the cooling device, there operates in the engine cylinder a further piston, usually referred to as the working piston, in phase-displaced relationship relatively to that piston which separates the hot chamber from the cold chamber, and is usually referred to as the displacement piston.

The working piston separates the buffer chamber from the cold chamber, which is connected with the buffer chamber by way of an overflow valve controlled at the stroke rhythm.

There are two possibilities of arranging the overflow valve, on the one hand in such a manner that the mean pressure in the buffer chamber is equal to or less than the mean pressure in the cold chamber, and the other

in such a manner that the mean pressure in the buffer chamber is equal to or greater than the mean pressure in the cold chamber.

The first-mentioned possibility provides the advantage for the control arrangement according to the invention, owing to the relatively small gas mass in the buffer chamber, of managing with a relatively small container.

The second possibility has the advantage of a change in the direction of force in the driving gear, which has an advantageous effect on the working life of the driving gear bearings. Both possibilities promote the action of the control system according to the invention because of an increased pressure difference for charging and discharging the container as compared with constructional forms without a buffer chamber.

Accordingly, in a construction with a relatively high buffer-chamber pressure the non-return valve which allows a flow from the cold chamber to the hot chamber by way of the container is connected to the buffer chamber. The basic principle of the invention is maintained, since with this arrangement, when there is a drop in power, flow takes place from the cold chamber into the hot chamber by way of the overflow valve, the buffer chamber and the container.

With a construction with relatively low buffer-chamber pressure, on the other hand, that non-return valve which allows flow from the hot chamber into the cold chamber by way of the container is connected to the buffer chamber so that in this case also, in accordance with the principle proposed in the present invention, when there is an increase in power there is a flow from the hot chamber through the container, the buffer chamber and the overflow valve into the cold chamber.

Since a considerable mass flow from the container into the cold chamber and vice versa is required only when changing to another power level, the throttling conduit can advantageously be closed with constant load.

In order to make it possible to cover any heat losses from the hot chamber in the case of a constant high load, it may also be advantageous to make the cross-section of the restricting conduit variable in such a manner, in dependence on the size and/or speed of the load change, that a relatively large cross-section is produced in the case of a considerable and/or rapid load change, whereas a relatively small cross-section is provided in the case of a constant load.

Since it is sufficient, for the purposes of the control arrangement according to the invention, if the heat supply to the container, when there is an increase in power, is limited to the part of the container to which the restricting conduit is connected, the container can be in the form of a cylinder in which there is situated an easily movable piston which constitutes a partition. The piston has the task of reducing an undesired outflow of heat into the cold chamber.

An almost complete separation of the container into a relatively hot and a relatively cold portion can advantageously be achieved by providing in the container a movable partition, preferably in the form of a bellows.

Mixing of the hot and cold container contents can advantageously be reduced by arranging a helical partition in the container.

The three aforesaid measures for separating the relatively hot portion of the container from the relatively cold portion are also used for increasing the control speed.

Further objects, features and advantages of the invention will become understood by reference to the following description when considered in the light of the drawings.

Several preferred, exemplary constructional examples of the invention are shown in the accompanying drawings, wherein

FIG. **1** shows a cylinder of a multi-cylinder double-action hot-gas piston engine which is provided with the control apparatus according to the invention;

FIG. **2** shows the pressure pattern in the working chambers and in the container of the engine shown in FIG. **1** over the crank angle, both for power increase and power decrease;

FIG. **3** shows the mass flows relative to FIG. **2** over the crank angle, also for power increase and power decrease;

FIG. **4** shows a single-cylinder hot-gas engine wherein the pressure in the buffer chamber is predominantly equal to or smaller than the pressure in the cold chamber;

FIG. **5** shows a single-cylinder hot-gas engine wherein the pressure in the buffer chamber is predominantly equal to or greater than the pressure in the cold chamber;

FIG. **6** shows the pressure pattern in the working chambers, in the container and in the buffer chamber, and also the mass flow in the engine shown in FIG. **4** when there is a power increase;

FIG. **7** shows the same parameters as in FIG. **6** but for a power reduction;

FIG. **8** shows the pressure pattern in the working chambers, in the container and in the buffer chamber in the engine shown in FIG. **5** for a power increase;

FIG. **9** shows the same parameters as FIG. **8** but for a power reduction;

FIG. **10** shows the container with a built-in piston;

FIG. **11** shows the container with a built-in bellows;

FIG. **12** shows the container with a helical partition; and

FIG. **13** shows the apparatus with which a flow restricting conduit can be temporarily wholly or partly closed.

In a cylinder **1** of a hot-gas piston engine shown in a schematic manner in FIG. **1**, a hot chamber **2** is separated from a cold chamber **3** by a piston **4**. The latter is connected in such a manner by means of a piston rod **5** with a crankshaft (not shown) of the engine that the piston **4** is given a reciprocating movement which alternately reduces and increases the size of the chambers **2** and **3** when the crankshaft rotates. The cold chamber **3** is connected by way of a cooling device **6**, a regenerator **7** and a heater **8** with the hot chamber of another cylinder (not shown) of the engine whose piston operates in a phase-displaced manner relatively to the piston **4**.

The hot chamber **2** is connected by way of a connection **9** in a similar manner to the cold chamber of a further cylinder not shown here in which a piston operates in a phase-displaced manner relatively to the piston **4**. The hot chamber **2** is connected by way of a preferably capillary conduit **10** with a container **11**, the interior of which is connected to the cold chamber **3** when a shut-off valve **12** is opened by way of a conduit **13** and a non-return valve **14**. The latter only allows a flow from

the cold chamber 3 by way of the container 11 and the conduit 10 into the hot chamber 2. When a shutoff valve 15 is opened, a connection is also established between the cold chamber 3 and the interior of the container 11, a non-return valve 16 only allowing a flow from the hot chamber 2 by way of the container 11 and a conduit 17 into the cold chamber 3.

It should be understood that the conduit 10 is just one example of an arrangement affording or incorporating throttling or other flow restricting means.

The operation of the apparatus described hereinbefore is clear from FIG. 2. With a constant load, the shutoff valves 12, 15 are closed. The mean pressure p_M of the working chambers 2 and 3 has been established in the container 11 by way of the conduit 10. The temperature in the container 11 is determined by the previous operations and is between the temperatures of the chambers 2, 3. To increase the load or power output, the shutoff valve 15 is opened. As a result, gas flows from the container 11 into the cold chamber 3 by way of the non-return valve 16 as long as the pressure p_K in this chamber, at the particular instant, is lower than the container pressure, that is to say during the period of time A when the non-return valve 16 is opened.

Accordingly, the container pressure drops to the value p_B. As a result, gas flows from the hot chamber 2 by way of the conduit 10 into the container 11, so that the container temperature rises to the temperature in the chamber 2, which reduces the gas density in the container 11. This state is shown in the upper part of FIG. 2. In this way the result is achieved that, of the total mass of gas, the smallest possible portion is present in the container 11, and the largest possible portion in the chambers 2 and 3.

If the power is to be reduced, the shutoff valve 12 is opened. As a result, gas flows from the cold chamber 3 through the non-return valve 14 into the container 11 as long as the instantaneous pressure $p_{K'}$ in this chamber is higher than the container pressure, i.e., during the period of time B when the non-return valve 14 is opened. As a result the container pressure rises above the pressure $p_{M'}$ to the value $p_{B'}$. By way of the conduit 10, gas flows into the hot chamber 2, and the temperature in the container 11 falls to the temperature in the chamber 3, while the gas density in the container 11 rises. This condition is shown at the foot of FIG. 2. In this way the result is achieved that, of the total mass of gas, the largest possible proportion is present in the container 11 and the smallest possible proportion is present in the chambers 2 and 3.

FIG. 3 shows the mass flows in the conduit 10 m_{KA} and $m_{KA'}$ in the case of power increase and power reduction and the mass flows m_A and m_B during the opening time A and B of the non-return valves 16 and 14. The areas above the zero lines show mass flows in the direction towards the chambers 2, 3 while the areas below the zero lines show mass flows into the container 11.

FIG. 4 and FIG. 5 show single-cylinder hot-gas engines wherein the hot and the cold chambers 2, 3 are separated from one another and adapted to be reduced and increased in size alternately by a displacement piston 18. The chambers 2, 3 of the cylinder 1 in these engines are connected to one another by way of the heater 8, the regenerator 7 and the cooling device 6. Relatively to the displacement piston 18, a working piston 19 operates in a phase-displaced manner, and is connected by way of a hollow piston rod 20 with a rhombic driving gear 21, like the piston rod 5 for the displacement piston 18. The working piston 19 separates a buffer chamber 22 from the cold chamber 3. These chambers are connected to one another in each case by way of an overflow valve 23, 24 respectively controlled at the stroke rhythm of the engine. The overflow valve 23 (FIG. 4) has the effect that the pressure p_P and $p_{P'}$ in the buffer chamber 22 is predominantly equal to or less than the pressure p_K and $p_{K'}$ respectively in the cold chamber 3.

This pressure pattern is shown in FIG. 6 and FIG. 7 together with the associated mass flows. In the power-increase phase shown in FIG. 6, that is to say when the shutoff valve 15 is opened, the gas flows out of the container 11 with the pressure p_P during the opening time A of the non-return valve 16 into the buffer chamber 22, and from there during the opening time C of the overflow valve 23 into the cold chamber 3.

In the power-reduction phase shown in FIG. 7 the overflow valve 23 remains closed. A mass flow simply occurs from the cold chamber 3 through the opened shutoff valve 12 during the opening time B of the non-return valve 14 into the container 11. On the other hand, the overflow valve 24 has the effect that the pressure p_P and $p_{P'}$ in the buffer chamber 22 is predominantly equal to or greater than the pressure p_K and $p_{K'}$ in the cold chamber 3.

This pressure pattern is shown in FIG. 8 and FIG. 9 together with the associated mass flows. In the power-increase phase shown in FIG. 8 the overflow valve 24 (FIG. 5), remains closed. A mass flow simply takes place from the container 11 through the opened shutoff valve 15 during the opening time A of the non-return valve 16 into the cold chamber 3.

In the power-reduction phase shown in FIG. 9, that is to say when the shutoff valve 12 is opened, gas flows from the cold chamber 3 during the opening time D of the overflow valve 24 into the buffer chamber 22, and from there during the opening time B of the non-return valve 14 into the container 11.

Therefore, the control of the engine shown in FIGS. 4, 5 is similar to principle to that of FIG. 1 with the difference that the mass flow during one of the two power-change phases in each case is effected by way of the buffer chamber 22.

In order to prevent unnecessary heat losses from the container 11 to the cold chamber 3 and to increase the controlling speed, the container 11 can be cylindrical in shape and can contain an easily movable piston 25 (FIG. 10) which, in the power-reduction phase, is in the vicinity of the mouth of the conduit 10, and in the power-increase phase in the vicinity of the mouths of the conduits 13, 17.

The almost complete separation of hot and cold gas in the container 11 can also be effected through partition means, e.g., in the form of a metal bellows 26 with a small aperture 39 (FIG. 11), the bottom or movable end 27 of which, in the power-reduction phase, is in the vicinity of the mouth of the conduit 10 and which, in the power-increase phase, is completely compressed.

Often it is sufficient to prevent the mixing of hot and cold gas. This can be effected by fitting a helical intermediate wall 28 (FIG. 12) into the container 11, which wall constitutes the partition means.

To prevent a mass flow which can be dispensed with in the case of constant load, the conduit 10 can be com-

pletely or partly closed at constant load. The corresponding apparatus is shown in FIG. **13.** There an example is also shown for the operation of the shutoff valves **12, 15** by means of a governor **29** driven by the hot-gas piston engine. When the rotational speed drops as the engine load increases, an axially slidable governor sleeve **30** moves downwards. A bell crank lever **31** is pivoted about a point **32** in the counter-clockwise direction and opens the valve **15** with its longer arm. A conventional coupling is provided on the shaft of the governor **29,** for actuating the shorter arm of the bell crank lever **31,** following the movements of the sleeve **30.**

As a result, the power output of the engine rises, so that the rotational speed again increases. When this speed exceeds a desired value, the shutoff valve **12** is opened by means of the lever **31.**

Any movement of the bell crank lever **31** from the illustrated middle position, in which both valves **12, 15** are closed, opens a valve **36** by means of a liquid cataract **33,** which behaves relatively to the movement almost like a fixed part, in opposition to the force of return springs **34** and **35,** which valve **36** is arranged in the conduit **10,** namely by pivoting of a lever **37** about a point **38.** The valve **36** can be closed in the middle position of the levers **31, 37** or slightly opened. After some time the springs **34, 35** return the lever **37** to the central position whether or not the lever **31** has returned to the middle position, and the cataract **33** behaves like a yieldable part.

It will be understood that the above description relates only to preferred, exemplary embodiments, while those skilled in the art will appreciate that various modifications and/or additions can be made, as defined by the spirit and scope of the invention.

What I claim is:

1. An apparatus for controlling the power of a hot-gas piston engine having a hot chamber and a separate cold chamber per cylinder; a piston displaceable in said cylinder for selectively and alternately increasing and reducing in size said chambers; a flow path for selectively connecting said hot chamber with said cold chamber of the same engine cylinder, and with another cylinder operating in a phase-displaced manner; said flow path including in succession a heater, a regenerator and a cooling device; a container operatively connected with said chambers; a flow-restricting conduit for connecting said hot chamber with said container; and two non-return valves for selectively connecting the interior of said container with said cold chamber; whereby the engine power is increased by connecting said interior with said cold chamber by way of one of said valves, which allows flow from said hot chamber by way of said container into said cold chamber, whereas the power is reduced when said interior is connected with said cold chamber by way of the other one of said valves, which allows flow from said cold chamber by way of said container into said hot chamber.

2. The control apparatus as defined in claim **1,** wherein said flow-restricting means is in the form of a capillary conduit which is closed when the load is constant.

3. The control apparatus as defined in claim **1,** further comprising means for changing the cross-section of said flow-restricting means, in depenendence on one of the size and the speed of at least one of large and rapid load changes, to provide a relatively large cross-section, but a relatively small cross-section when there is a constant load.

4. The control apparatus as defined in claim **1,** wherein said container is in the form of a cylinder in which a readily movable piston is situated.

5. The control apparatus as defined in claim **1,** further comprising movable partition means arranged in said container.

6. The control apparatus as defined in claim **5,** wherein said partition means is in the form of a bellows.

7. The control apparatus as defined in claim **5,** wherein said partition means is in the form of a helical intermediate wall.

8. An apparatus for controlling the power of a hot-gas piston engine having a hot chamber and a separate cold chamber per cylinder; a displacement piston movable in said cylinder for selectively and alternately increasing and reducing in size said chambers; a flow path for connecting said hot chamber with said cold chamber; said flow path including in succession a heater, a regenerator and a cooling device; a buffer chamber; a working piston separating said buffer chamber from said cold chamber, and being movable in a phase-displaced manner relative to said displacement piston; means for maintaining a mean pressure in said buffer chamber which is at most equal to that in said cold chamber; a container operatively connected with said chambers; a flow-restricting conduit for connecting said hot chamber with said container; and two non-return valves for selectively connecting the interior of said container with said buffer chamber; whereby the engine power is increased by connecting said interior with said buffer chamber by way of one of said valves, which allows flow from said hot chamber by way of said container into said buffer chamber, whereas the power is reduced when said interior is connected with said cold chamber by way of the other one of said valves, which allows flow from said cold chamber by way of said container into said hot chamber.

9. An apparatus for controlling the power of a hot-gas piston engine having a hot chamber and a separate cold chamber per cylinder; a piston displaceable in said cylinder for selectively and alternately increasing and reducing in size said chambers; a flow path for connecting said hot chamber with said cold chamber; said flow path including in succession a heater, a regenerator and a cooling device; a buffer chamber; a working piston separating said buffer chamber from said cold chamber, and being movable in a phase-displaced manner relative to said displacement piston; means for maintaining a mean pressure in said buffer chamber which is at least equal to that in said cold chamber; a container operatively connected with said chambers; a flow-restricting conduit for connecting said hot chamber with said container; and two non-return valves for selectively connecting the interior of said container with said cold chamber; whereby the engine power is increased by connecting said interior with said cold chamber by way of one of said valves, which allows flow from said hot chamber by way of said container into said cold chamber, whereas the power is reduced with said interior is connected with said buffer chamber by way of the other one of said valves, which allows flow from said buffer chamber by way of said container into said hot chamber.

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