Nov. 3, 1953 C. O. JONKERS ET AL 2,657,528

HOT GAS ENGINE ENCLOSING TWO THERMODYNAMIC CYCLES

Filed Nov. 29, 1949 2 Sheets-Sheet 1

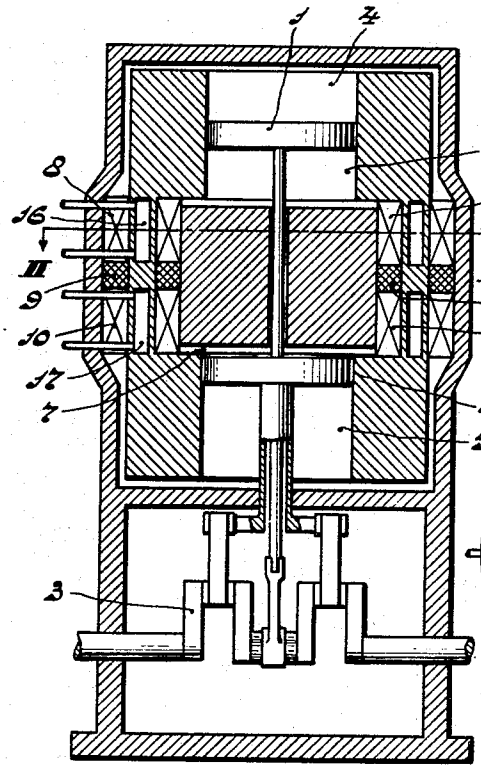


Fig. 1

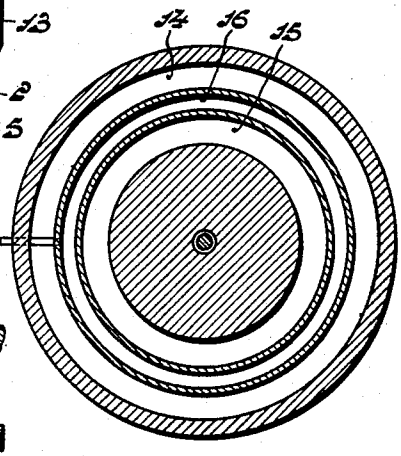


Fig. 2

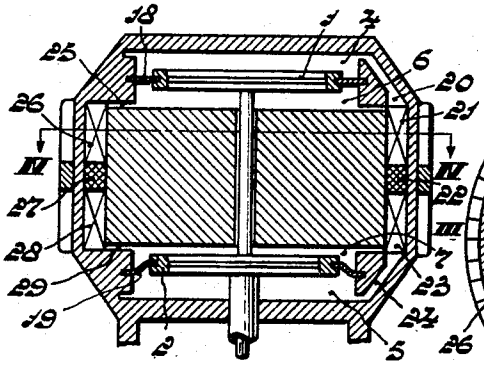


Fig. 3

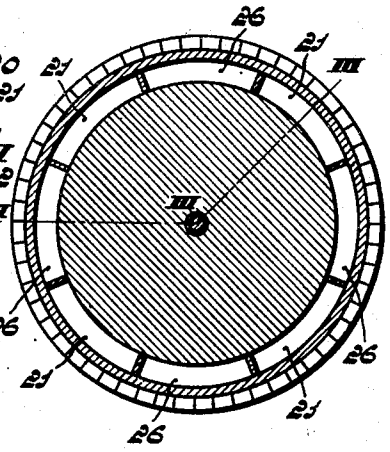


Fig. 4

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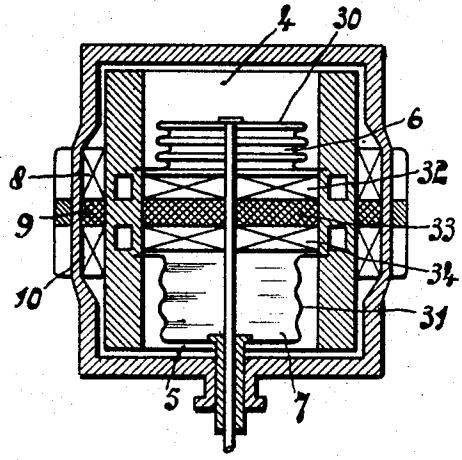


Fig. 5

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HOT GAS ENGINE ENCLOSING TWO THERMODYNAMIC CYCLES

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11 Claims. (Cl. 60—24)

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This invention relates to hot-gas engines in which at least two closed thermodynamic cycles are performed, the volumes of these cycles being varied by members moving with a suitable phase difference and at least two members acting upon two cycles, similar working spaces being provided on either side of the movable members. The term "hot-gas engine" is to be understood to include a refrigerator or a heat pump operating according to the reversed hot-gas engine principle.

In known hot-gas engines comprising reciprocating members, one cycle is, as a rule, acted upon solely by two members moving with a phase difference. The engine has in this case the advantage that no valves or slides are used, such as required, for example, in internal combustion engines and reciprocating steam engines. However, in hot-gas engines having one cycle, owing to the presence of the two movable members, absorption of energy due to friction during each cycle is comparatively high. A solution was found only with three- and multicycle engines in which the number of moving members was equal to the number of cycles. In order to provide an engine which is advantageous in structural respect, the working spaces above and below the pistons have hitherto been made different. The term "different" applied to working spaces is to be understood to mean working spaces, in the associated heat exchangers of which the mean directions of flow of heat between the working medium and the medium having thermal contact therewith are opposite. This means, consequently, that one space is a hot space and the other a cold space. In three- and multicycle engines the space above the movable member in one cylinder has hitherto been connected with the space below the movable member in another cylinder, whereas the space below the movable member in the first-mentioned cylinder is connected with the space above the movable member in a third cylinder. Thus, for example, hot spaces are provided above all movable members and cold spaces below the movable members, or conversely. In a three-cycle engine, the two remaining spaces in the first and the third cylinder are likewise connected with each other. Consequently, the number of cycles in such engines is equal to the number of moving members, so that the efficiency is comparatively high.

These engines, however, have the disadvantage that medium is liable to leak from the hot space to the cold space and conversely. This leakage of medium and the heat transmission through the

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wall of the cylinder and through the piston body between the two spaces produces a thermal leakage, so that the efficiency of the engine is adversely affected.

It is also known to construct a hot-gas reciprocating engine as a two-cycle engine, in which similar working spaces are provided on either side of the moving members.

The term "similar working spaces" is to be understood to mean working spaces in the associated heat exchangers of which the mean directions of flow of heat between the working medium and the medium having thermal contact therewith are the same. This means, consequently, that both spaces are hot or both spaces are cold spaces. However, the temperatures in these heat exchangers need not necessarily be the same.

In these hot-gas reciprocating engines of known type the moving members are provided with cylindrical envelopes, whilst one member, i. e. that having cold spaces on either side, is adapted to move in the envelope of the other moving member. Obturation of the space between the two moving members is effected on the side of the cold spaces.

This engine provides the possibility, in two-cycle engines, of having the two cycles acted upon by only two moving members.

However, this engine has a limitation in that the communication ducts between the hot and cold spaces are constituted by slots between a stationary wall and the wall of the envelope of a moving member, so that these boundary walls move relatively to one another.

This may involve a considerable thermal leakage along the heat exchangers, which may be provided in a slot. Since the channel associated with one cycle surrounds the channel associated with the other cycle, and since heat is supplied to and abstracted from the working medium from the outside, this supply of heat to or abstraction of heat from the working medium is not of a high order in the inner channel, so that the efficiency of the engine is furthermore adversely affected.

The object of the invention is to provide an improved hot-gas engine.

According to the invention, a hot-gas engine in which at least two closed thermodynamic cycles are performed, the volumes of these cycles being varied by members moving with a suitable phase difference, at least two members acting upon at least two cycles and similar working spaces being provided on either side of the movable members, is characterized in that the com-

munication ducts between the variable spaces associated with one cycle are bounded by fixed walls. Thermal leakage either through and along the movable member or along any heat exchangers to be housed in the ducts is thus substantially avoided.

A regenerator may be provided between the variable spaces associated with one cycle in the communication ducts, bounded by the fixed walls.

A heater, a regenerator and a cooler may be provided between the variable spaces of one cycle in the communication ducts bounded by fixed walls. This ensures that the heat exchange between the working medium and the cooling and heating mediums is of a high order.

If the members moving with a suitable phase difference are arranged to be co-axial, a construction may be realized, which is advantageous in structural respect.

One or more of the elements heater, regenerator and cooler, associated with one cycle may be co-axial with at least one or more similar elements associated with another cycle, one or more elements associated with the one cycle at least substantially surrounding one or more similar elements associated with the other cycle.

In a number of sections at right angles to the axis of a working space and taken through one of the elements heater, regenerator and cooler associated with one cycle, these sections preferably being divided over at least half the height of the element, both one of the sections of the element associated with the one cycle and a section of a similar element associated with the other cycle may be located on an annular strip.

The centre lines of the members moving with a suitable phase difference may be at an angle with one another.

At least one movable member may reciprocate without friction.

Where reference is made to a frictionless moving member, this is to be understood to mean that this movable member moves without or substantially without friction at the ordinary operating conditions. Any friction still occurring is, for example, materially lower than that which would occur with a piston with piston rings operating at the same conditions. Any friction still occurring may be constituted by external friction (friction of two bodies along each other) or by internal friction. The last-mentioned friction is produced, for example, if the reciprocating member or part thereof is periodically deformed. In the engine according to the invention, it is of particular importance that the movable members between heated spaces can move without friction, since in refrigerators the energy produced by the friction of piston rings may adversely affect the efficiency of the engine, even to an extent such that in a given case the absorption of heat from the volume to be cooled by the engine becomes very small or even nil. In hot-gas engines it may be important that the movable members having heated spaces on either side should have no piston rings, since lubrication of piston rings at high temperatures becomes very difficult.

Several constructions of movable members reciprocating without friction are possible. In one embodiment of the hot-gas engine according to the invention, the obturation of the space between this movable member and the wall of the cylinder consists of a flexible elastic material, such as rubber, which is secured between the

cylinder wall and the movable member, a certain amount of play being left between the movable member and the cylinder wall. Thus, frictional losses may be reduced and leakage losses may be substantially avoided.

It is particularly advantageous if, in the aforesaid case, the hot-gas engine according to the invention comprises a movable member which is constructed in the form of a diaphragm.

In a further embodiment of the invention, the movable member made of a flexible elastic material is constructed in the form of bellows.

Lubrication of the movable members may be dispensed with in the said embodiments. The embodiments may be used with particular success, if the temperatures prevailing in the working spaces on either side of the member are neither particularly high nor particularly low.

The obturation of the space between a movable member and the wall of the cylinder may be constituted by a labyrinthine slot.

In order that the invention may be more clearly understood and readily carried into effect, it will now be described more fully with reference to the accompanying drawings, given by way of example, in which

Fig. 1 shows a hot-gas engine comprising pistons without piston rings, in which the heater, the cooler and the regenerator associated with one cycle surround the heater, the regenerator and the cooler associated with the other cycle and

Fig. 2 is a cross-sectional view taken on the line II—II of Fig. 1;

Fig. 3 is a sectional view, taken on the line III—III—III of Fig. 4, of a refrigerator comprising two pistons, the space between the pistons and the cylinder wall being obturated by rubber. The heater, the regenerator and the cooler associated with one cycle are housed in the same annular space as the heater, the regenerator and the cooler associated with the other cycle.

Fig. 4 is a sectional view taken on the line IV—IV of Fig. 3; and, finally,

Fig. 5 shows a hot-gas engine comprising bellows, the heat exchangers and the regenerator associated with one cycle being arranged in the space between the bellows.

Referring now to Figs. 1 and 2, a piston 1 and a piston 2 are adapted to move with a suitable phase difference the pistons co-operating with a crank shaft 3. The pistons 1 and 2 are not provided with piston rings and reciprocate in the cylinders with a small amount of play. One cycle is performed in working spaces 4 and 5 and the other in working spaces 6 and 7. The working space 4 communicates through an annular heater 8, a regenerator 9 and a cooler 10 with the working space 5, and the working space 6 communicates through a heater 11, a regenerator 12 and a cooler 13 with the working space 7. The heater 8, the regenerator 9 and the cooler 10 are housed in an annular space 14 and surround heater 11, regenerator 12 and cooler 13, which are housed in an annular space 15. Between the two annular spaces 14 and 15, at the level of the heaters, is a third annular space 16 in which a heating medium circulates. Between the annular spaces, at the level of the coolers, is an annular space 17 in which a cooling medium circulates. Consequently, in this embodiment both the working space 4 and the working space 6 are hot spaces, whereas the working spaces 5 and 7 are cold spaces.

In Figs. 3 and 4 the same reference numerals

designate parts corresponding to those of the engine in Fig. 1. In this engine the piston 1 and the piston 2 are adapted to reciprocate each piston being provided with a rubber ring 18, 19 respectively, obturating the space between the wall of the cylinder and the piston. Owing to the securing of each rubber ring both to the cylinder wall and to a piston, the stroke of the pistons cannot be large and, consequently, the surface of the piston-like bodies is made large. The working space 4 communicates by way of a channel 20, a heater 21, a regenerator 22, a cooler 23 and a channel 24 with the working space 5, and the working space 6 communicates by way of a channel 25, a heater 26, a regenerator 27, a cooler 28 and a channel 29 with the working space 7. As may be seen from Fig. 4, a sectional area at right angles to the axis of the working space comprises both heaters for the medium contained in the working spaces 4 and 5 and heaters for the medium contained in the working spaces 6 and 7. Here 21 designates the heater elements associated with one cycle and 26 the heater elements associated with the other cycle. It is obvious that the number of elements may be chosen at will, it may, for instance, be desirable to provide thick walls between the various heater elements in which case the annular space may be divided into two parts, one part comprising the heater elements associated with one cycle and the other part comprising the heater elements associated with the other cycle. The pistons may co-operate with a crank-shaft in a manner similar to that shown with reference to the crank-shaft 3 in Fig. 1.

In Fig. 5, the same reference numerals designate parts corresponding to those of the engine of Figs. 1 and 3. This engine comprises two sets of bellows 30 and 31, which are adapted to reciprocate with the use of a crank-shaft similar to the crank-shaft 3 shown in Fig. 1. The working space 4 communicates by way of the heater 8, the regenerator 9 and the cooler 10 with the working space 5 and the working space 6 communicates by way of a heater 32, a regenerator 33 and a cooler 34 with the working space 7. The working spaces 4 and 6 and the working spaces 5 and 7 are similar. Here the working spaces 4 and 6 are hot spaces, and the working spaces 6 and 7 cold spaces.

It will be obvious that the invention may be applied, for example, with an engine in which the centre lines of the members moving with a suitable phase difference are at an angle to one another. Even if these centre lines are parallel to one another, several different constructions may be used successfully. Furthermore, each piston rod may be provided with a plurality of pistons. This provides that more than two cycles can be performed in the engine.

What we claim is:

1. A hot-gas engine in which two closed thermodynamic cycles are performed comprising a casing formed with two openings therein, a working medium for each cycle, a member in each of said openings acting on the working medium of both cycles and forming working spaces on each side thereof, said working medium in the working spaces on each side of said member being substantially the same temperature, and ducts bounded by fixed walls connecting the working spaces of each cycle.

2. A hot-gas engine in which two closed thermodynamic cycles are performed comprising a casing formed with a first and second opening therein arranged in tandem, a working medium for each cycle, a member in each of said openings acting on the working medium in both cycles, said member forming working spaces on each side thereof in each opening, said working medium in the working spaces on each side of said member being substantially the same temperature, and duct means bounded by fixed walls connecting a space on one side of the member in said first opening to a space on one side of the member in the second opening and the other space in said first opening to the other space in said second opening.

3. A hot-gas engine in which two closed thermodynamic cycles are performed comprising a casing formed with a first and second opening therein arranged in tandem, a working medium for each cycle, a reciprocating member in each of said openings acting on the working medium of both cycles, means to reciprocate said members with a phase difference, each of said members forming working spaces on each side thereof in each opening, said working medium in the working spaces on each side of each of said members being substantially the same temperature, and duct means bounded by fixed walls connecting a space on one side of the member in said first opening to a space on one side of the member in the second opening and the other space in said first opening to the other space in said second opening.

4. A hot-gas engine in which two closed thermodynamic cycles are performed comprising a casing formed with a first and second opening therein arranged in tandem, a working medium for each cycle, a reciprocating member in each of said openings acting on the working medium of both cycles, a common crankshaft for reciprocating said members, a crank on said crankshaft connecting one member to said crankshaft, a second crank out of phase with said first crank connecting the other member to said crankshaft, said member forming working spaces on each side thereof in each opening, and duct means bounded by fixed walls connecting a space on one side of the member in said first opening to a space on one side of the member in the second opening and the other space in said first opening to the other space in said second opening.

5. A hot-gas engine in which two closed thermodynamic cycles are performed comprising a casing formed with a first and second opening therein arranged in tandem, a working medium for each cycle, a member in each of said openings acting on the working medium in both cycles, said member forming working spaces on each side thereof in each opening, said working medium in the working spaces on each side of said member being substantially the same temperature, first and second duct means bounded by fixed walls connecting a space on one side of the member in said first opening to a space on one side of the member in the second opening and the other space in said first opening to the other space in said second opening respectively, both said duct means having herein a heater, a regenerator and a cooler.

6. A hot-gas engine in which two closed thermodynamic cycles are performed comprising a casing formed with a first and second cylindrical opening therein arranged in tandem, a working medium for each cycle, a piston member in each of said cylindrical openings with a small amount of clearance between the piston and the cylinder walls, said piston member acting on the work-

ing medium in both cycles, said piston member forming working spaces on each side thereof in each opening, said working medium in the working spaces on each side of said piston member being substantially the same temperature, first and second duct means bounded by fixed walls connecting a space on one side of the member in said first opening to a space on one side of the member in the second opening and the other space in said first opening to the other space in said second opening respectively, both of said duct means having therein a heater, a regenerator and a cooler.

7. A hot-gas engine in which two closed thermodynamic cycles are performed comprising a casing formed with first and second cylindrical openings therein arranged in tandem, a working medium for each cycle, a member in each of said openings acting as the working medium in both cycles, said member forming working spaces on each side thereof in each opening, first duct means bounded by fixed walls connecting a space on one side of the member in said first opening to a space on one side of the member in the second opening, second duct means concentric with said first duct means connecting the other space in said first opening to the other space in said second opening, both said duct means having therein a heater, a regenerator and a cooler with the three latter elements in said first duct means surrounding the corresponding element in said second duct means.

8. A hot-gas engine in which two closed thermodynamic cycles are performed comprising a casing formed with first and second cylindrical openings therein arranged in tandem, a working medium for each cycle, a member in each of said openings acting on the working medium of both cycles, said member forming working spaces on each side thereof in each opening, first duct means bounded by fixed walls connecting a space on one side of the member in said first opening to a space on one side of the member in the second opening, second duct means connecting the other space in said first opening to the other space in said second opening, both of said duct means being annular and concentric and having therein a heater, a regenerator and a cooler with the three latter elements in said first duct means surrounding the corresponding element in said second duct means, an annular space between said heater elements and an annular space between said cooler elements supplied with hot and cold fluid respectively.

9. A hot-gas engine in which two closed thermodynamic cycles are performed comprising a casing formed with a first and second cylindrical opening therein arranged in tandem, a working medium for each cycle, a movable member in each of said cylindrical openings acting on the working medium in both cycles, a flexible, resilient material element secured to both said member and the cylinder wall and forming a closure therebetween, said member forming working spaces on each side thereof in each opening, first and second duct means bounded by fixed walls connecting a space on one side of the member in said first opening to a space on one side of the member in the second opening and the other space in said first opening to the other space in said second opening respectively, both of said duct means having therein a heater, a regenerator and a cooler.

10. A hot-gas engine in which two closed thermodynamic cycles are performed comprising a casing formed with a first and second cylindrical opening therein arranged in tandem, a working medium for each cycle, a movable member in the form of a diaphragm in each of said cylindrical openings acting on the working medium in both cycles, said member forming working spaces on each side thereof in each opening, a plurality of duct means, said duct means being partially formed in an annular space provided with partitions, each of said duct means having a heater, a regenerator and a cooler in said annular space, alternate duct means in said annular space connecting corresponding working spaces of each thermodynamic cycle.

11. A hot-gas engine in which two closed thermodynamic cycles are performed comprising a casing formed with a first and second opening therein arranged in tandem, a working medium for each cycle, a movable bellows member in each of said openings acting on the working medium in both cycles, said member forming working spaces on each side thereof in each opening, first and second duct means bounded by fixed walls connecting a space on one side of the member in said first opening to a space on one side of the member in the second opening and the other space in said first opening to the other space in said second opening respectively, said first and second duct means each having therein a heater, a regenerator and a cooler.

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