

[54] **DOUBLE-ACTING GAS MULTI-CYLINDER  
EXTERNAL COMBUSTION ENGINE**

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[51] Int. Cl. .... **F03g 7/06**

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60/526

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[57] **ABSTRACT**

To provide an engine construction in which both the hot gas connections and the cold gas connections will not differ in length and will be short, the operating piston-cylinder units are aligned in a row and the regenerator-cooler units are disposed in two rows flanking the cylinder rows. The heater tubes forming part of the hot gas connections form one or more walls of tubes disposed above the cylinders, and a combustion chamber can be arranged to apply heat to these tubes in the upper part of the engine. Engines of various sizes may be built out of identical units comprising a cylinder, a regenerator cooler and a hot gas connection.

**20 Claims, 6 Drawing Figures**

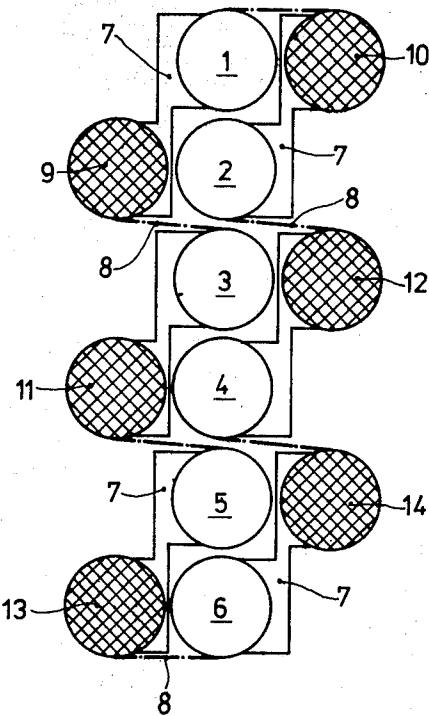


Fig. 1

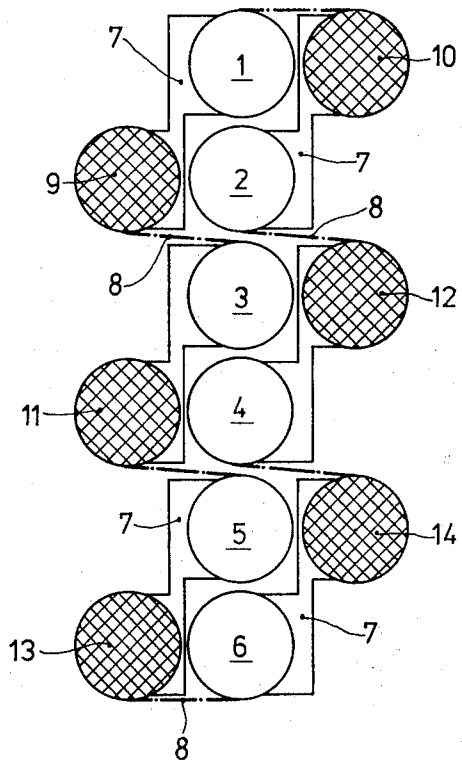


Fig. 2

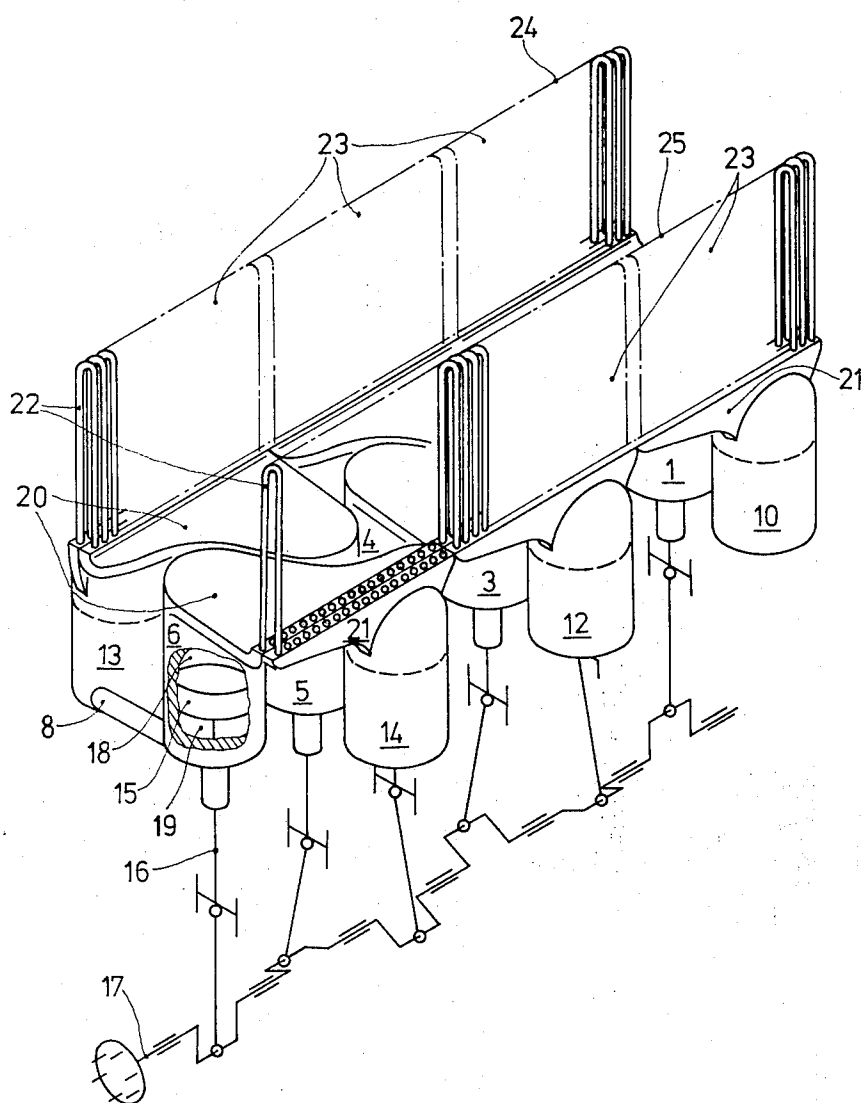


Fig. 3

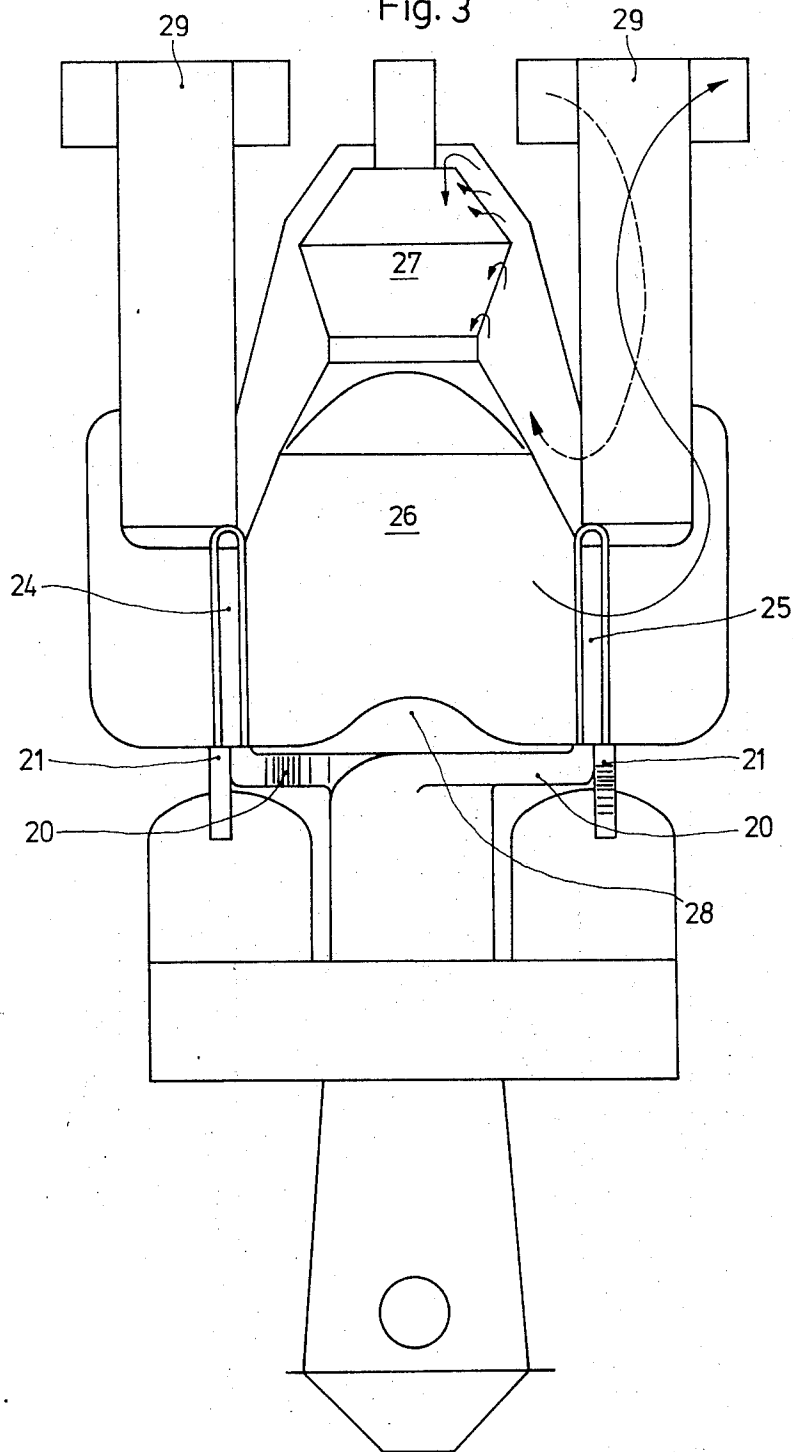


Fig. 4

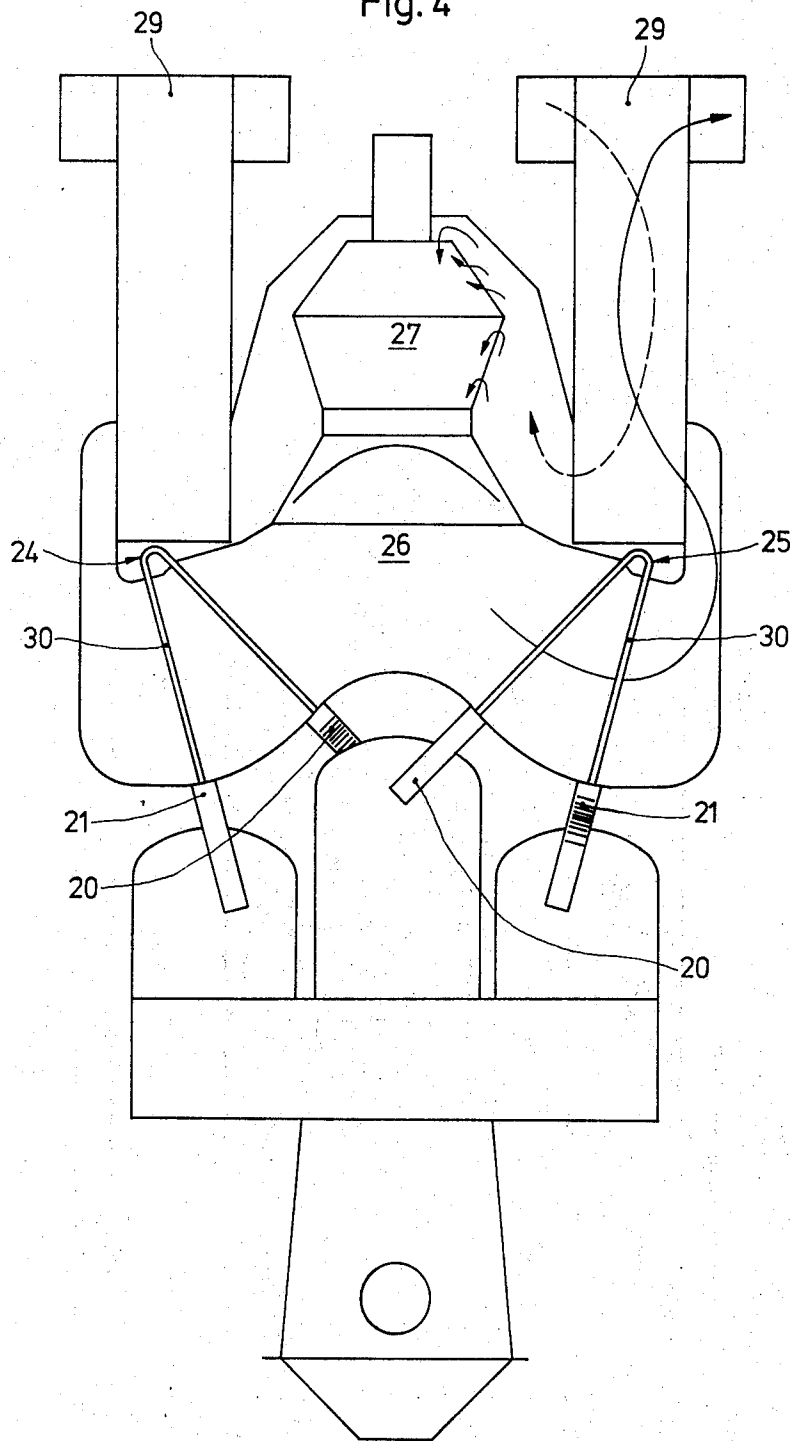


Fig. 5

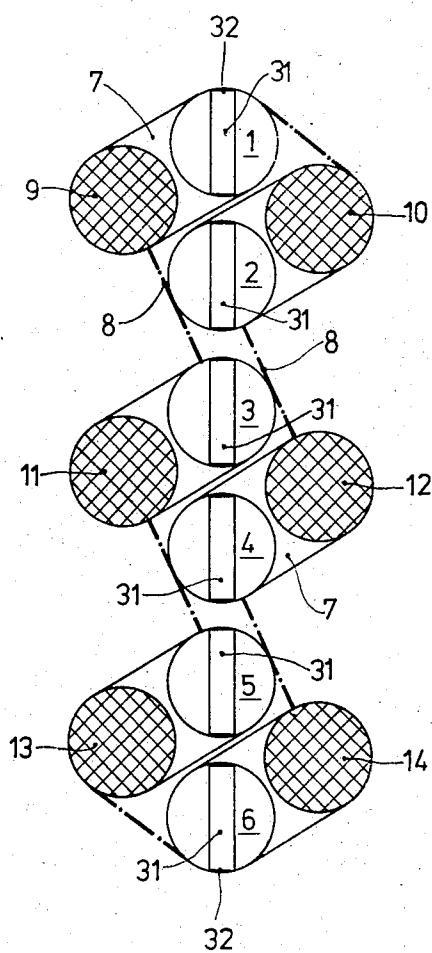
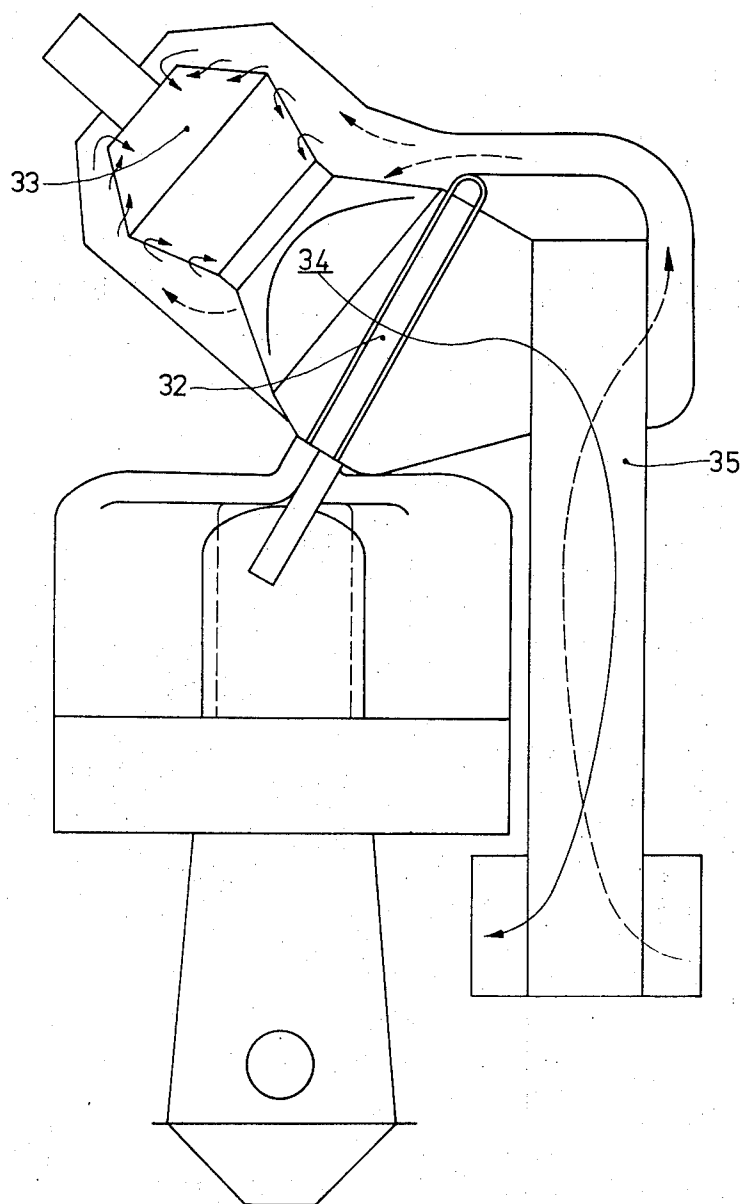


Fig.6



## DOUBLE-ACTING GAS MULTI-CYLINDER EXTERNAL COMBUSTION ENGINE

Cross reference to related applications: U.S. Ser. No. 346,107 filed Mar. 29, 1973. Cross reference to related applications: U.S. Ser. No. 315,930 filed Dec. 18, 1972.

U.S. Ser. No. 317,778 filed Dec. 22, 1972.

This invention concerns a double-acting multi-cylinder gas engine of the external combustion type in which the cylinders are in line and each is connected over a hot gas connection to a regenerator which in turn is connected, through a cooler and a cold gas connection, to the cold space of another cylinder which is either the adjacent cylinder or one next beyond the adjacent cylinder.

Double-acting thermal gas piston engines of the external combustion type are known from German patent 802,486 and the corresponding U.S. Pat. No. 2,611,235, so that the general construction and the principle of operation of such engines is known. Little is known, however, regarding favorable arrangements of the heater, regenerator and cooler of such an engine. The question of the disposition and length of the gas connections in the hot and cold regions and between connected cylinders are extremely important for the efficiency and safety of the entire engine.

It is an object of this invention to provide an arrangement of the gas connections and of the heater, regenerator and cooler, in relation to the cylinders of an external combustion engine which is highly efficient, compact, economical and safe. In particular it is an object of the invention to provide such an engine with short cold gas connections of approximately equal length and likewise short hot gas connections of approximately equal lengths.

### SUBJECT MATTER OF THE PRESENT INVENTION

Briefly, each regenerator is housed with a cooler in a common casing and these casings are disposed in two rows which flank the single row of cylinders on both sides. The two rows of these casings each contain the same number of casings and they may be relatively staggered longitudinally, although in any case these two rows overlap in large part. These casings and their contained units form part of interconnecting means, including a hot gas connection and a cold gas connection, which interconnect the hot working space of one cylinder with the cold working space of another cylinder, which is either the next cylinder, when the last mentioned cylinder is at the end of the cylinder row, or the after-next cylinder in all other cases. In every case the combination of cylinder, hot gas connection and regenerator-cooling casing has the same configuration. Only in the cold gas connection is there a difference in the configuration for the connection at the end of the cylinder row and the connections within the cylinder row, and even that difference is very small and does not involve a substantial difference in the length of the connection. In consequence, engines with different numbers of cylinders in the cylinder row can all be built with identical cylinder-heater-regenerator-cooler modules, while maintaining in each case equality of the gas connection lengths, thus keeping to a minimum the so-called dead space and greatly reducing the energy losses related to gas flow.

The two rows of regenerator casings flanking the row of cylinders are preferably parallel and of the same length and may be opposite each other or staggered, in the latter case by not more than one cylinder unit space. The hot gas connections are provided with arrays of heater tubes interposed between suitable manifolds. The heater tubes are in two-leg form with one leg either returning parallel to the other or disposed at a diverging angle. The tubes are arranged in parallel arrays forming one or more walls of parallel tubes which may be disposed around or across a common combustion chamber located above the cylinders, regenerators, etc. In this combustion chamber, one or more burners may act on the heater tubes. One burner may apply heat to more than one heater tube array or even to the arrays of heater tubes of more than one hot gas connection, so that the choice of the number of burners is independent of the number of heater tubes or of unit heater tube arrays.

In a particularly useful arrangement, the axis of the cylinder and that of the regenerator casing connected to it by the hot gas connection are parallel to each other, and in the assembled engine the respective planes so defined by the cylinder and regenerator casing axes of each module are parallel to each other and are all oblique to the plane containing the axes of all the cylinders.

It is advantageous to associate alternate members of the cylinder row with different regenerator casing rows, which is to say that if the cylinders are sequentially numbered in line, it is desirable to connect the even numbered cylinders by hot gas connections to the regenerators on one side of the cylinder row and to connect the odd numbered cylinders by hot gas connections to the regenerators on the other side. By this alternating arrangement of the regenerator casings room is provided for heater means of extended dimensions composed of long arrays of many heater tubes, disposed so as to form continuous heater tube walls above each of the regenerator casing rows. In this embodiment of the invention, it is feasible to provide relatively short heater tubes that are easily made by casting. This configuration has the further advantage of reducing the height of the engine and providing a desirable low profile.

The invention will be described by way of example with reference to the accompanying drawings, wherein:

FIG. 1 is a plan view diagram of an embodiment of the invention;

FIG. 2 is a perspective view of the embodiment shown in FIG. 1;

FIG. 3 is a cross-sectional view of the embodiment shows in FIGS. 1 and 2;

FIG. 4 is a cross-sectional view of another embodiment of the invention corresponding to FIG. 1;

FIG. 5 is a diagrammatic plan of another embodiment of the invention, and

FIG. 6 is a cross-section of the embodiment shown in FIG. 5.

The in-line motor shown in FIG. 1 has six cylinders, 1-6, arranged in a straight row. Each cylinder contains a hot and a cold working space. The hot space of a first cylinder is connected for cooperation with the cold space of another cylinder, and so on, to provide the necessary engine work cycle. The flow path between a hot and a cold working space for the working medium

that flows back and forth is completed by hot gas conduits connected to the hot work space and cold gas conduits connected to the cold work space.

In the example shown in FIG. 1, the hot conduits 7 are each shown diagrammatically by lines enclosing a space. The cold conduits 8 are diagrammatically shown with dot-dash lines. Each hot conduit 7 connects the hot space of a cylinder with a regenerator that is housed in a common casing with a cooler with which it connects. The cooler is connected by a cold conduit 8 with the cold working space of another cylinder.

The casings each containing a regenerator and a cooler are designated with reference numerals 9 to 14. These casings are arranged in two parallel rows, one on each side of the cylinder row. The casings 9, 11 and 13 are connected by hot conduits 7 with the odd numbered cylinders and the casings 10, 12 and 14 of the other row are similarly connected to the even numbered cylinders. Each of the casings 9-14 stands opposite to a cylinder which is next to the cylinder with which the casing is connected by the hot conduit 7. Thus, the casing 9 associated with the cylinder 1 is disposed laterally opposite cylinder 2, and the casing 14 associated with cylinder 6 stands laterally next to cylinder 5. The offsetting of the casings with respect to the associated cylinders thus corresponds to one cylinder unit space. The casings of one casing row are offset in the same direction with respect to the cylinders to which they are connected by a hot conduit, and the offsets of the two rows are in opposite directions. In consequence, the two rows of casings are staggered by one cylinder unit space, so that each casing of a casing row stands opposite the gap between two casings in the other casing row.

In this arrangement each combination of cylinder, hot conduit and casing has the same configuration, so that component parts of the same configuration may be used for all of these modules. In the arrangement of FIG. 1, these modules are used in interlocking orientations. Each module can accordingly be preassembled and individually stored, so that as needed they may be combined quickly and simply for the assembly of motors of different numbers of cylinders.

The two end cylinders 1 and 6 are provided with cold conduits 8 running perpendicularly to the longitudinal axis of the cylinder row to connect respectively with casings 10 and 13 which are located laterally opposite the end cylinders. The other cold conduits 8 providing the connections between the aforementioned modules are all parallel, but are oblique, being somewhat off the perpendicular, with respect to the longitudinal axis of the engine. It is simple to choose the lengths of the cold conduits so that those connected to the end cylinders are of the same lengths as those connected to the other cylinders, and so that all the cold conduits have the same lengths. Since only neighboring modules are connected by the cold conduits, both in the middle and at the ends of the row, and since the modules are simply offset or turned around with respect to each other, it is possible to use very short cold conduits 8. As the result of the small volume of the flow paths thus obtained in the individual work cycle combinations interconnecting the cold space of one cylinder with the hot space of another, it is possible in this way to reduce greatly the so-called dead spaces and to obtain an increase of the overall efficiency of the machine. A reduced quantity of the flow medium, moreover, will then suffice to fill

all the individual work cycle units of the machine completely. This arrangement, finally, has the further advantage of providing non-interfering paths for the cold conduits. It is not necessary to distort the paths of these conduits to pass them around each other. This means also that the engine is easy to assemble in a gas-tight fashion, because of the substantially straight and short cold conduits that make the operative connections between the modules. The equality in the lengths of the cold gas connections not only makes possible economies in the production of these components, but simplifies the assembly, just as the identical configuration of each module and of its component part produces economies in parts cost and in assembly work. The number of casting patterns involved, for example, is greatly reduced. Storage space requirements for parts is reduced because of the smaller number of different parts involved.

Because all the operative parts of a thermal gas engine must be soldered or screwed together in gas-tight fashion, a readily grasped functional pattern and good accessibility for assembly is unusually important. Furthermore, it is possible with this sort of a piping plan, where there are no cross-overs of the cold conduits, to provide manifolds at the cold side of the casing containing a cooler and a regenerator, between the cooler and the cold conduit, so as to obtain favorable flow characteristics in the neighborhood of the cold conduits. Then, because all of the cold conduits have the same length, the distribution of the load among cylinders does not get out of balance, a factor which contributes to the increased efficiency of the whole machine.

The principle of operation of a double-action thermal gas piston engine, as already mentioned, is described in U.S. Pat. No. 2,611,235. The construction of the pistons and cylinders, as well as connections through the crankshaft is shown in copending patent application U.S. Ser. No. 315,930, filed Dec. 18, 1972, the disclosure there, however, being a V engine rather than an in-line engine. Briefly stated, the medium is heated and caused to expand while most of it is on the warm side of the regenerator and it is then caused to flow through the regenerator which stores a large part of the heat and then through the cooler, after which, when most of the medium is on the cold side of the regenerator, its pressure falls, so that it causes the piston on the cold side to reduce the cold working space, this providing the double-action, for at the same time hot gas is expanding on the other side of that piston. In order that there may be expansion and contraction of the medium in such a system without the provision of auxiliary pistons, the gas on the cold side of the regenerator during the time most of the gas handled by that regenerator is on the hot side of it is working with a piston moving slowly near its dead spot, while the larger portion of gas is hot and expanding against a piston near the middle of its stroke. The converse holds when most of the gas is on the cold side. The amount of relative displacement of the piston cycles of the various cylinders is one of the elements of the design of the engine. In the example shown in FIG. 2, as may be seen from the crankshaft 17, the six cylinders have their strokes evenly staggered in flow connection sequence so as to provide substantially uniform transmission of power to the crankshaft.

The form of the hot conduits 7 can be particularly well seen in FIG. 2. Each cylinder has a piston 15 which is connected with a diagrammatically shown crankshaft 17 by means of a likewise schematically drawn piston rod 16. In this case the hot working space 18 is above the piston 15, while the cold working space 19 is below the piston. The operating medium, a gas chosen for its heat transfer and other physical characteristics, flows from the hot working space 18 of a first cylinder, for example cylinder 6, over the hot conduits 7, which comprises the manifolds 20 and 21 as well as the heater tubes 22, through a regenerator and a cooler, which in this case are in the casing 14, then over the cold conduits 8 to the cold working space 19 of a further cylinder, in this case the cylinder 4. The hot working spaces 18 of the cylinders 1 to 6, all communicate with their respective manifolds 20 which extend horizontally towards the appropriate one of the casings 9 to 14. In the neighborhood of this regenerator casing, the wide end of the manifold 20 meets the wide end of a manifold 21 rising in a vertical plane. The manifold 20 is turned up at its wide end, so that the wide ends of the manifolds 20 and 21 are adjacent side by side over a long length. Here these manifolds are connected with an array of heater tubes 22 that are bent in U-shape with two relatively long legs, so that the passage through all these heater tubes connects the two manifolds and permits the gas to flow from one to the other therethrough. The heater tubes 22 in a connection between a particular cylinder, for example cylinder 6, with an associated regenerator and cooler contained in a common casing, for example the casing 14, forms a heater unit 23.

As the result of the projecting and fanned out shape of the manifolds 20 and 21, and by the provision of the heater tubes 22 as an array of identical components, the result is obtained that all of the branch streams flowing through the respective heater tubes have approximately the same total flow path length. That has the advantage of avoiding local overloading of the heater 23, that is, thermal overloading of particular heater tubes 22, so that the operating temperature of the heaters can be brought close to the upper limit set by the characteristics of the material of which the heater tubes are made.

The several heaters 23 associated with the respective regenerator casings 9 to 14, above which they are located, form two continuous heater tube walls 24 and 25, which run parallel to each other over the full length of the engine. The space above the cylinders 1 to 6 included between the two heater tube walls 24 and 25 and provides a convenient place, as further described below, for the location of a longitudinally extending combustion chamber from which heat can be applied to both heater tube walls.

FIG. 3 shows how a combustion chamber 26 can be provided between the two heater tube walls 24 and 25. The combustion chamber 26 is fired by a burner system 27, which projects a flame from above down into the combustion chamber 26. A heat shield 28 is located on top of the cylinder array, as a fire wall separating the engine from the combustion chamber 26, so as to avoid overheating of the components located below the combustion chamber. As already mentioned above, the combustion chamber 26 extends longitudinally over the whole length of the engine. The number of the burners forming the burner system 27 can accordingly

be independent of the number of the heaters 23 and can be determined simply with reference to burner efficiency. In a particularly simple embodiment, a single burner can be quite sufficient to provide the necessary heat for the engine.

The combustion product gases issuing from the combustion chamber 26, having already given up a major portion of the heat to the heater 23, flow through a preheater 29 located above the two heater tube walls 24 and 25, where the combustion products give up a further portion of their heat to the supply of combustion-supporting air which flows countercurrent through the preheater 29 on its way to the burner system 27. The combustion products then issue to the atmosphere upon discharge from the preheater 29. An advantage of external combustion engines such as the present embodiment is that the combustion can be completely carried out in the engine, so that the gases issuing to the atmosphere will be substantially free of noxious components. The path of the exhaust gases through the preheater is shown in FIG. 3 by a continuous arrow, while that of the fresh air needed for combustion is shown by a dashed arrow. As a rule the fresh air is supplied to the combustion system 27 by a blower, not shown in this drawing.

In the embodiment of the invention shown in FIG. 4, the heater tube walls 24 and 25 are formed of heater tubes 30 spread out in V-shape. In this case the hot gases have their direction of flow more gradually changed in the neighborhood of the heater tube walls 24 and 25, so that favorable flow characteristics are obtained. The manifolds 20 and 21 in this case are disposed in the same direction as the legs of the V-shaped heater tubes to which they are connected, so that energy losses as the result of sharp changes of direction of the gas flow are also minimized for the flow of the working medium through the heater tubes 30. Furthermore, in the design of FIG. 4 the bending moment of the heater tubes, as the result of the difference in expansion of the leg facing the flames compared to the leg away from the flames, is substantially reduced. Instead of the downwardly directed burner system 27, there could be located directly above the cylinder array a burner system where combustion starts from below and extends upwardly. In such a case the heater tube walls 24 and 25 could then be inclined inwardly to form a sort of roof over the burner, incidentally reducing the height of the machine as a whole.

FIG. 5 shows another embodiment of the invention in which the row formed by the casings 9, 11 and 13 and the row formed by the casings 10, 12 and 14 are not relatively offset in their positions on the two sides of the cylinder row 1-6. The casings 9 and 10 respectively associated with the cylinders 1 and 2 are located opposite each other in the region of the gap between the cylinders 1 and 2. The casings 11 and 12 are similarly located in the neighborhood of the gap between cylinders 3 and 4, and casings 13 and 14 likewise by the gap between cylinders 5 and 6. The hot conduits 7 again lead from the hot working space of a cylinder, through the casing of the same module which contains a regenerator and a cooler, from which the cold conduits 8 leads to the cold working space of another cylinder. The connection plan of the casings of the two flanking casing rows to the particular cylinders is the same as in the previously mentioned example shown in FIG. 1: thus the odd numbered cylinders 1, 3 and 5 are

connected by hot conduits 7 to the casings 9, 11 and 13 of one casing row and the even numbered cylinders 2, 4 and 6 are connected by hot conduits to the casings 10, 12 and 14 of the other casing row. In this case as well as in the case of FIG. 1, it is clear that the disposition of the hot conduits 7 and that of the cold conduits 8 could be interchanged, provided attention is paid to the fact that there is not more than one cylinder between two cylinders connected with casings of the same row and that the end cylinders of the cylinder row are connected by an applied conduit and through a regenerator to the next cylinder in the row. The direction of rotation of the crankshaft would then be simply reversed in this case. In the arrangement of FIG. 5 the heaters 31 associated with the hot conduits 7 are located above the cylinder row and form continuous heater tube wall 32 extending over the length of the engine.

As shown in more detail in FIG. 6, the heater tube wall 32 formed of the heaters 31 can with advantage be made inclined to one side, although of course a vertical disposition of the heater tube wall is also conceivable. In the inclined arrangement shown in FIG. 6 a space saving can be obtained by allowing the external combustion system 33 to project to one side, so that it discharges the hot gases perpendicularly to the plane of the heater tube wall 32. In this way the hot gases coming out of the combustion chamber 34 flow straight through the heater tube wall 32 without any previous change of direction. In this version of the engine of this invention, a preheater 35 is also used in which the fresh air needed to support combustion is preheated. The preheater 35 is provided at the side of the engine in this case. Of course in this case also the combustion chamber 34 and the preheater 35 can be made to occupy spaces extending along the full length of the engine.

The advantage of the embodiment just described is particularly that only one heater tube wall is provided, saving the expense for an additional heater tube wall. In this case, however, longer heater tubes must be provided in order to supply sufficiently large heat transfer surfaces. In the example shown in FIGS. 1-4, in which two heater tube walls are provided in each case, the heater tubes can, on the other hand, be made relatively short, which is a favorable factor for the overall shape of the machine, since it reduces the necessary height. The thermal gas motors above described in each case have six cylinders. Obviously, the invention here described can also be used in thermal gas engines with different numbers of cylinders, for example 4 or 8. In the particular case of an odd number of cylinders, all but one of the regenerator-cooler casings can be disposed in two rows flanking the cylinders and the odd one can be aligned with the cylinder row beyond one end of the cylinder array. This is an alternative for having the rows of casings of different lengths when there is an odd number of cylinders.

I claim:

1. A double-acting thermal gas piston engine having a plurality of cylinders successively adjacent in a straight row, each cylinder having a hot working space and a cold working space, comprising:

interconnecting means between the hot working space of each cylinder and the cold working space of another cylinder, said means including a hot conduit connected to said hot working space, a cold conduit connected to said cold working space

and a regenerator and a cooler interposed in series between said hot conduit and said cold conduit in such a way that said regenerator is connected to said hot conduit and said cooler is connected to said cold conduit, said regenerator and said cooler of each interconnecting means being contained in a common casing (9,10,11,12,13,14);

said interconnecting means being so disposed that said row of cylinders (1,2,3,4,5,6), at least in the longitudinal direction, is flanked by two at least partly overlapping rows (9,11,13 and 10,12,14) of said casings, that the end cylinders (1,6) of said row are connected to the end casings (9,10 and 13,14) of said two rows of casings, and that the inner cylinders (2,3,4,5) of said row are connected to two adjacent casings of the same casing row.

2. A double-acting thermal gas piston engine as defined in claim 1, in which said rows of casings (9,11,13 and 10,12,14) are disposed parallel to each other, are of the same length and are offset with respect to each other by not more than one cylinder space of said cylinder row.

3. A double-acting thermal gas piston engine as defined in claim 1, in which said hot conduits (7) include parallel arrays of two-leg heater tubes arranged so that said heater tubes of all said hot conduits (7) form at least one continuous heater tube wall (24,25,32).

4. A double-acting thermal gas piston engine as defined in claim 1, in which the central longitudinal axis of each cylinder (1 to 6) and that of the casing (9 to 14) connected to such cylinder over one of said hot conduits (7) lie in a plane and in which, further, the said planes of all said cylinder-casing pairs are parallel to each other and oblique to the common plane of said central axes of said cylinders.

5. A double-acting thermal gas piston engine as defined in claim 1, in which said cold conduits (8) which are connected to those cylinders (2,3,4,5) which are interior members of said row of cylinders are disposed parallel to each other.

6. A double-acting thermal gas piston engine as defined in claim 5, in which said cold conduits (8) which are connected to the two end cylinders (1,6) of said row of cylinders are disposed parallel to each other.

7. A double-acting thermal gas piston engine as defined in claim 6, in which all of said cold conduits (8) are of the same length.

8. A double-acting thermal gas piston engine as defined in claim 1, in which if the cylinders of said cylinder row are numbered in sequence beginning with 1, the even numbered cylinders (2,4,6) are connected with the casings (9,11,13) of one casing row and the odd numbered cylinders (1,3,5) are connected with the casings (10,12,14) of the other casing row.

9. A double-acting thermal gas piston engine as defined in claim 3, in which each casing row (9,11,13 and 10,12,14) is connected to a separate heater tube wall (24,25).

10. A double-acting thermal gas piston engine as defined in claim 9, in which a combustion chamber (26) is provided between said two heater tube walls (24,25).

11. A double-acting thermal gas piston engine is defined in claim 3, in which at least one leg of said heater tubes forming said heater tube walls (24,25) is directed obliquely to the common plane of said central axes of said cylinders (1 to 6).

12. A double-acting thermal gas piston engine as defined in claim 2, in which the said casings (9 to 14), each containing a regenerator and a cooler, are disposed so that said casings of each row are opposite every second interval between two cylinders.

13. A double-acting thermal gas piston engine as defined in claim 12, in which the heater tubes (32) are arranged in a heater tube wall disposed above said cylinder row in a laterally offset combustion chamber (34).

14. A double-acting thermal gas piston engine as defined in claim 13, in which the plane of said heater tube wall (32) is disposed obliquely with respect to the common plane of said central axes of said cylinders (1 to 6).

15. A double-acting thermal gas piston engine as defined in claim 3, in which said heater tubes (22,30) are arranged to form at least one heater tube wall disposed in a combustion chamber, and in which counter-current preheating means (29,35) is provided for heating air supplied to support combustion from the heat of exhaust gases from said combustion chamber.

16. A double-acting thermal gas piston engine as defined in claim 15, in which said preheating means has

an elongated heat exchanger extending over substantially the full length of the engine.

17. A double-acting thermal gas piston engine as defined in claim 15, in which a reinforced shield (28) is provided on the floor of said combustion chamber (26) for reversing the direction of flow of combustion gases.

18. A double-acting thermal gas piston engine as defined in claim 3, in which said heater tubes (22) are connected by manifolds (20,21) respectively with said hot working space and with said regenerator of each connecting means, and in which said manifolds provide a gradual change in cross section.

19. A double-acting thermal gas piston engine as defined in claim 18, in which said manifolds extend in offset fashion from the respective cylinders and casings and that the corresponding manifolds mutually overlap in the region of the heater tube ends.

20. A double-acting thermal gas piston engine as defined in claim 19, in which the two manifolds (20,21) of the same interconnecting means have substantially the same cross section in the neighborhood of the ends of the heater tubes (22).

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