

[54] HOT GAS MACHINE

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[51] Int. Cl. F01k 25/00

[58] Field of Search 60/24, 59 T, 59 R, 36, 60/49, 522; 62/159

[56]

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[57]

ABSTRACT

A hot gas machine is presented, suitable for use either as an engine, heat pump or a refrigerator, wherein a single stream of external fluid is in heat exchange with a working fluid in two counterflow heat exchangers to heat and cool the working fluid.

12 Claims, 7 Drawing Figures

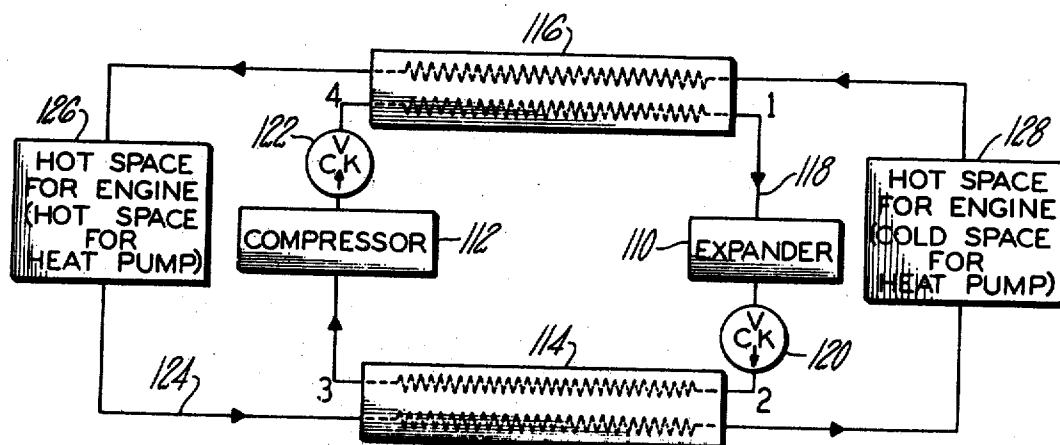


FIG. 1B PRIOR ART

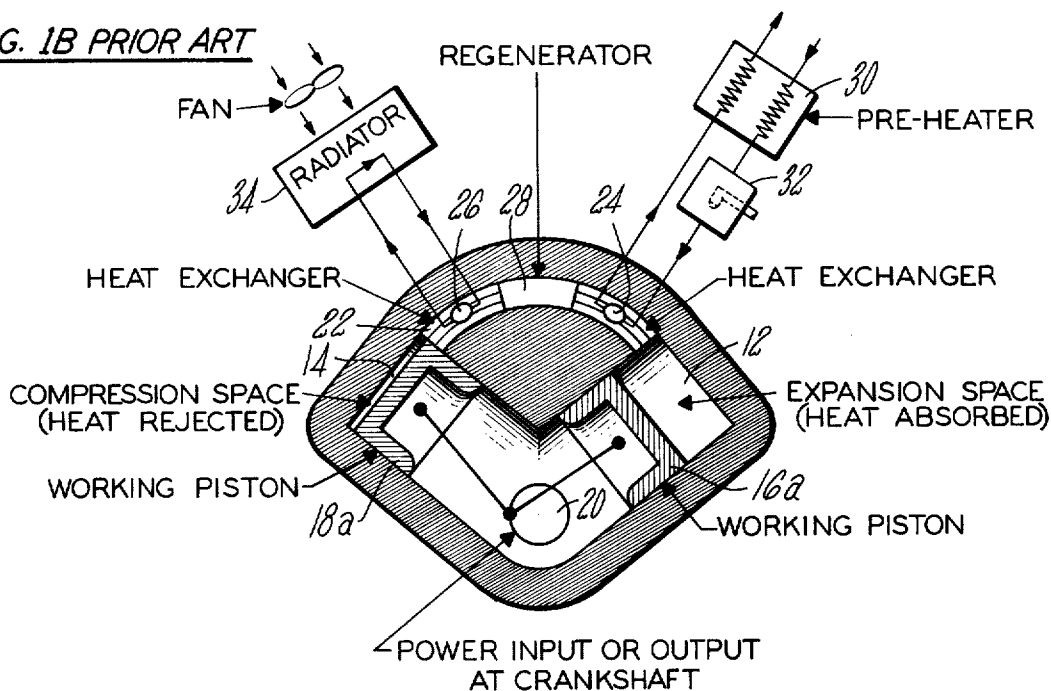


FIG. 1A PRIOR ART

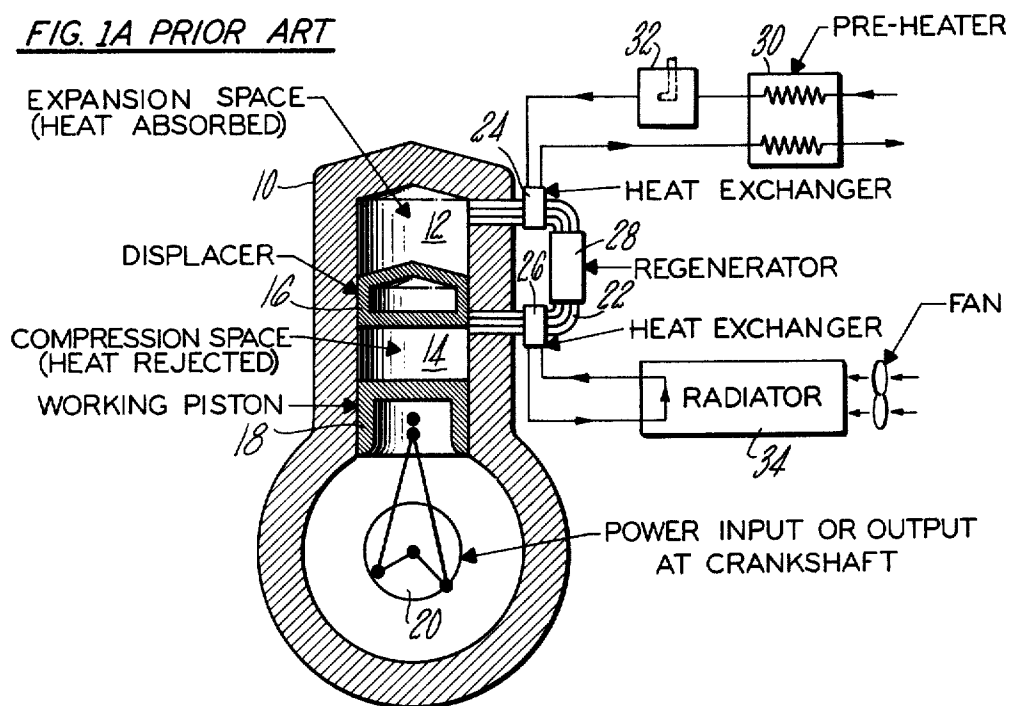


FIG. 2

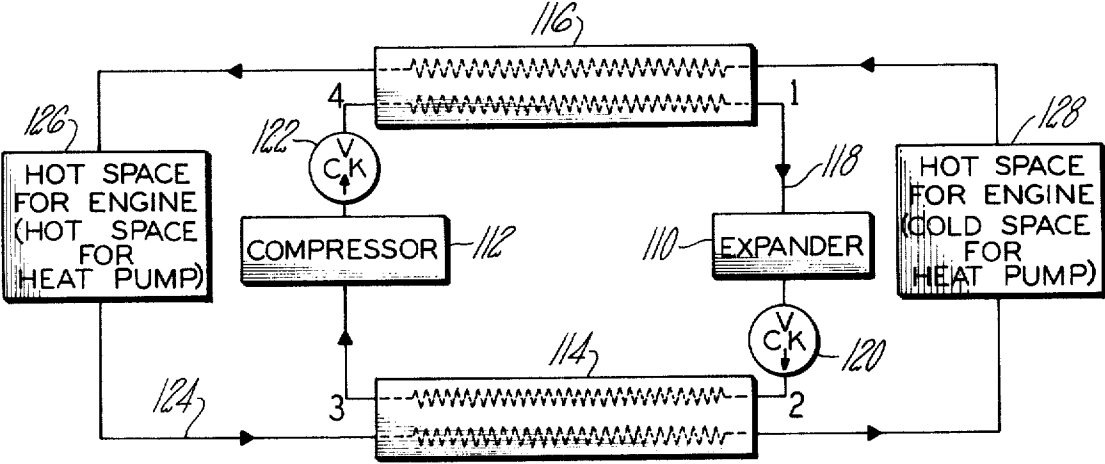


FIG. 3

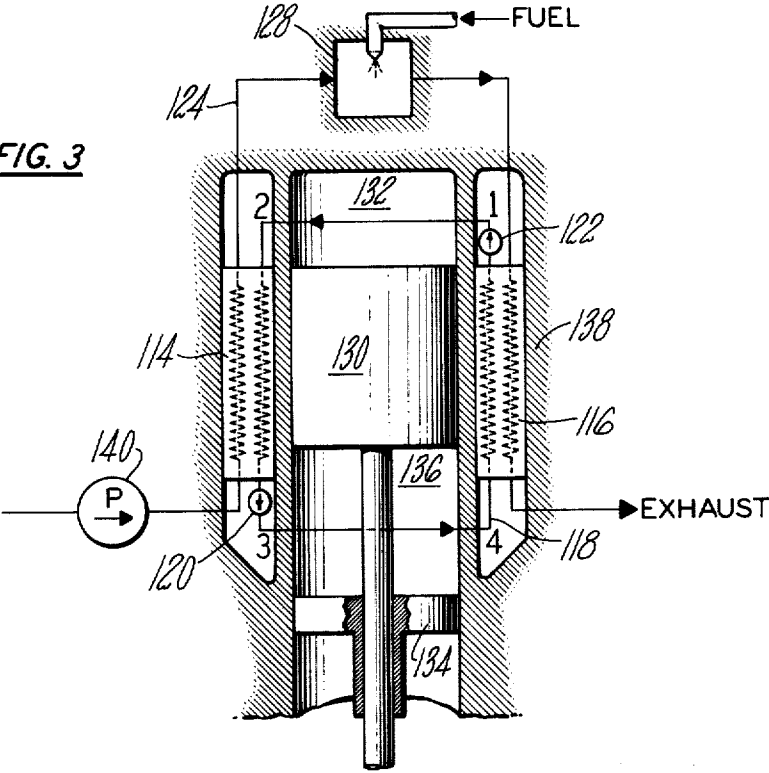


FIG. 4

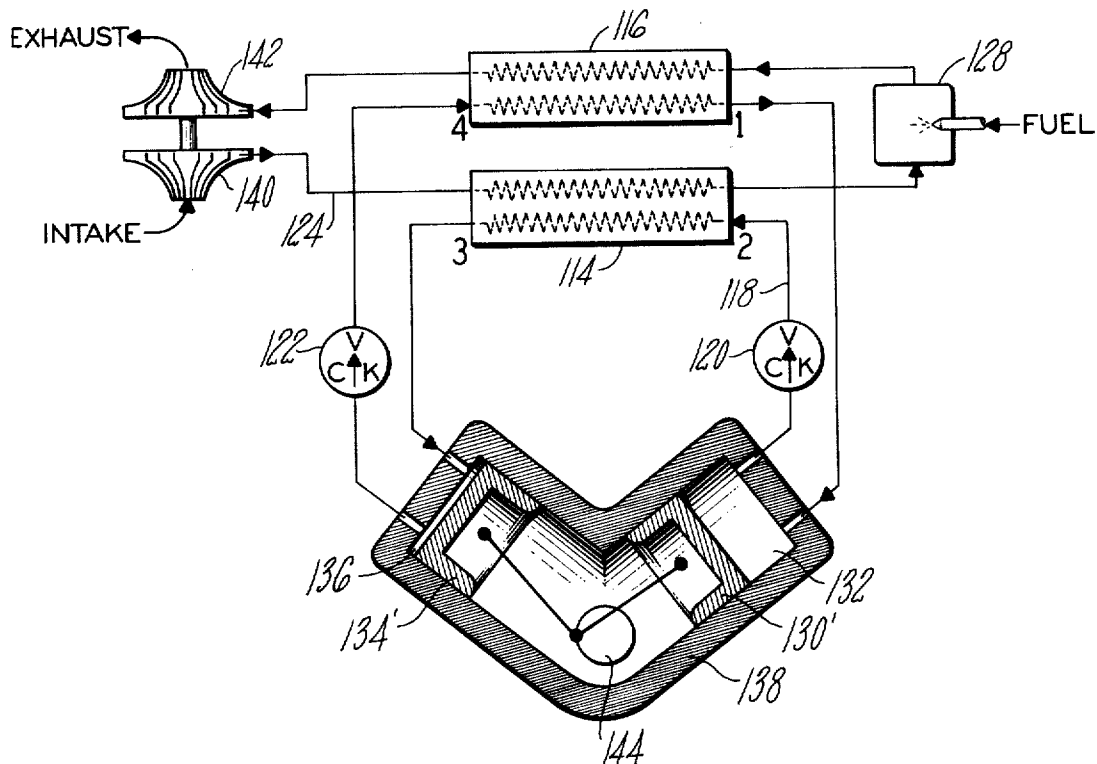
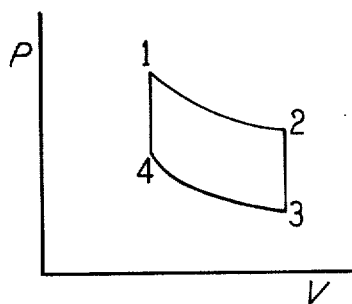
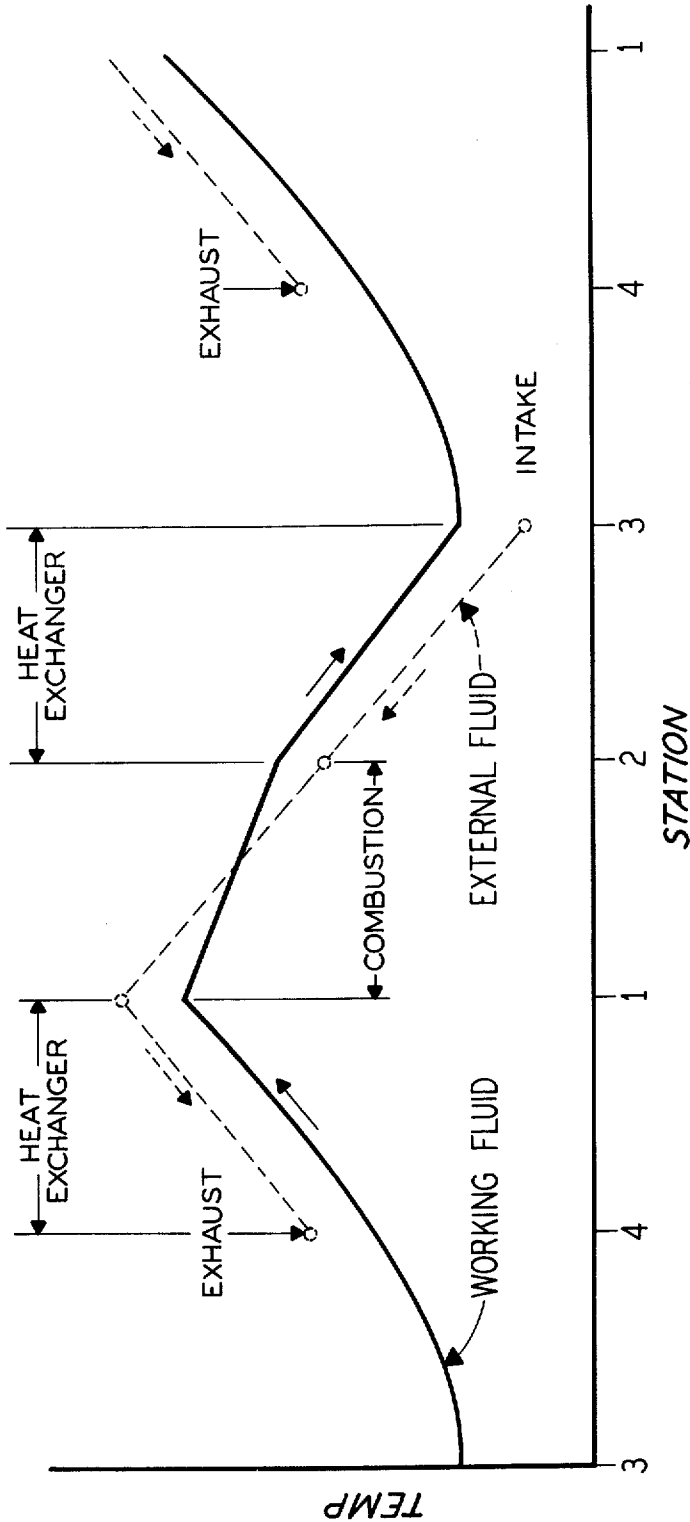


FIG. 5

FIG. 6



HOT GAS MACHINE

BACKGROUND OF THE INVENTION

This invention relates to the field of hot gas machines. More particularly, this invention relates to the field of hot gas machines which can be used either as engines, heat pumps, or refrigerators, and the hot gas machine of the present invention may be characterized as a modified Stirling engine wherein the regenerator, previously required for Stirling engines, is eliminated. The regenerator is structurally eliminated along with the standard preheater and radiator while their functions are retained by the use of a pair of counterflow heat exchangers through which both the working fluid and the external fluid pass in reverse sequence.

Hot gas machines which may serve as engines, heat pumps or refrigerators are well known in the art. A conventional hot gas machine normally includes a working piston and a displacing piston which are mounted for out-of-phase movement. Air or some other external fluid is heated in a hot space by an external source of heat and delivered to an expansion (or hot) chamber. During the cycle the displacement piston moves up into the expansion chamber to displace the hot air through a regenerator to a compression (or cold) chamber where the air undergoes an adiabatic compression. The displacement piston then moves downwardly to meet the working piston which is moving up, and air from the compression chamber is forced back through the regenerator to the hot chamber. The pressure of the air in the expansion chamber is greater than atmospheric and the pressure forces both the displacement piston and working piston downwardly to provide the power stroke. The displacement piston then returns in an upward stroke while the working piston continues to move downwardly so that hot air from the compression chamber is again displaced through the regenerator to the cold chamber where it is again compressed as the working piston begins its upward stroke to repeat the cycle. The working fluid is heated in cross-flow heat exchange from an external source such as a combustion chamber, and is cooled by cross-flow heat exchange with a radiator cooled fluid. Thus, the typical prior art hot gas engine has an internal working fluid which moves back and forth between expansion and compression spaces along a duct which includes two cross-flow heat exchangers with a regenerator between the heat exchangers, one of the heat exchangers being connected to a heat source, and the other being connected to a heat sink.

Another typical embodiment of prior art hot gas engines is a double cylinder, two piston type wherein a pair of working pistons are arranged in a V formation, the piston cylinders being connected by a duct and forming the hot and cold spaces for expansion and compression of the working fluid. The connecting duct houses the regenerator and the pair of cross-flow heat exchangers.

Typical examples of prior art hot gas engines may be found in references such as the Standard Handbook for Mechanical Engineers, Baumeister & Marks, seventh Ed. (McGraw Hill, 1958, 1967) in Section 4, Page 29, and in such patents as Finkelstein et al. U.S. Pat. Nos. 2,724,248, Sigsttra et al. 3,310,954 and Reinhoudt et al. 3,318,100, which patents are typical of the prior art but by no means a complete compilation thereof.

These prior art hot gas machines all require a regenerator in the working fluid flow path, and this regenerator is a particularly complicating factor which adds to the cost of the engine, limits performance and impairs efficiency. Furthermore, it should also be noted that these prior art engines require three fluid paths, there being one internal path and two external paths. The internal path, of course, is the working fluid which traverses between the expansion space and the compression space through the ducting which includes the regenerator. One external fluid path incorporates the heat exchanger associated with the expansion space and includes the preheater and combustion chamber, this external fluid path being for heating. The second external fluid path, for cooling, includes the heat exchanger associated with the compression space and a radiator or other cooling device. The requirement for two external fluid paths is still another complicating and limiting factor in these hot gas machines.

Still another significantly limiting or complicating factor of the prior art machines is that the working fluid, since it must pass through the same regenerator and heat exchangers in both directions when traveling between the expansion space and compression space, is recooled after the compression stroke and reheated after the expansion stroke. Both this reheating and recooling are counterproductive to the desired result at that part of the engine cycle, and thus reduce the efficiency of the engine.

SUMMARY OF THE INVENTION

The above discussed and other problems of prior art hot gas engines are eliminated or significantly reduced by the hot gas machine of the present invention wherein the regenerator is completely eliminated and only a single external fluid circuit is required in conjunction with the one internal working fluid. Stated broadly, the hot gas machine of the present invention comprises an expansion (or hot) space, a compression (or cold) space, operating mechanisms (such as pistons, turbines, pumps or rotors) for the expansion and compression spaces, and a pair of counterflow heat exchangers whereby a single external fluid is in counterflow heat exchange with the internal working fluid at two separated locations in the path or cycle of the internal working fluid. When it is stated that the counterflow heat exchangers are at two separate locations in the path or cycle of the internal working fluid, it is meant that one of the heat exchangers is between the expansion space and the compression space in the direction of flow of the working fluid, and the other heat exchanger is between the compression space and the expansion space in the direction of flow of the working fluid. The direction of flow of the external working fluid through these heat exchangers is, of course, always opposite to the direction of flow of the working fluid.

The arrangement of the present invention completely eliminates the regenerator and all of the disadvantages associated with it and its two associated cross-flow heat exchangers. The present invention also provides for a single continuous closed flow path for the working fluid without the need for it to double-back upon itself as in the prior art, thus eliminating the previously experienced undesirable recooling after compression and reheating after expansion; and the present invention requires only a single external fluid, thus eliminating the

prior art requirement for two external fluid paths. Furthermore, while the prior art hot gas machines have required a preheater in the external heating path and a radiator in the external cooling path, the present invention also eliminates the need for a separate preheater and radiator, these functions being performed by the counterflow heat exchangers. Thus, a significant aspect of the present invention is found in the fact that the regenerator and separate preheater and radiator of the prior art are eliminated while their functions are retained by the pair of cross-flow heat exchangers. Furthermore, only a single external fluid is required and the internal working fluid is permitted to travel in a continuous path thereby eliminating the counterproductive recooling after compression and reheating after expansion experienced in the prior art. A further significant advantage of the present invention is the simplicity of construction which can be achieved, thus eliminating the complex piping and cylindrical heat exchangers and combustion chamber configurations of the prior art.

Accordingly, one object of the present invention is to provide a novel and improved hot gas machine.

Another object of the present invention is to provide a novel and improved hot gas machine wherein the regenerator is eliminated.

Still another object of the present invention is to provide a novel and improved hot gas machine requiring only one external fluid for heat exchange with the working fluid.

Still another object of the present invention is to provide a novel and improved hot gas machine wherein all heat exchange is accomplished in a pair of counterflow heat exchangers which interact with the internal working fluid.

Still another object of the present invention is to provide a novel and improved hot gas machine wherein the internal working fluid travels in a continuous closed path.

Still another object of the present invention is to provide a novel and improved hot gas machine of higher efficiency and considerably simpler construction than the prior art.

Other objects and advantages of the present invention will be apparent to and understood by those skilled in the art from the following detailed drawings and description.

BRIEF DESCRIPTION OF THE DRAWING

Referring to the drawings, wherein like elements are numbered alike in FIGS. 1A and 1B and wherein like elements are numbered alike in FIGS. 2, 3 and 4:

FIG. 1A is a representation of one form of a prior art hot gas machine.

FIG. 1B is a representation of another form of a prior art hot gas machine.

FIG. 2 is a schematic representation of a hot gas machine in accordance with the present invention.

FIG. 3 is a representation of one form of a hot gas machine in accordance with the present invention.

FIG. 4 is a representation of a second form of a hot gas machine in accordance with the present invention.

FIG. 5 is a pressure volume diagram relating to the working fluid of the present invention.

FIG. 6 is a diagram showing the temperature relationships of the external fluid and working fluid at various cycle stations.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A full appreciation of the features and advantages of the present invention can perhaps best be achieved by an introductory discussion of and comparison with prior art hot gas machines, and schematic representations of such prior art machines are shown in FIGS. 1A and 1B. In discussing both the prior art and the present invention, these hot gas machines will be discussed in their engine configurations. However, it will be understood and appreciated by those skilled in the art that these machines can be operated in heat pump or refrigerating modes in accordance with modifications and techniques well known in the art.

Referring to the prior art hot gas machine shown in FIG. 1A, a typical Stirling configuration is shown wherein the engine housing 10 has an expansion space 12 (also known as a hot space) and a compression space 14 (also known as a cold space) separated by a movable displacer piston 16. A working piston 18 at the bottom of the compression space is connected to a crankshaft 20 for power output in the engine mode (the crankshaft being for power input in other modes). A duct 22 extends between and connects the expansion space 12 and the compression space 14 to allow for transfer of a working fluid back and forth between the expansion and compression spaces. The working fluid may be hydrogen or helium or any other known suitable working fluid.

Duct 22 contains a cross-flow heat exchanger 24 which is associated with expansion space 12, a cross-flow heat exchanger 26 which is associated with compression space 14 and a regenerator 28. The working fluid passes through both heat exchangers 24 and 26 and regenerator 28 each time it flows from one of the chambers 12 and 14 to the other. An external heat transfer fluid, most typically air, is delivered at an elevated temperature to cross-flow heat exchanger 24 to add heat to the system. As shown in FIG. 1A, the typical arrangement includes a preheater 30 where the air, the flow direction of which is indicated by the arrows, is preheated and then delivered to a combustion chamber 32 where the temperature is elevated to a desired level by the burning of a fuel prior to delivery to heat exchanger 24. After passing through the heat exchanger 24, the air then flows to preheater 30 where it is used to preheat the incoming air and is then discharged to ambient. This prior art system also incorporates a second external transfer fluid, which may be water or some other suitable liquid, which flows through cross-flow heat exchanger 26 to cool the working fluid. This second external fluid is in a closed circuit between heat exchanger 26 and a radiator 34 as indicated in the arrows in the flow path therebetween, and heat is dissipated from the radiator as by the fan indicated schematically.

Referring to FIG. 1B, another form of a typical prior art Stirling hot gas engine of the double cylinder, two piston type is shown. The engine of FIG. 1B has a pair of pistons 16a and 16b instead of the displacement pistons 16 and working piston 18 of FIG. 1A, but the engines are otherwise conceptually actually the same. A transfer duct or conduit 22 connects the spaces 12 and 14, and this duct contains the two cross-flow heat exchangers 24 and 26 and the regenerator 28, the working fluid being transferred back and forth between ex-

pansion and compression spaces 12 and 14 via duct 22. As with the FIG. 1A embodiment, there is also a pair of external fluid circuits to provide heating at heat exchanger 24 and cooling at heat exchanger 26.

While the engines of FIGS. 1A and 1B are shown only schematically and in simple form, many significant complications of these engines are well known in the art. The cylinder walls are often used as heating devices with resultant complex piping, fluting and finning being necessary to achieve efficient heat transfer. Also, many present designs have the combustion chamber buried in the midst of the cylinder head heat exchangers. These complicating configurations for the heat exchangers and combustion chambers have been found to be required in the prior art in order to achieve an engine of acceptable efficiency, but these complications lead to great expense and present severe problems in maintenance and reliability.

Referring now to FIG. 2, a general schematic of a hot gas machine in accordance with the present invention is shown. The engine has an expander 110, a compressor 112, a counterflow heat exchanger 114 between the exit from expander 110 and the entrance to compressor 112 and another counterflow heat exchanger 116 between the exit from compressor 112 and the entrance to expander 110. The working fluid flows in a closed fluid circuit indicated at 118 in the direction indicated by the arrows so that the working fluid flows from heat exchanger 116 to expander 110 and then through heat exchanger 114 to compressor 112 and then back to heat exchanger 116. Check valves 120 and 122 positioned as shown at the exit from the expander and compressor prevent any reverse flow in the fluid surface. The working fluid flowing in the closed circuit 118 may be hydrogen, helium, or any other suitable fluid as known in the art.

An external heat transfer fluid flows in a circuit 124 in the direction indicated by the arrows to heat and cool the working fluid as required. The external transfer fluid is drawn from a cold source or space 126 which, typically, would simply be the ambient atmosphere. The external fluid flows from the cold space or source to heat exchanger 114 wherein it is in counterflow heat exchange with the working fluid after discharge from the expander. The heat exchange occurring in exchanger 114 results in a cooling of the working fluid in circuit 118 and a preheating of the external fluid in circuit 124. The external fluid then flows to a hot space or heat source 128 which, typically, would be a combustion chamber to which fuel is supplied for combustion with the external fluid. The heated external fluid then flows to heat exchanger 116 wherein it is in counterflow heat exchange with the working fluid in circuit 118. The heat exchange in exchanger 116 results in a significant increase in the temperature of the working fluid and a corresponding decrease in the temperature of the external fluid. The external fluid is then discharged to the cold space, which, as previously indicated, may be the atmosphere.

While the cycle with respect to the external fluid is taking place as described above, the working fluid is undergoing a cycle of heating, expansion, cooling and compression to perform its work function. The working fluid is heated in counterflow heat exchanger 116 and is then delivered to expander 110 where it is expanded and performs work. The working fluid then flows through counterflow heat exchanger 114 where it is

cooled and gives up heat to the external fluid for the preheating thereof. The working fluid then flows to compressor 112 where work is done on it to compress it, and the fluid is then delivered to heat exchanger 116 to absorb heat from the higher temperature external fluid flowing through the heat exchanger.

It will be understood that the machine shown in FIG. 2 is intended to be a general schematic of the present invention and has been described in relation to operation in an engine mode. If the machine were to be operated as a heat pump or refrigerator, space 126 would be a hot space and space 128 would be a cold space. Furthermore, it will be understood that the hot space or heat source 128 may be any suitable source of heat and the cold space 126 may be any suitable low temperature sink. External fluid circuit 124 could, if desired, be a closed circuit, but it is generally contemplated that it will be an open circuit in the sense that the cold space would simply be the atmosphere from which the external fluid would be drawn and to which the external fluid would be exhausted from heat exchanger 116. The compressor and expander have also been schematically indicated in FIG. 2. The expander-compressor mechanisms could be selected from a variety of such mechanisms such as phased pistons operating on a Stirling cycle, axial or radial turbines operating on a Brayton cycle, vane pumps operating on a Brayton cycle or Wankel rotors operating on a Stirling cycle.

Referring now to FIG. 3, an engine of the general configuration of FIG. 1A is shown incorporating the present invention. In the FIG. 3 embodiment the expander is composed of a displacer piston 130 and expansion space 132; and the compressor is composed of working piston 134 and compression space 136. Both the expander and the compressor are, of course, contained within housing 138, and the working fluid is delivered to the spaces 132 and 136 for expansion and compression.

As with the general schematic of FIG. 2, the working fluid flows in circuit 118 and absorbs heat in passing through counterflow heat exchanger 116, is delivered to space 132 for expansion against displacer piston 130, then flows to heat exchanger 114 where it is cooled and serves to preheat the external fluid, and is then delivered to space 136 for compression between displacer piston 130 and working piston 134, and is then delivered back to heat exchanger 116 to complete the cycle. Coincidentally, the external fluid, such as air, is delivered via a pump 140 to heat exchanger 114 wherein it is preheated, is then delivered to combustion chamber 128 (i.e., hot space) where it is significantly raised in temperature, and it is then delivered to heat exchanger 116 for heat transfer to the working fluid, and thence to exhaust. Work is extracted from the oscillatory motion of working piston 134 which drives a crankshaft.

Referring now to FIG. 4, a hot gas machine incorporating the present invention and similar to the configuration of FIG. 1B is shown. In FIG. 4, the engine housing 138 houses the expander which consists of a piston 130' and expansion space 132 and a compressor which consists of piston 134' and cold space 136. The pistons 130 and 134 have been indicated with a prime superscript since they are more appropriately both considered to be working pistons rather than a displacer and working piston pair. The working fluid flows in circuit 118 from counterflow heat exchanger 116, in which the

working fluid is heated, to expansion space 132 of the expander, and thence through the check valve 120 to heat exchanger 114 wherein it is cooled and preheats the external fluid, and then to the cold space 136 of the compressor, and then through the check valve 122 back to heat exchanger 116. Coincidentally, air for the external fluid is drawn through pump 140 and delivered via fluid circuit 124 to heat exchanger 114 wherein it is preheated, and is then delivered to the combustion chamber 128 to be heated and thence to heat exchanger 116 where it heats the working fluid, and thence to exhaust. The exhaust path may include a turbine 142 connected to drive the intake pump 140. Work is extracted from the engine at shaft 144.

As has been indicated above, the hot gas machine of the present invention is truly reversible. If heat is the input, work is the output. Conversely, if work is the input, heat will be moved from one level to another and in this mode the machine will either be a heat pump or a refrigerator. Regardless of the mode of operation, it will be observed that the engine is significantly simplified over prior art hot gas engines in that the complication of the regenerator as well as a cooling radiator and a separate preheater are eliminated. The present engine requires only the pair of counterflow heat exchangers, a heat source and a cold source.

Referring now to FIG. 5, a pressure-volume diagram of the working fluid through one complete cycle is shown. Points in the cycle are labeled 1, 2, 3 and 4, and these cycle points are noted by the same numerical designations in FIGS. 2, 3 and 4. Starting at point 1, which corresponds to the condition of the working gas after having passed through heat exchanger 116, the working fluid is at its highest pressure and temperature. The working fluid then expands between points 1 and 2 doing work in the process, point 2 corresponding to the state of the gas after having passed through the expander. From 2 to 3 the gas is cooled without a change in volume, and no work is done, point 3 corresponding to the state of the gas after having passed through heat exchanger 114. From 3 to 4 the working gas is compressed, requiring work, state 4 corresponding to the state of the gas after having passed through the compressor. From 4 to 1 the gas is heated without a change in volume, and once again, no work is required.

Referring now to FIG. 6, a diagram is presented of the working fluid and the external fluid on a plot of temperatures against stations in the cycle. The working fluid is in the solid line, and the external fluid is in the dashed line. The diagram illustrates that the working fluid is in a closed path while the external fluid is in a path open to atmosphere between exhaust and intake at stations 4 and 3. The locations in the cycle where heat exchange and combustion take place are also indicated. The arrows parallel to the working fluid line and the external fluid line represent flow direction and show a most important feature of the invention in that the fluids are in ideal counterflow heat exchange, with one heating and the other cooling, whenever they are in communication.

Still referring in part to FIG. 6, the pressure and volume of the external fluid are relatively unimportant because the external fluid is isolated from the working fluid by the heat exchangers. The external fluid enters heat exchanger 114 at 3 and gains heat until it exits at 2. The temperature gain from 2 to 1 is a step change as fuel is burned in the combustion chamber. The external

gas then exits through heat exchanger 116 at stage 4. This exiting of the external fluid at stage 4 is a most significant feature in the analysis of the present invention. It shows that while the engine itself is actually working between the temperature at 1 and 3, a significantly higher temperature than at 4, the exhaust will be at the much lower temperature at 4. This determines the maximum amount of heat that can be extracted from the fuel, and it also shows that extreme compression ratios, which would cause a large temperature difference between points 3 and 4, would not be desirable in this type of engine since that would result in a higher temperature exhaust; too low a compression ratio would, on the other hand, extract too little work each cycle and would result in a low power to weight ratio for the engine. The significant fact is, however, that the engine can operate at the high temperatures existing between 1 and 3 while the external fluid can be exhausted, without supplemental cooling, at the much lower temperature at point 4.

In addition to eliminating the complexity of the regenerator in prior art engines, the elimination of the need for supplemental cooling of the external fluid is significant. This is especially so when considering applications such as automotive applications where an air cooled engine is a definite advantage. The present invention also introduces significant simplifications in that the combustion chamber need not be as intimately connected with the hot end of the engine as the prior art, and more attention may be given to complete fuel combustion, a particularly important consideration from an environmental standpoint. Furthermore, the counterflow heat exchangers may be separated somewhat from the cylinders and so may be constructed in a convenient shape and placed in a convenient location. Thus, attention can be given to constructing a heat exchanger of optimum performance rather than one whose shape is dictated by its required location. While the working fluid must go through the basic heating-expansion-cooling-compression cycle of the Stirling cycle, the transfer fluid only has to satisfy the temperature requirements in the two heat exchangers. Also, the use of two paths through the heat exchangers prevents the gas from being recooled after the compression stroke and reheated after the expansion stroke, thus eliminating another objection of the prior art.

While a preferred embodiment has been shown and described, various modifications and substitutions can be made thereto without departing from the spirit and scope of the invention. Accordingly, the present invention has been described by way of illustration and not limitation.

What is claimed is:

1. A cyclically operating hot gas machine including: a working fluid;

expander means for cyclic expansion of said working fluid, said expander means having an expansion space with a fluid inlet and a fluid outlet and operating means in said expansion space for cyclic expansion of said working fluid;

compressor means for cyclic compression of said working fluid, said compressor means having a compression space with a fluid inlet and a fluid outlet and operating means in said compression space for cyclic compression of said working fluid;

first fluid circuit means in said hot gas machine, said first fluid circuit means being a closed circuit containing said working fluid, said expansion space and said compression space being in said closed fluid circuit, a first part of said closed fluid circuit extending from the outlet of said expansion space to the inlet of said compression space, and a second part of said closed fluid circuit extending from the outlet of said compression space to the inlet of said expansion space;

first counterflow heat exchanger means in said first part of said closed fluid circuit;

second counterflow heat exchanger means in said second part of said closed fluid circuit;

second fluid circuit means in said hot gas machine, said second fluid circuit means being connected in series to each of said first and second counterflow heat exchanger means and having a heat exchange fluid flowing therein, the direction of flow of said heat exchange fluid in said second fluid circuit means and said working fluid in said first fluid circuit means being opposite to provide counterflow heat exchange between said fluids;

heat source means in said second fluid circuit means; cold source means in said second fluid circuit means; one of said heat or cold source means being in said second fluid circuit means between said first and second counterflow heat exchangers;

said expander means and said compressor means cooperating during one part of the operating cycle of the hot gas machine to transfer working fluid from one of said expansion and compression spaces to the other of said spaces through one of said counterflow heat exchangers whereby heat is transferred from said heat exchange fluid to said working fluid to increase the pressure of said working fluid at substantially constant volume of said working fluid, and said expander means and said compressor means cooperating during another part of the operating cycle of the hot gas machine to transfer working fluid from the other of said expansion and compression spaces to said one of said spaces through the other of said counterflow heat exchangers whereby heat is transferred from said working fluid to said heat exchange fluid to reduce the pressure of said working fluid at a substantially constant volume of said working fluid; and

check valve means in each of said first and second parts of said first fluid circuit to permit fluid to flow only in one direction serially through said parts of said first fluid circuit to limit the direction of flow of said working fluid in said first fluid circuit to the direction required to effect counterflow heat exchange between said working fluid and said heat exchange fluid in said first and second counterflow heat exchangers.

2. A hot gas machine as in claim 1 wherein: said second fluid circuit is an open circuit, and the other of said heat or cold source means includes means open to the atmosphere.
3. A hot gas machine as in claim 2 wherein: said cold source means is means communicating with the atmosphere.
4. A hot gas machine as in claim 1 wherein: said heat source means includes combustion chamber means between said heat exchangers.
5. A hot gas machine as in claim 1 wherein:

the temperature of fluid in said first fluid circuit in one of said heat exchangers is greater than the temperature of fluid in said second fluid circuit in said one heat exchanger whereby heat is transferred by counterflow heat exchange in said one heat exchanger from said first fluid circuit to said second fluid circuit; and

the temperature of fluid in said first fluid circuit in the other of said heat exchangers is less than the temperature of fluid in said second fluid circuit in said other heat exchanger whereby heat is transferred by counterflow heat exchange in said other heat exchanger from said second fluid circuit to said first fluid circuit.

6. A hot gas machine as in claim 1 wherein said check valve means includes:

check valve means in said closed fluid circuit downstream of the outlet of each of said expansion and compression spaces in the direction of fluid flow in said circuit.
7. A hot gas machine as in claim 1 wherein:

said heat source means in said second fluid circuit is between said first and second heat exchangers in the direction of flow of fluid in said second fluid circuit.
8. A method of operating a hot gas machine including the steps of:

circulating a working fluid in a first closed circuit in a working cycle which includes serially:

 - cyclically expanding the working fluid in cyclically operating expander means;
 - passing the working fluid through a first counterflow heat exchanger by cooperating action of said expander and a compressor means;
 - cyclically compressing the working fluid in cyclically operating compressor means; and
 - passing the working fluid through a second counterflow heat exchanger by cooperating action of said expander and compressor means;

circulating a heat transfer fluid in a second fluid circuit in a cycle which includes:

 - passing said heat transfer fluid from a heat source to a cold source, said heat transfer fluid being passed through one of said counterflow heat exchangers in passing from said heat source to said cold source to increase the pressure of said working fluid at a substantially constant volume of said working fluid; and
 - passing said heat transfer fluid from a cold source to a heat source, said heat transfer fluid being passed through the other of said counterflow heat exchangers in passing from said cold source to said heat source to reduce the pressure of said working fluid at a substantially constant volume of said working fluid;

said working fluid and said heat transfer fluid being in counterflow heat exchange in each of said first and second heat exchangers to cool said working fluid and heat said heat transfer fluid in said other of said heat exchangers and heat said working fluid and cool said heat transfer fluid in said one of said heat exchangers;

reducing the temperature of said heat transfer fluid at said cold source;

increasing the temperature of said heat transfer fluid at said heat source; and

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limiting the direction of flow of said working fluid to
a chosen direction in said first closed circuit.
9. The method as in claim 8 wherein:
the step of circulating a heat transfer fluid in a second
fluid circuit includes circulating said heat transfer 5
fluid in a circuit open to the atmosphere at one of
said heat or cold sources.
10. The method as in claim 8 wherein:
the step of reducing the temperature of the heat
transfer fluid includes exhausting said heat transfer 10
fluid to atmosphere at said cold source and taking

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in fluid from atmosphere at said cold source.
11. The method as in claim 8 wherein:
the step of increasing the temperature of said heat
transfer fluid includes heating said heat transfer
fluid in a combustion chamber.
12. The method as in claim 8 wherein:
the step of increasing the temperature of said heat
transfer fluid includes heating said heat transfer
fluid at a station in said second fluid circuit be-
tween said heat exchangers.

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