US 20110262269A1

(19) **United States**

(12) **Patent Application Publication**

Lior

(10) **Pub. No.: US 2011/0262269 A1**

(43) **Pub. Date: Oct. 27, 2011**

(54) **VALVES FOR GAS-TURBINES AND MULTIPRESSURE GAS-TURBINES, AND GAS-TURBINES THEREWITH**

(75) Inventor: **David Lior**, Herzliya (IL)

(73) Assignee: **ETV ENERGY LTD.**, Herzliya (IL)

(21) Appl. No.: **13/127,726**

(22) PCT Filed: **Nov. 18, 2009**

(86) PCT No.: **PCT/IB2009/055154**

§ 371 (c)(1),
(2), (4) Date: **Jun. 22, 2011**

Related U.S. Application Data

(60) Provisional application No. 61/116,394, filed on Nov. 20, 2008.

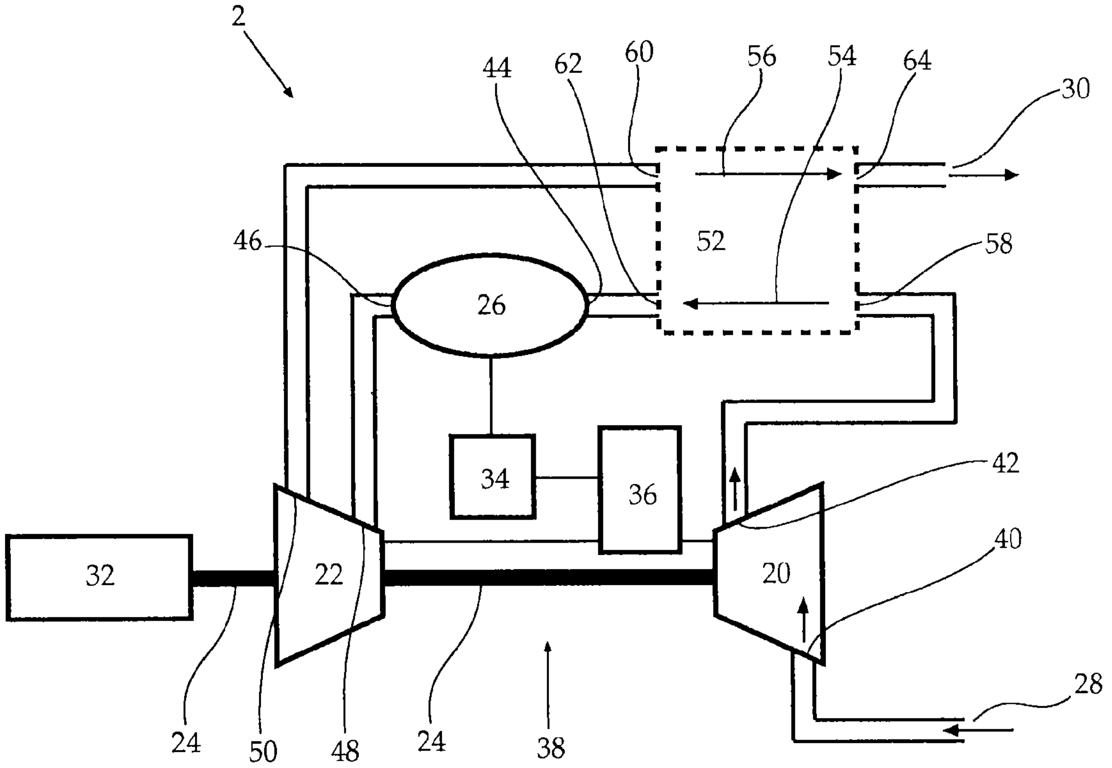
Publication Classification

(51) **Int. Cl.**
F01D 5/08 (2006.01)

(52) **U.S. Cl.** **415/180**

(57) **ABSTRACT**

A multiport valve suitable for use with a gas-turbine allowing switching of a mode of gas-turbine operation between a Brayton cycle and an inverse Brayton cycle, and a gas-turbine configured to switch between a high-pressure operation mode according to a Brayton cycle and a low-pressure operation mode according to an inverse Brayton cycle employing the valve are provided. Also provided are a method and apparatus for operating a gas-turbine according to an inverse Brayton cycle.



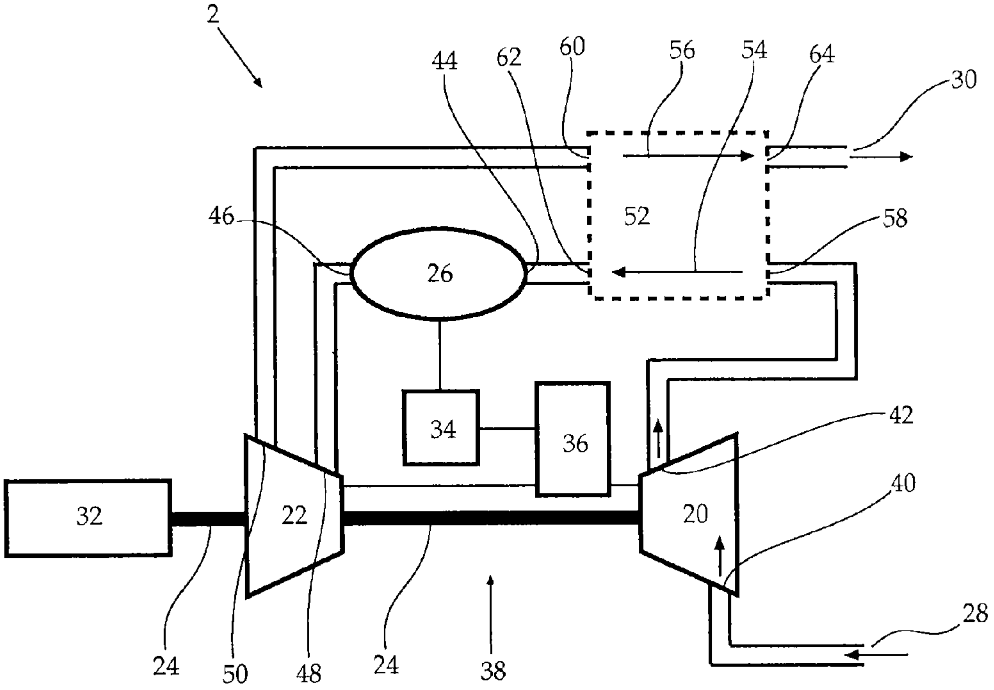

2
44
62
60
56
54
64
30
46
52
58
26
34
36
42
40
32
22
20
28
24
50
48
24
38

FIG. 1A

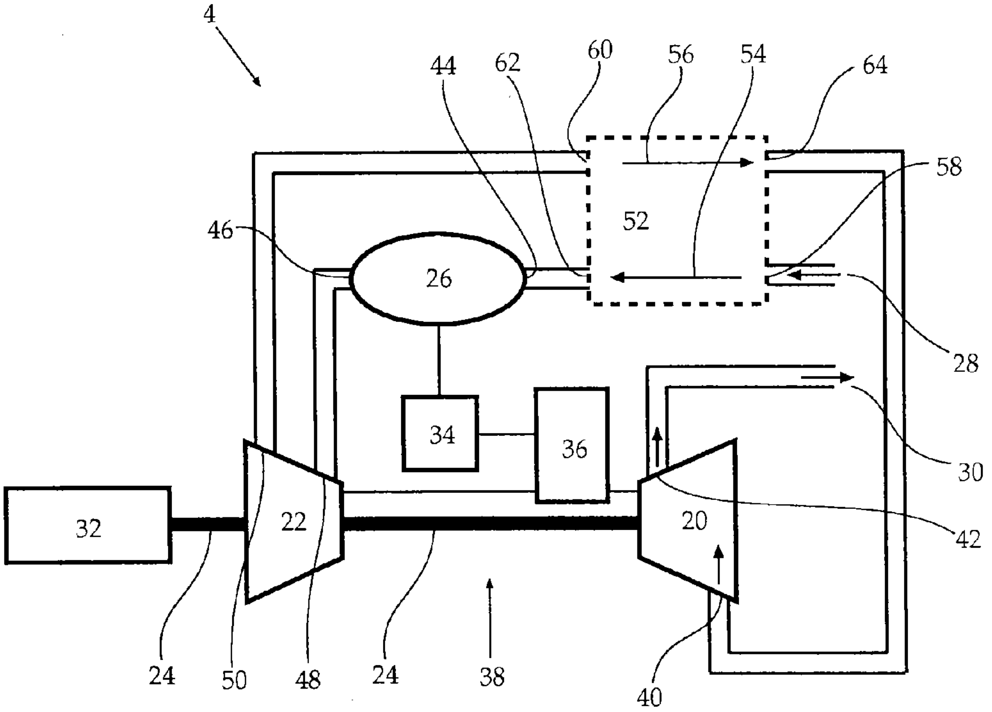

4
44
62
60
56
54
64
58
46
52
26
28
34
36
30
32
22
20
42
24
50
48
24
38
40

FIG. 1B

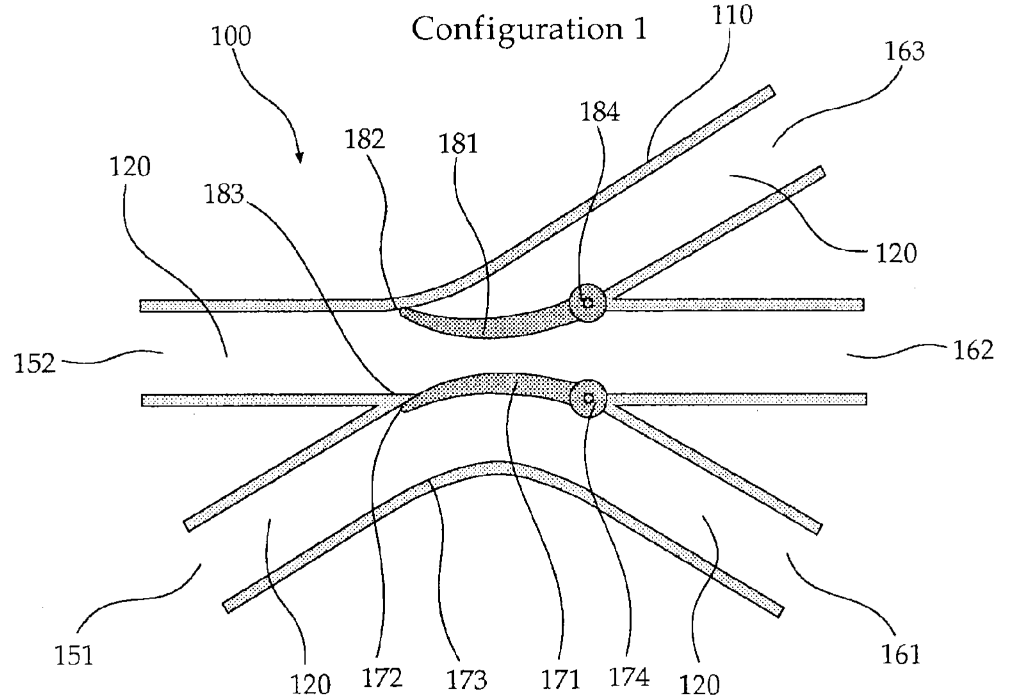

Configuration 1
100
110
163
184
182
181
120
183
120
152
162
151
120
172
173
171
174
120
161

FIG. 2A

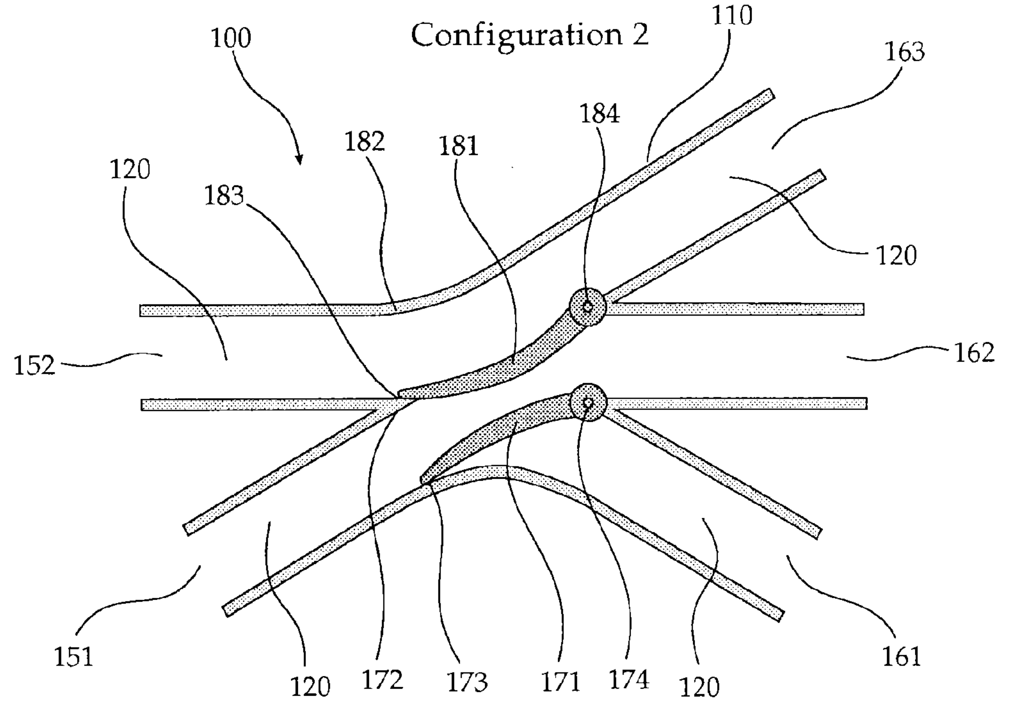

Configuration 2
100
110
163
184
182
181
120
183
120
152
162
151
120
172
173
171
174
120
161

FIG. 2B

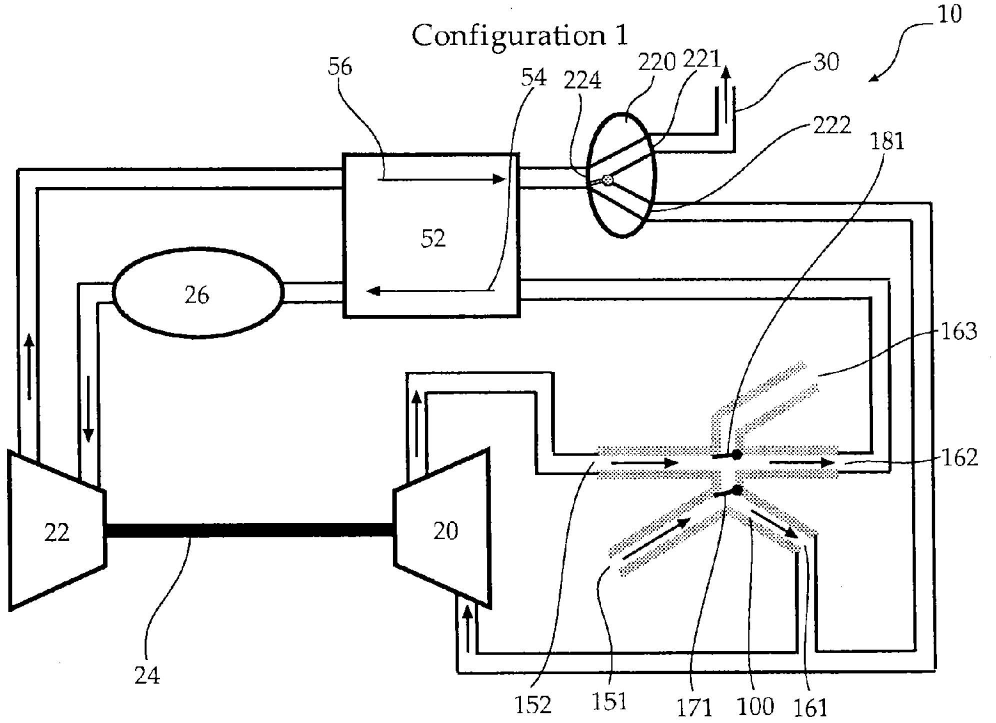

Configuration 1
10
56
54
224
220
221
30
222
181
52
26
163
162
22
20
24
152
151
171
100
161

FIG. 3A

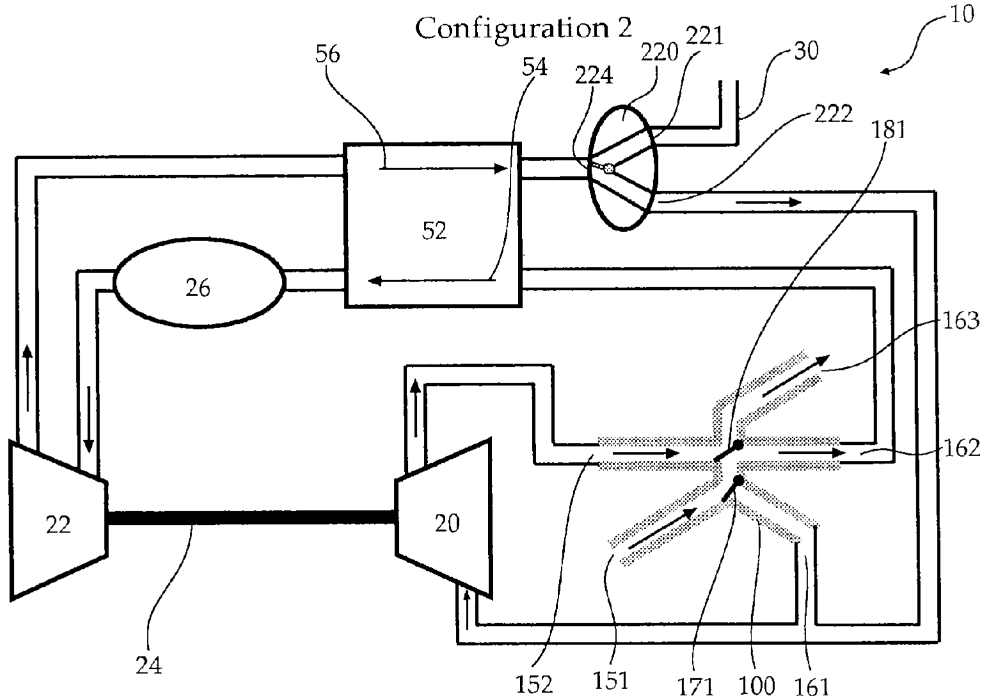

Configuration 2
10
56
54
224
220
221
30
222
181
52
26
163
162
22
20
24
152
151
171
100
161

FIG. 3B

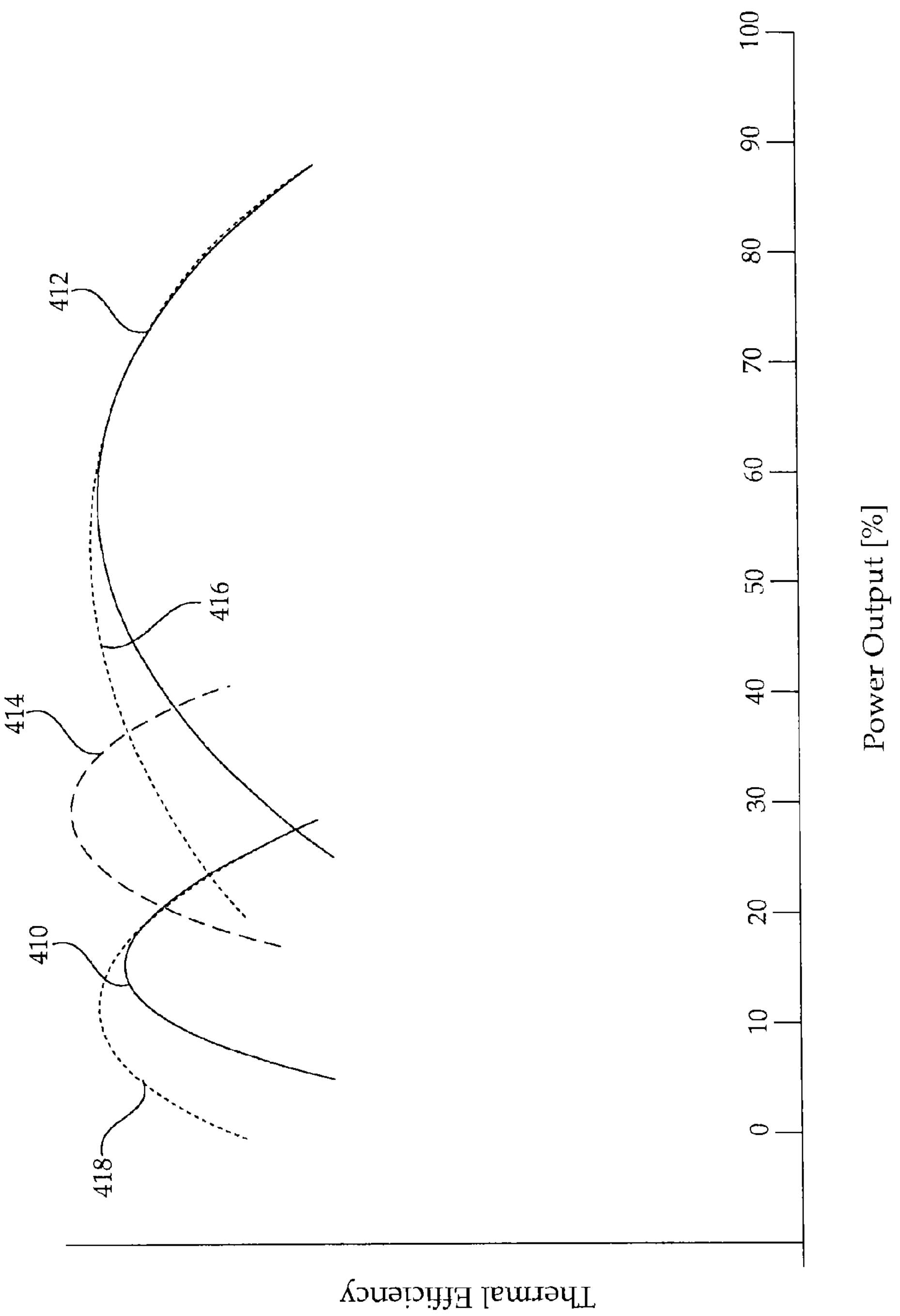

Thermal Efficiency
Power Output [%]
0
10
20
30
40
50
60
70
80
90
100
410
412
414
416
418

FIG.4

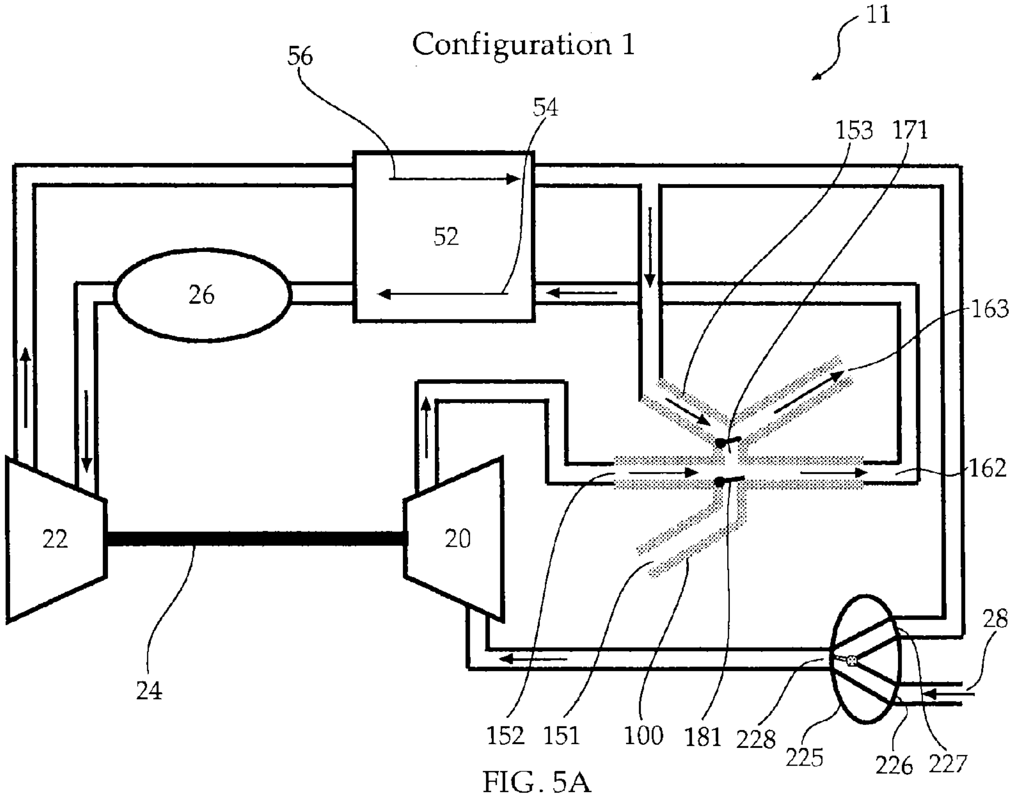

Configuration 1
11
56
54
52
26
153
171
163
162
22
20
24
28
152
151
100
181
228
225
226
227

FIG. 5A

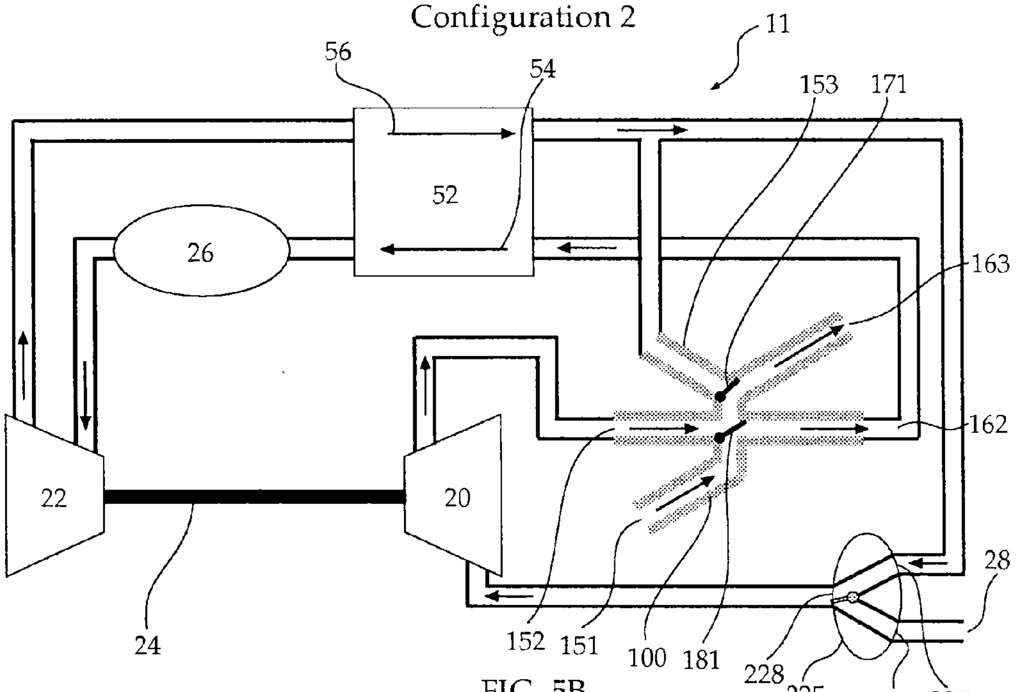

Configuration 2
11
56
54
52
26
153
171
163
162
22
20
24
28
152
151
100
181
228
225
226
227

FIG. 5B

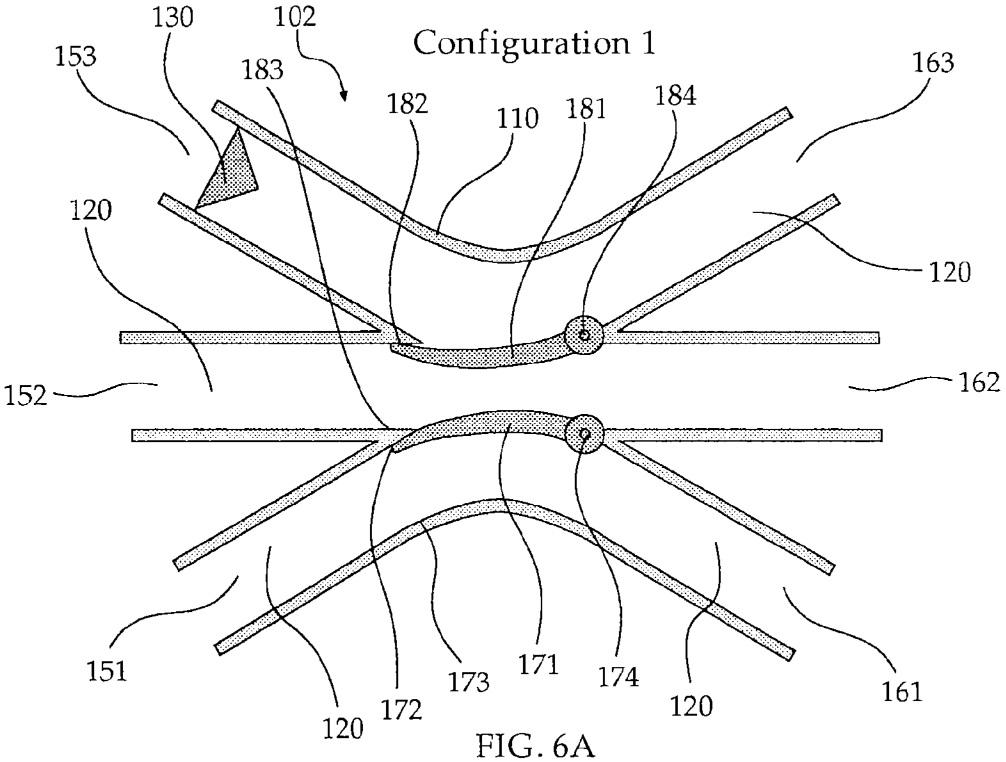

130
102
Configuration 1
153
183
163
182
110
181
184
120
120
152
162
151
120
172
173
171
174
120
161

FIG. 6A

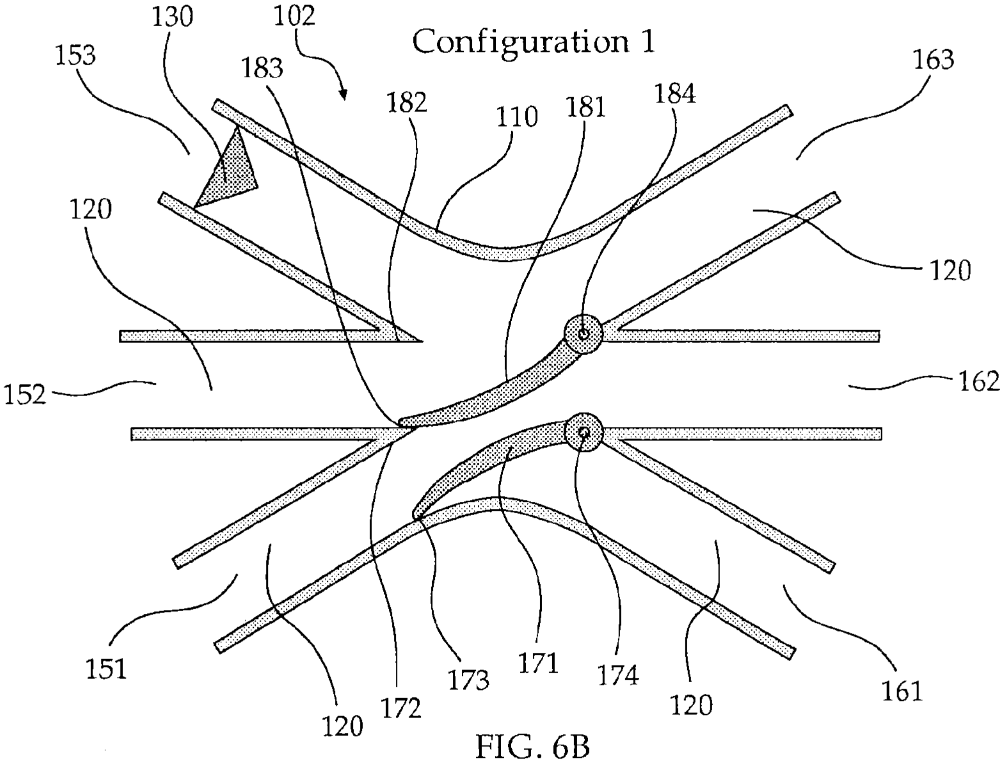

130
102
Configuration 1
153
183
163
182
110
181
184
120
120
152
162
151
120
172
173
171
174
120
161

FIG. 6B

Configuration 1

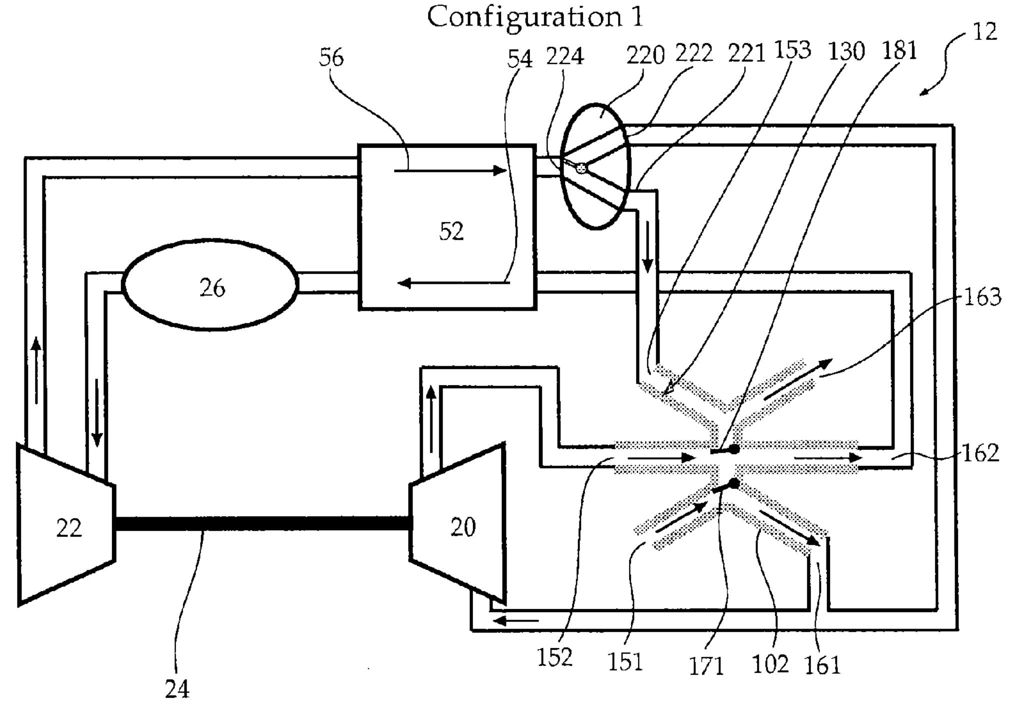


FIG. 7A

Configuration 2

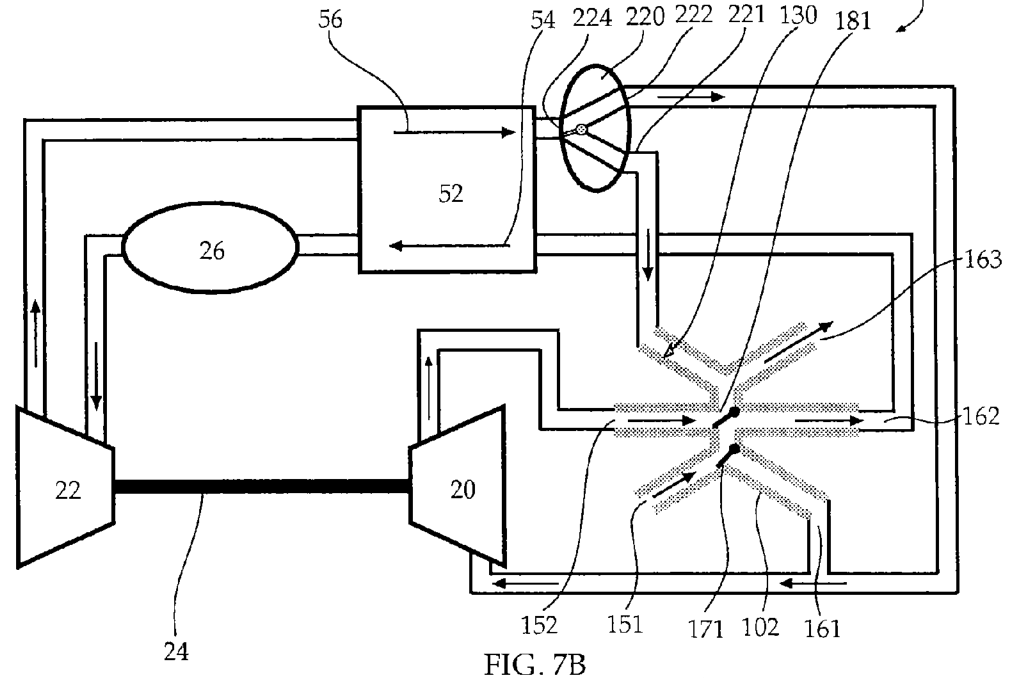


FIG. 7B

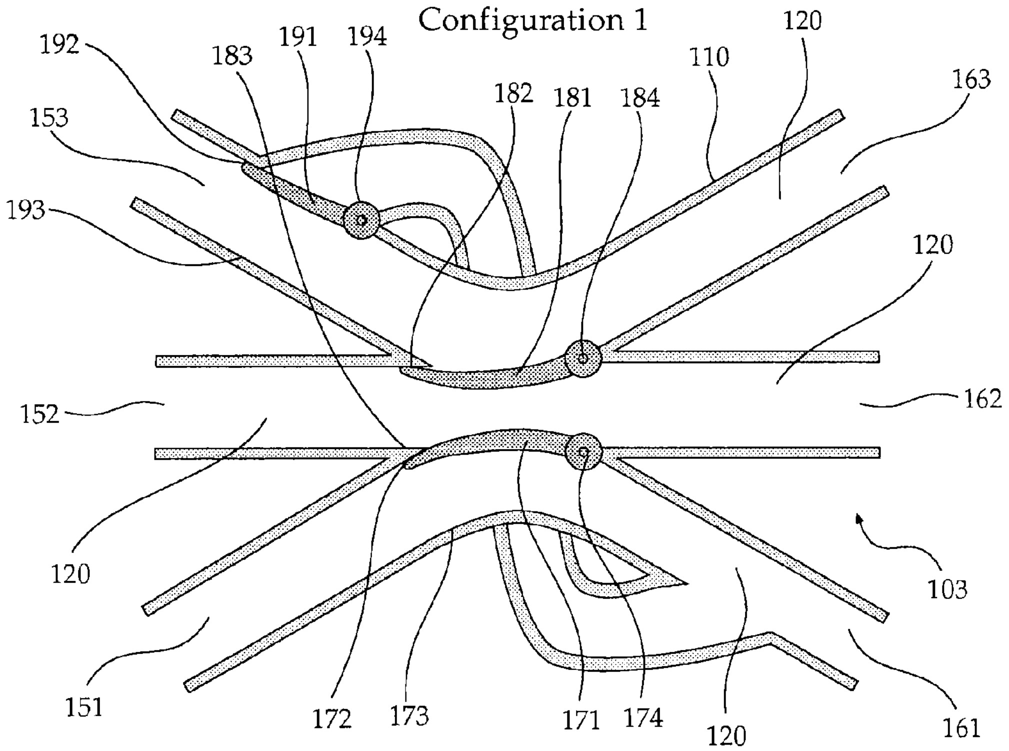

Configuration 1
192
183
191
194
120
110
163
182
181
184
153
193
120
152
162
120
103
151
172
173
171
174
120
161

FIG. 8A

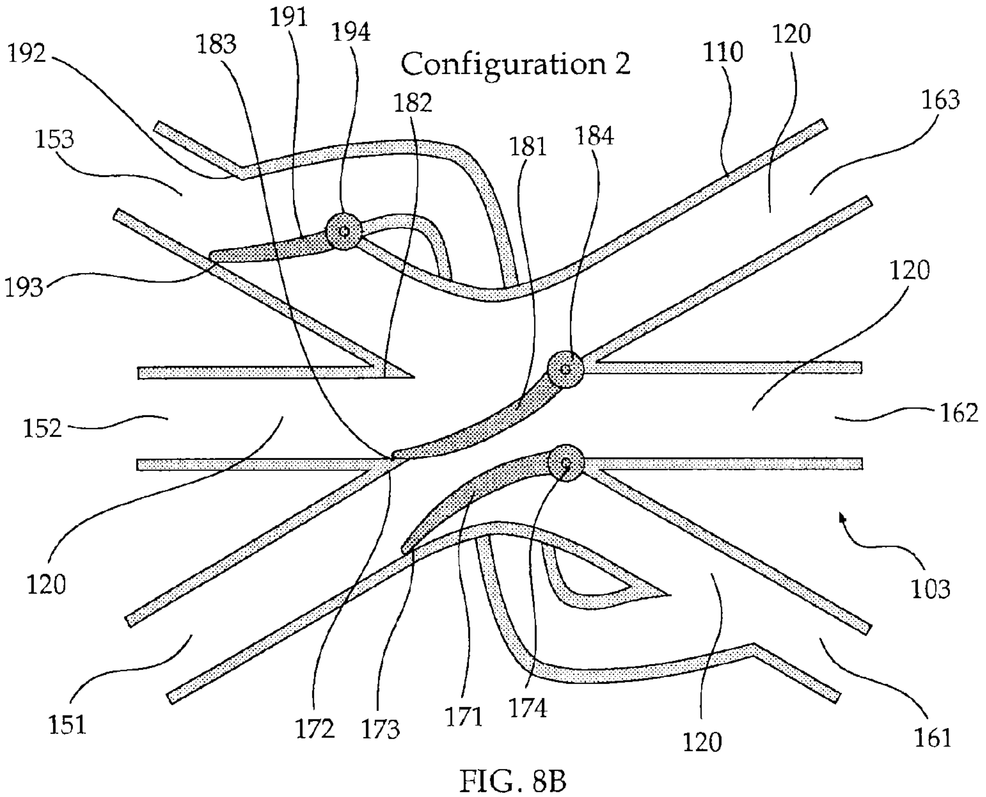

191
194
192
183
Configuration 2
110
120
182
163
181
184
153
193
120
152
162
120
103
151
172
173
171
174
120
161

FIG. 8B

Configuration 1

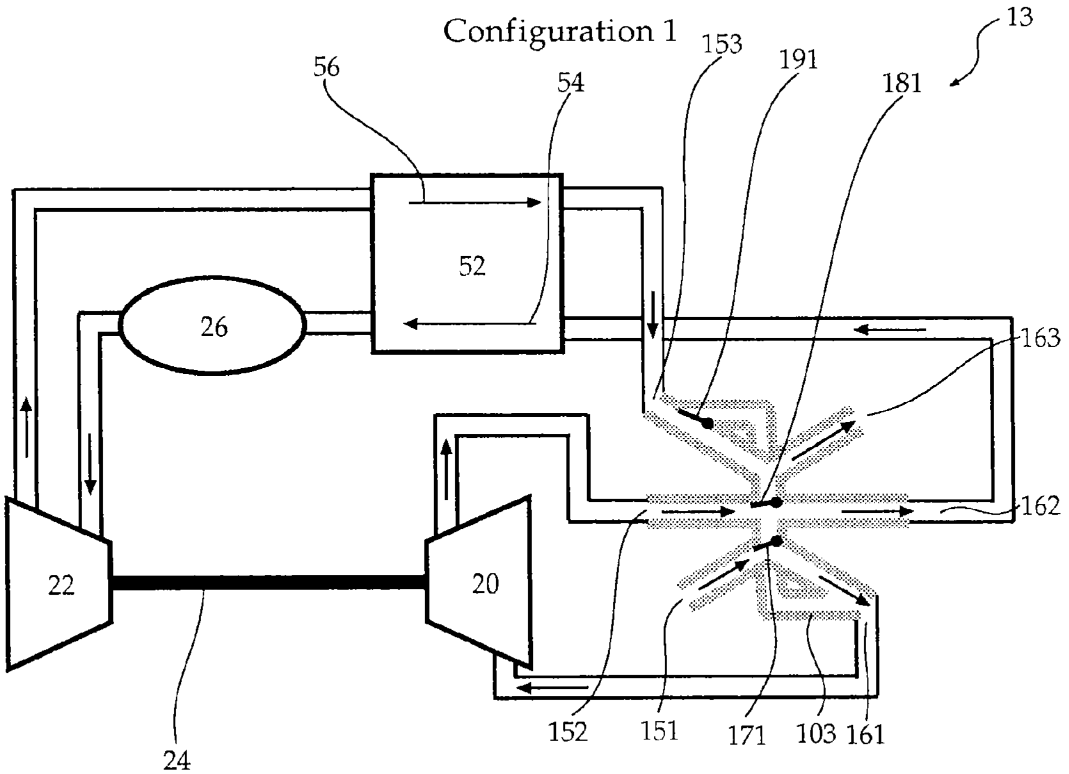


FIG. 9A

Configuration 2

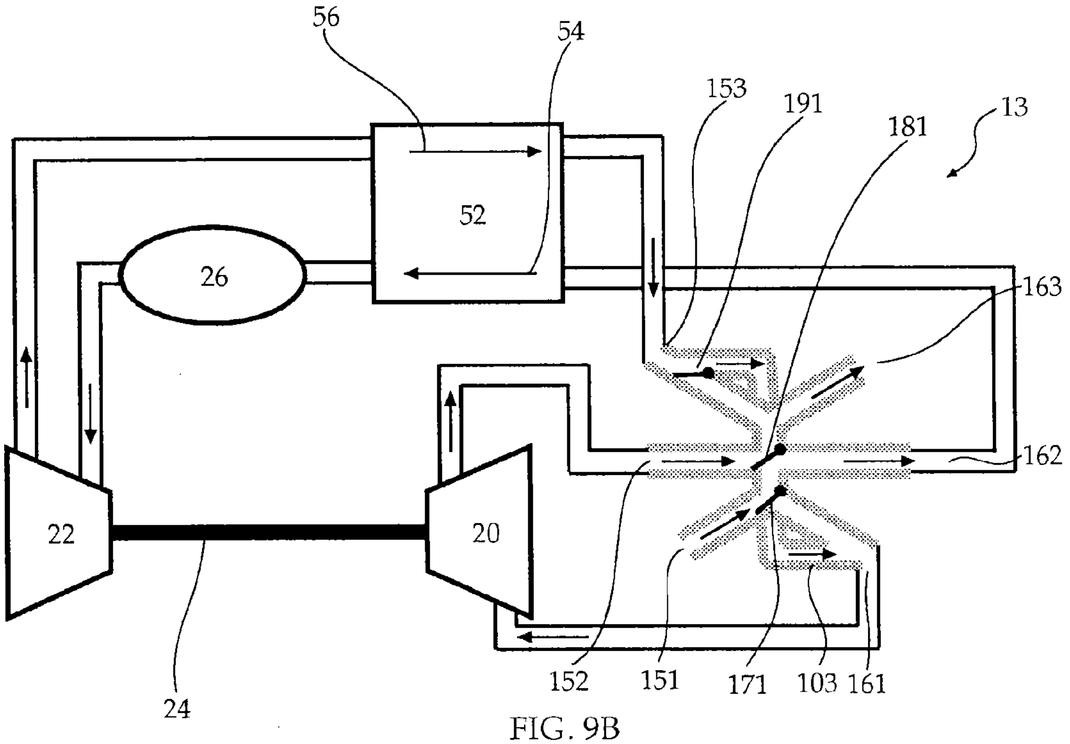


FIG. 9B

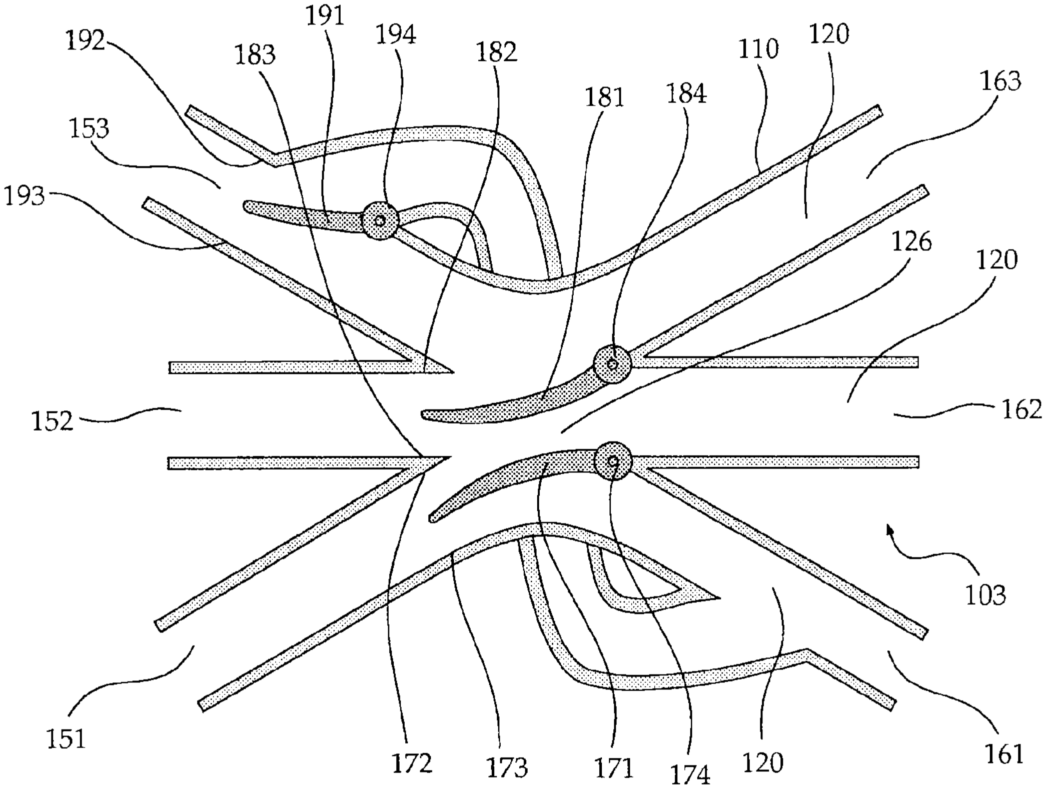

192
191
194
183
182
110
120
163
181
184
153
193
126
120
152
162
103
151
172
173
171
174
120
161

FIG. 10

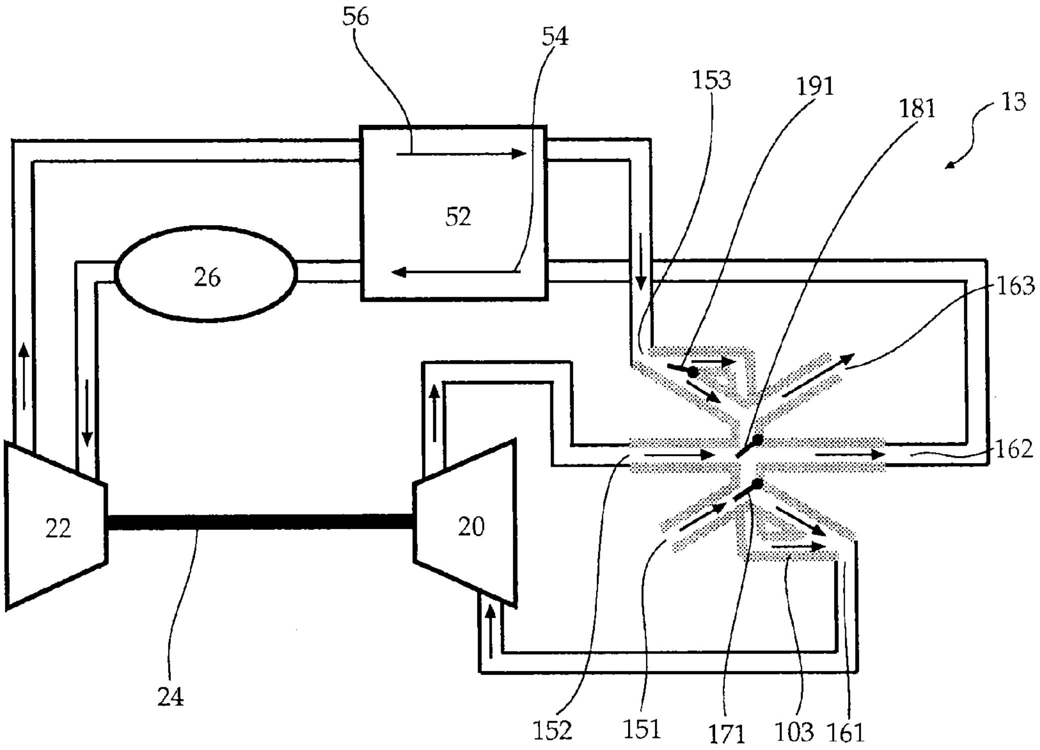


FIG. 11

Position 1

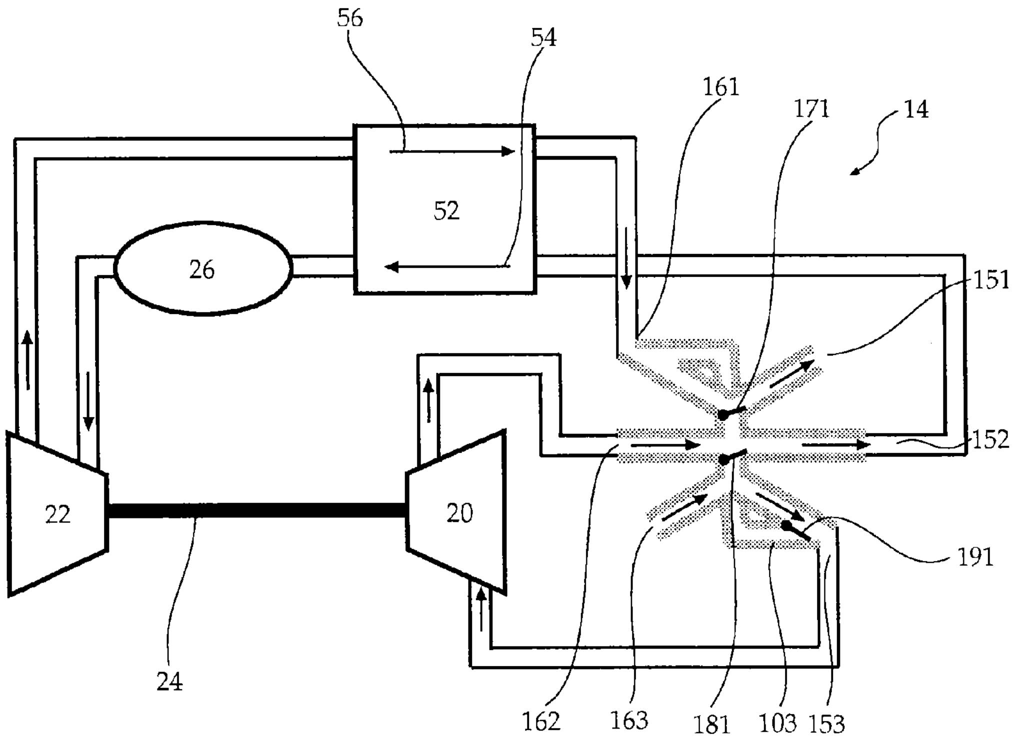


FIG. 12

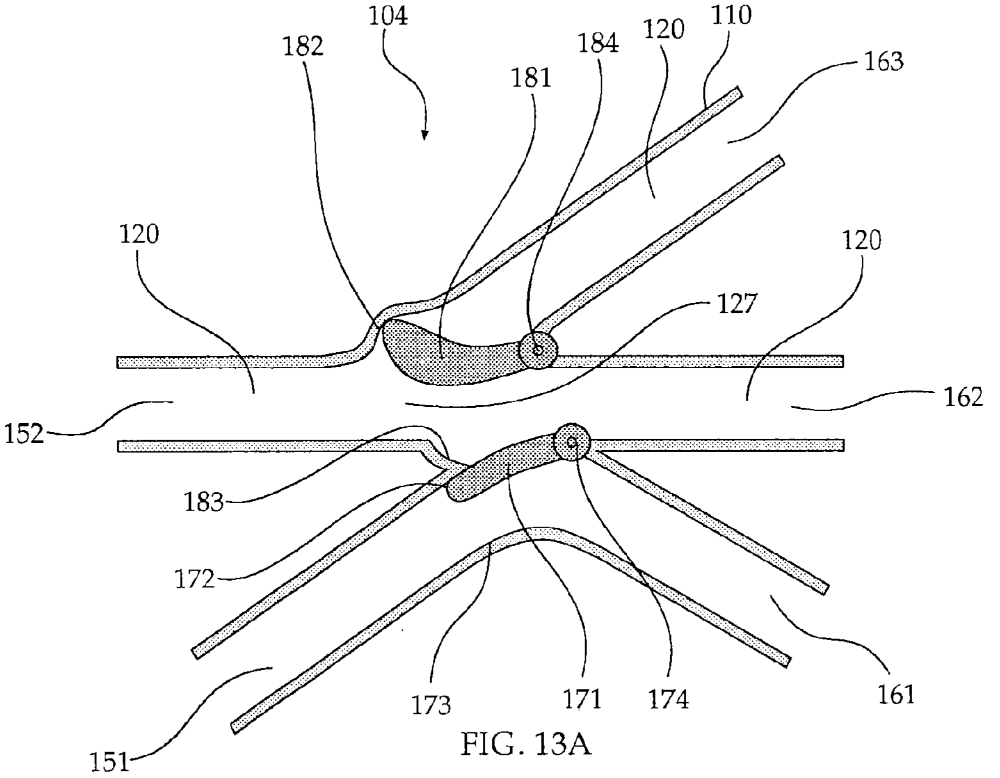


FIG. 13A

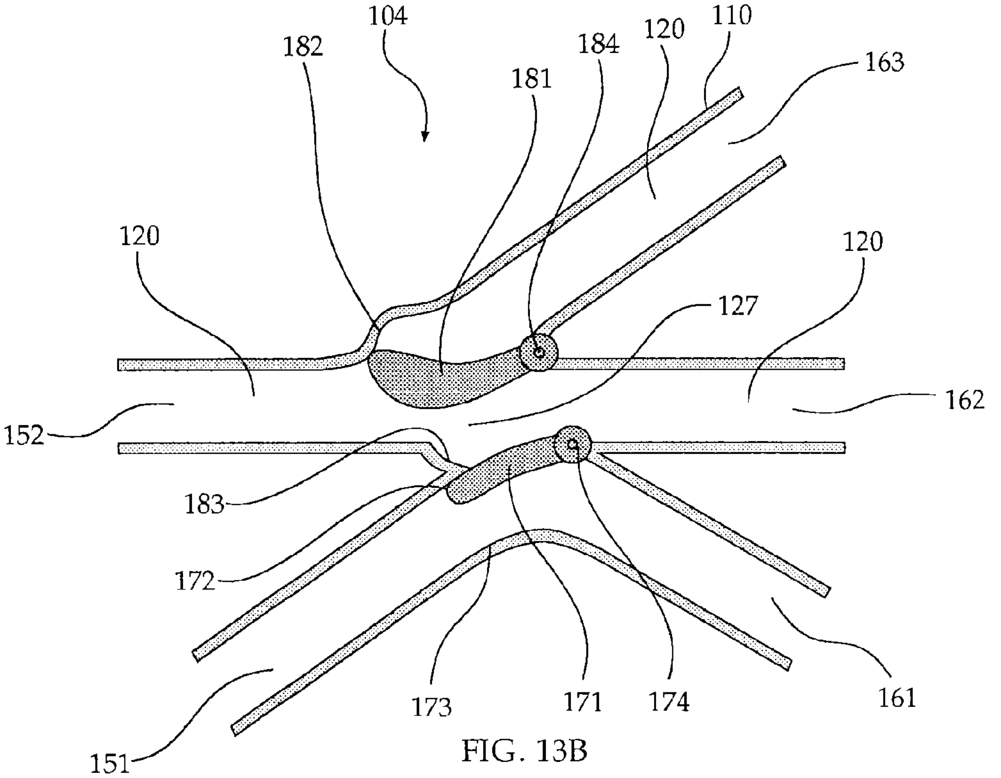


FIG. 13B

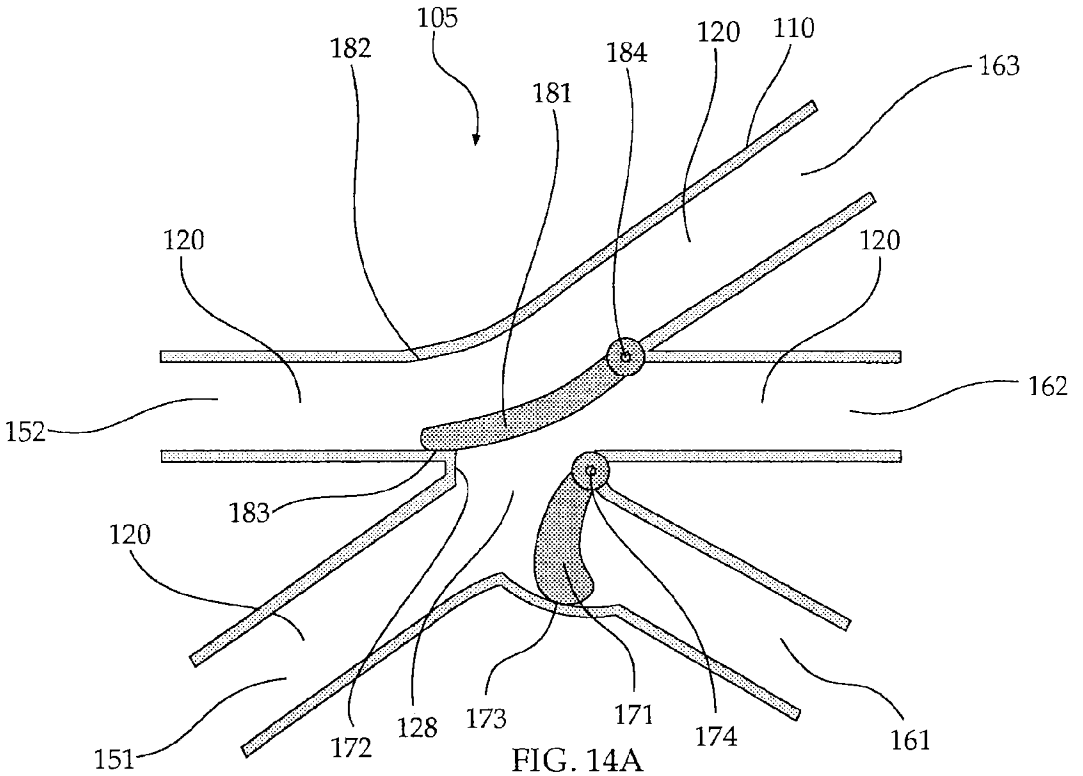


FIG. 14A

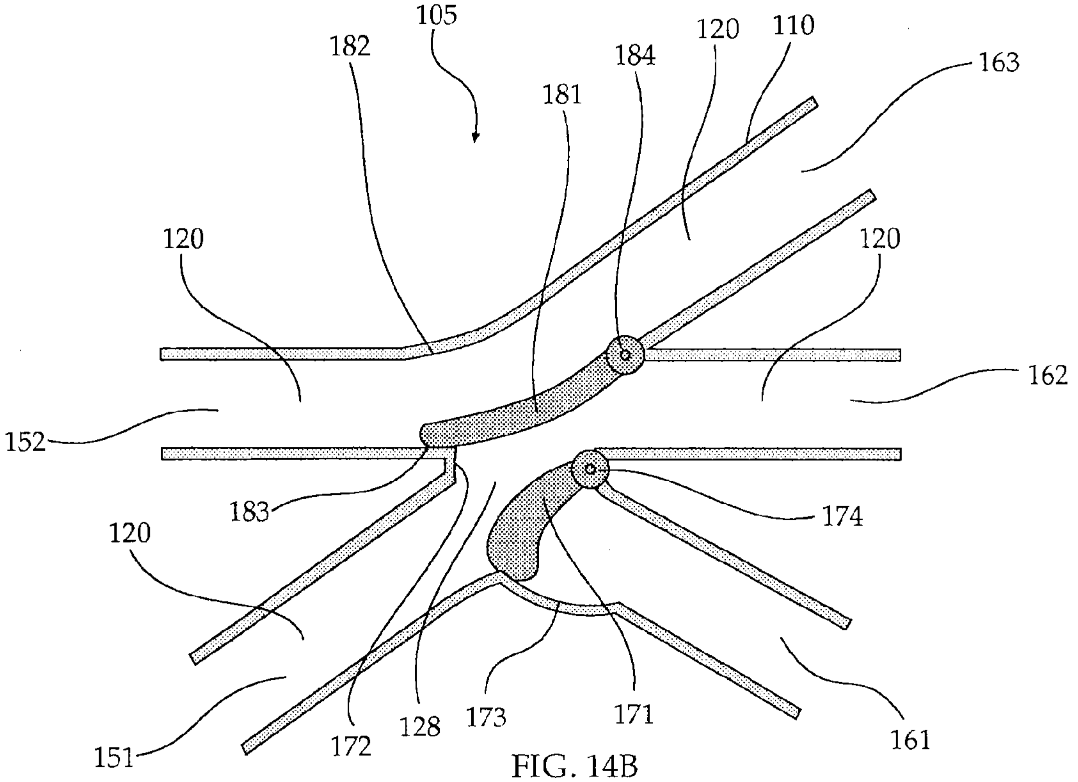


FIG. 14B

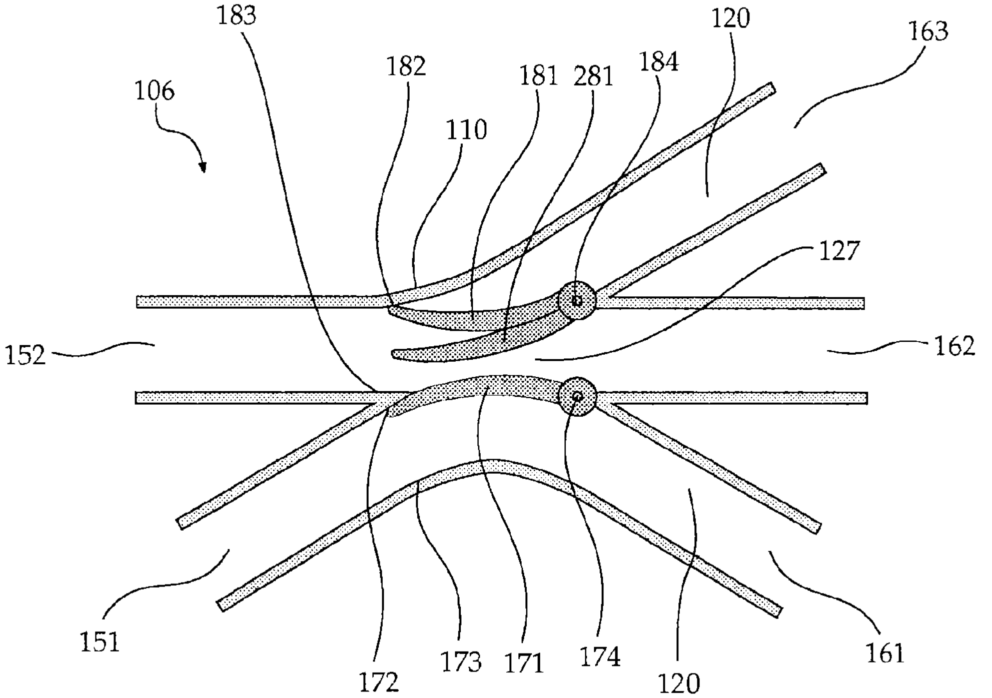


FIG. 15A

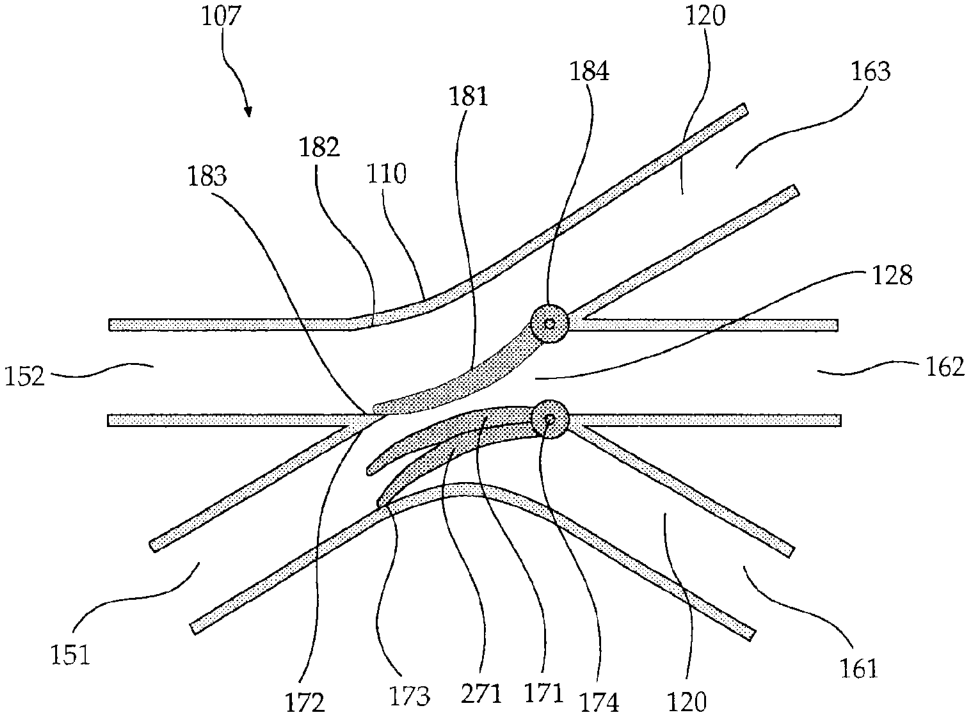


FIG. 15B

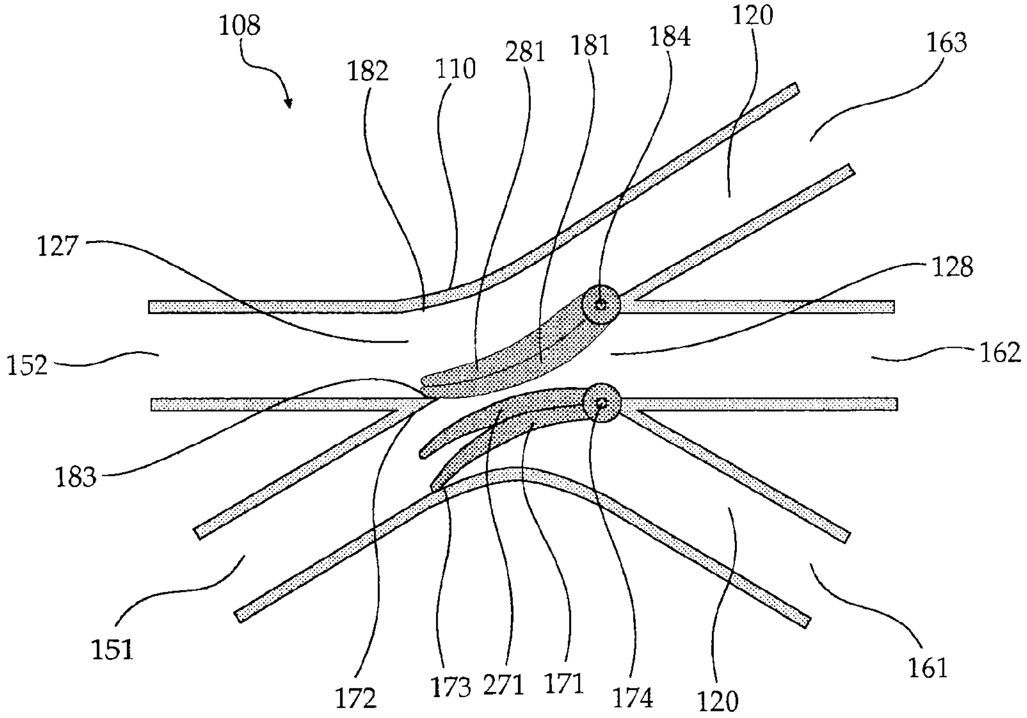

108
182
110
281
181
184
120
163
127
128
152
162
183
151
172
173
271
171
174
120
161

FIG. 15C

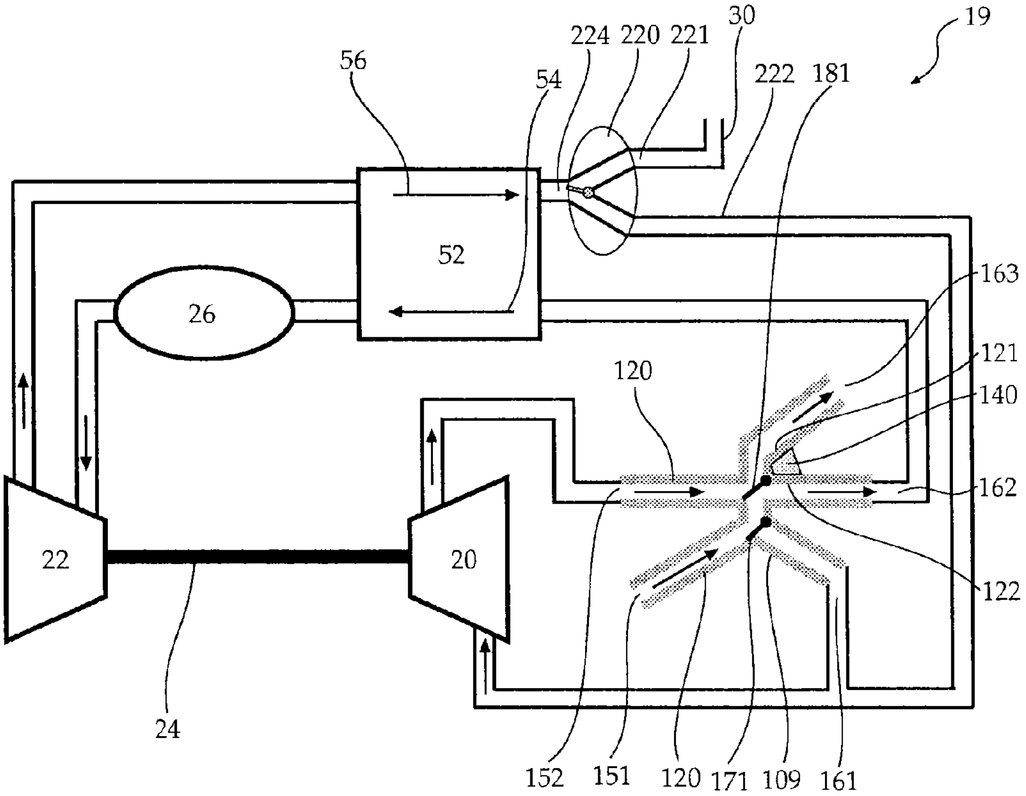

19
56
54
224
220
221
30
222
181
52
26
163
121
140
120
162
122
22
20
24
152
151
120
171
109
161

FIG .16

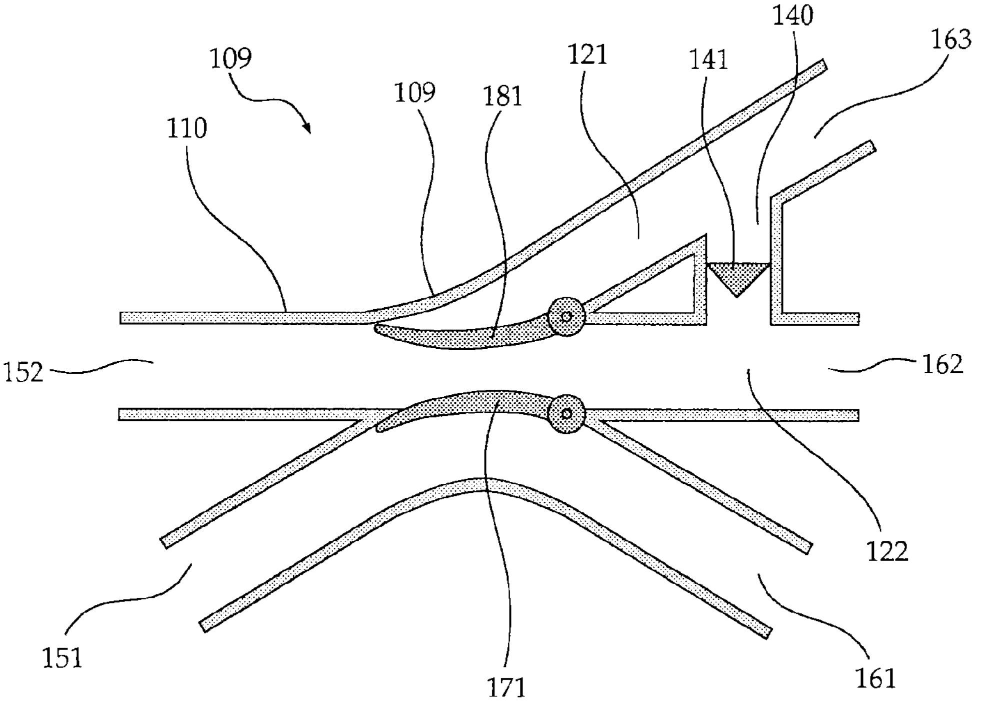


FIG. 17A

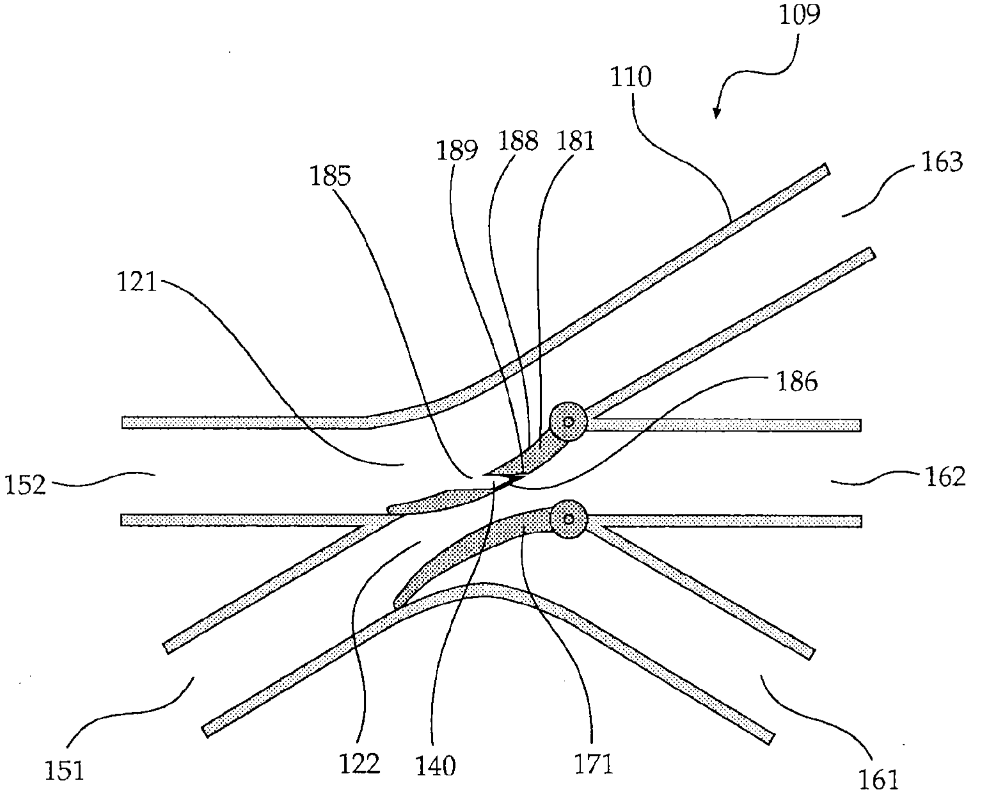


FIG .17B

VALVES FOR GAS-TURBINES AND MULTIPRESSURE GAS-TURBINES, AND GAS-TURBINES THEREWITH

RELATED APPLICATION

[0001] The present application gains priority from U.S. Provisional Patent Application No. 61/116,394 filed 20 Nov. 2008 which is included by reference as if fully set forth herein.

FIELD AND BACKGROUND OF THE INVENTION

[0002] The present invention, in some embodiments, relates to the field of gas-turbines, and more particularly, but not exclusively, to gas-turbines operable in both high-pressure (Brayton cycle) and low-pressure (inverse Brayton cycle) modes. The present invention, in some embodiments, relates to the field of gas-turbines, and more particularly, but not exclusively, to gas-turbines operable in low-pressure mode (inverse Brayton cycle).

[0003] Gas-turbines are known for being lightweight, reliable and requiring little maintenance compared to alternative work-producing motors, e.g. an internal combustion engine (ICE). Above all, gas-turbines are known for efficiently converting chemical energy stored in a combustible fuel to mechanical energy when working at an optimum work point. However, in spite of their potential, gas-turbines are currently not well known in applications requiring work-producing motors—for example ground vehicles such as cars and trucks—for several reasons.

[0004] One reason is that a given gas-turbine may generate a certain power at high efficiency for a prescribed load, but is less efficient at part load, particularly if turbine speed is maintained. Many applications, vehicular applications in particular, generally have changing power demands, for instance requiring more power for rapid acceleration or climbing hills, and requiring less power when driving in traffic.

[0005] A second reason is "turbine lag": it takes a noticeably long time for a given gas-turbine to speed-up to produce more power, e.g., for acceleration. Thus, if turbine speed is reduced when power demand is low, a sudden increased power demand can be met only after a noticeable time lag.

[0006] A third reason is that the lifetime of gas-turbines is severely limited by startup/shutdown events. Unlike an ICE, it is not practical to shut down a gas-turbine when idling.

[0007] A fourth reason is that the power requirements for many applications, e.g. ground vehicles, are low compared to the power gas-turbines efficiently produce. Although large gas-turbines are relatively efficient, the efficiency of a gas-turbine decreases with smaller size (less than 300 kW) for various reasons including leakage around the periphery of the turbine which is increasingly significant with smaller turbine size.

[0008] Commonly, gas-turbines are operated according to either a high-pressure Brayton cycle or a low-pressure inverse Brayton cycle. A gas-turbine operating according to the inverse Brayton cycle efficiently produces less power than a similar-sized gas-turbine operating according to the Brayton cycle. In FIG. **1**A a gas-turbine **2** in a typical Brayton cycle operation, and in FIG. **1**B a gas-turbine **4** in a typical inverse Brayton cycle operation, are schematically depicted. Both gas-turbines **2** and **4** comprise a compressor **20** and a turbine **22**, together mounted on a common rotatable shaft **24** constituting a spool, a combustor **26**, an air inlet **28** and an exhaust outlet **30**. One end of shaft **24** constitutes the rotor of a generator **32**. Gas-turbines **2** or **4** and generator **32** together with other components such as a fuel-supply unit **34** and a gas-turbine controller **36** constitute a power generation unit **38**.

[0009] In typical high-pressure (Brayton-cycle) operation, FIG. **1**A, ambient air is drawn through air inlet **28** into a compressor inlet (low-pressure port) **40**, and forced by compressor **20** through a compressor outlet (high-pressure port) **42** into a combustor inlet **44**. In combustor **26**, the air is mixed with fuel and the mixture combusted. The hot exhaust gases resulting from the combustion are directed through a combustor outlet **46** into a turbine inlet **48**. The hot exhaust gases expand through and rotate turbine **22**, consequently rotating shaft **24** and compressor **20** before exiting turbine **22** through a turbine outlet **50**, to be released to the surroundings through exhaust outlet **30**.

[0010] In typical low-pressure (inverse Brayton-cycle) operation, FIG. **1**B, ambient air is drawn into combustor **26** through air inlet **28** and through combustor inlet **44**. In combustor **26** the air is mixed with fuel and the mixture combusted. The hot exhaust gases resulting from the combustion are directed into turbine **22** through turbine inlet **48**. The hot exhaust gases expand through and rotate turbine **22**, consequently rotating shaft **24** and compressor **20**. The hot exhaust gases are then drawn into compressor inlet **40** and forced by compressor **20** through compressor outlet **42** and through exhaust outlet **30** to be released to the surroundings.

[0011] In both the Brayton cycle and inverse Brayton cycle, the rotation of shaft **24** by exhaust gases expanding through turbine **22** provides usable mechanical work, e.g. for generation of electric power by generator **32**.

[0012] Gas-turbines such as **2** or **4** typically include gas-turbine controller **36** that monitors and controls the gas-turbine, including by regulating the amount of fuel supplied to combustor **26** by fuel-supply unit **34**.

[0013] To increase thermal efficiency, gas-turbines such as **2** or **4** typically include a heat-exchanger **52**, such as a recuperator or regenerator. Heat-exchanger **52** includes a cold-stream conduit **54** and a hot-stream conduit **56**, both having inlets **58** and **60**, respectively, and outlets **62** and **64**, respectively. Heat-exchanger **52** increases the thermal efficiency of a gas-turbine by recovering heat from hot exhaust gases passing through hot-stream conduit **56** to preheat air passing through cold-stream conduit **54** prior to entering combustor **26**.

[0014] In U.S. Pat. Nos. 6,526,757 and 6,606,864 both of McKay are provided multipressure mode gas-turbines, gas-turbines with valving having two configurations. In a first valving configuration the gas-turbine operates in a high-pressure mode according to a Brayton cycle. In a second valving configuration the gas-turbine operates in a low-pressure mode according to an inverse Brayton cycle. The gas-turbine is toggled between the two modes by the synchronized switching of a plurality of valves between the two valving configurations changing the pressure and therefore the mass flow through the gas-turbine while maintaining a constant temperature and shaft speed, allowing two substantially equally efficient power outputs, where the power output during low-pressure mode operation is less than during high-pressure mode operation.

SUMMARY OF THE INVENTION

[0015] Aspects of the invention relate to valves suitable for use with gas-turbines that, in some embodiments, allow switching between high-pressure and low-pressure operation modes of a gas-turbine. Aspects of the invention relate to gas-turbines that are configured to operate in both high-pressure and low-pressure modes.

[0016] Aspects of the invention relate to valves suitable for use with gas-turbines that, in some embodiments, allow switching between high-pressure, low-pressure and intermediate-pressure operation modes of a gas-turbine. Aspects of the invention relate to gas-turbines that are configured to operate in high-pressure, low-pressure and intermediate-pressure modes.

[0017] Aspects of the invention relate to valves that allow simple and efficient varying of the pressure and power output of a gas-turbine, that in some embodiments is substantially continuous. Aspects of the invention relate to gas-turbines that are configured to efficiently operate in different pressure modes, allowing different power outputs at substantially similar efficiencies.

[0018] According to an aspect of some embodiments of the invention, there is provided a gas-turbine configured for operation according to both Brayton-cycle and inverse-Brayton cycle, comprising:

[0019] a) a multiport valve including movable valve members and at least five ports of which at least two inlet ports and at least two outlet ports: a compressor-outlet inlet port, an ambient inlet port, a heat-exchanger cold-stream inlet outlet port, an exhaust outlet port, and a fifth port;

[0020] b) a compressor-outlet of a compressor of the gas-turbine in fluid communication with the compressor-outlet inlet port; and

[0021] c) a heat-exchanger cold-stream inlet of a heat-exchanger of the gas-turbine in fluid communication with the heat-exchanger cold-stream inlet outlet port;

  [0022] wherein during Brayton-cycle operation of the gas-turbine,

  [0023] a valve member blocks fluid communication between the compressor-outlet inlet port and the exhaust outlet port, and

  [0024] a valve member blocks fluid communication between the ambient inlet port and the heat-exchanger cold-stream inlet outlet port;

  [0025] and

  [0026] during inverse Brayton-cycle operation of the gas-turbine,

  [0027] a valve member blocks fluid communication between the compressor-outlet inlet port and the heat-exchanger cold-stream inlet outlet port.

[0028] According to an aspect of some embodiments of the invention there is also provided a multiport valve suitable for use with a gas-turbine and allowing switching the mode of operation of a gas-turbine between a high-pressure mode according to a Brayton cycle and a low-pressure mode according to an inverse Brayton cycle, the valve comprising:

[0029] a) a valve body defining a void in the form of a plurality of fluid conduits;

[0030] b) at least five ports leading to the void of which at least two inlet ports and at least two outlet ports: a compressor-outlet inlet port, an ambient inlet port, a heat-exchanger cold-stream inlet outlet port, an exhaust outlet port and a fifth port;

[0031] c) a first valve member inside the valve body movable between at least two positions, a first position and a second position; and

[0032] d) a second valve member inside the valve body movable between at least two positions, a first position and a second position.

[0033] where the position of the first valve member and the position of the second valve member (together) define fluid communication between the inlet ports and the outlet ports through the void.

[0034] According to an aspect of some embodiments of the invention, there is also provided a gas-turbine, configured to switch between a high-pressure operation mode according to a Brayton cycle and a low-pressure operation mode according to an inverse Brayton cycle, comprising a multiport valve as described herein. In some embodiments, the gas-turbine is also configured to switch to an intermediate pressure mode between the high-pressure operation mode and the low-pressure operation mode.

[0035] Aspects of the invention relate to gas-turbines operating in low-pressure mode that have reduced NOx emissions. Thus, according to an aspect of some embodiments of the invention, there is also provided a method of operating a gas-turbine according to an inverse Brayton cycle, comprising:

[0036] a) providing a conduit allowing fluid communication between a compressor of the gas-turbine and a cold-stream inlet of a heat-exchanger of the gas-turbine; and

[0037] b) during inverse Brayton cycle operation of the gas-turbine, directing fluid from the compressor to the heat-exchanger cold-stream inlet through the conduit so that a portion of the fluid entering the heat-exchanger cold-stream inlet is from the compressor. As a result, inlet air is mixed with a portion of the oxygen-depleted exhaust from the compressor, decreasing oxygen content of the combustible mixture in the combustor, reducing the amount of NOx produced in the combustor and emitted by the gas-turbine.

[0038] According to an aspect of some embodiments of the invention, there is also provided a gas-turbine comprising, when operating according to an inverse Brayton cycle,

[0039] a) an air inlet configured to direct fluid into a cold-stream conduit of a heat-exchanger through a cold-stream inlet;

[0040] b) conduits to direct fluid from the cold-stream conduit to a combustor, from the combustor to a turbine, from the turbine to a hot-stream conduit of the heat-exchanger, from the hot-stream conduit to a compressor, and from the compressor to an exhaust outlet port; and

[0041] c) a conduit allowing passage of fluid from the compressor into the cold-stream inlet of the heat-exchanger. In some embodiments, the gas-turbine is configured to operate only according to the inverse Brayton cycle. In some embodiments, the gas-turbine is a multi-power gas-turbine configured to operate according to both the Brayton cycle and the inverse Brayton cycle.

[0042] According to an aspect of some embodiments of the invention, there is also provided a motor vehicle (e.g., an automobile, a light truck, a truck, a bus) comprising a gas-turbine substantially as described herein.

[0043] As used herein, the term "high-pressure mode" refers to operation of a gas-turbine where compressor inlet pressure is close to atmospheric (~1× ambient) and compressor outlet (exhaust) pressure is superatmospheric (typically ~3× ambient pressure).

[0044] As used herein, the term "low-pressure mode" refers to operation of a gas-turbine where compressor inlet pressure is subatmospheric (~0.3× ambient pressure) and compressor outlet (exhaust) pressure is close to atmospheric (~1× ambient pressure).

[0045] As used herein, the term "intermediate pressure mode" refers to operation of a gas-turbine where compressor inlet pressure is subatmospheric (between above 0.3× ambient pressure to ~1× ambient pressure) and compressor outlet (exhaust) pressure is higher than atmospheric (between above 1× ambient pressure to ~3× ambient pressure).

[0046] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention pertains. In case of conflict, the patent specification, including definitions, will control.

[0047] As used herein, the terms "comprising", "including", "having" and grammatical variants thereof are to be taken as specifying the stated features, integers, steps or components but do not preclude the addition of one or more additional features, integers, steps, components or groups thereof. These terms encompass the terms "consisting of" and "consisting essentially of".

[0048] As used herein, the indefinite articles "a" and "an" mean "at least one" or "one or more" unless the context clearly dictates otherwise.

BRIEF DESCRIPTION OF THE FIGURES

[0049] Some embodiments of the invention are described herein, with reference to the accompanying figures The description, together with the figures, makes apparent how embodiments of the invention may be practiced to a person having ordinary skill in the art. The figures are for the purpose of illustrative discussion of embodiments of the invention and no attempt is made to show structural details of an embodiment in more detail than is necessary for a fundamental understanding of the invention. For the sake of clarity, objects depicted in the figures are not drawn to scale.

[0050] In the Figures:

[0051] FIGS. **1**A and **1**B are schematic depictions of a Brayton cycle gas-turbine (**1**A) and an inverse Brayton cycle gas-turbine (**1**B);

[0052] FIGS. **2**A and **2**B are schematic depictions of an embodiment of a 5-port valve suitable for use with a gas-turbine in two configurations allowing the gas-turbine to operate in a high-pressure operation mode and in a low-pressure operation mode, respectively;

[0053] FIGS. **3**A and **3**B are schematic depictions of an embodiment of a gas-turbine including an embodiment of a 5-port valve of FIG. **2** where the valve is in two configurations so that the gas-turbine operates in a high-pressure operation mode and in a low-pressure operation mode, respectively;

[0054] FIG. **4** is of a conceptual graph qualitatively showing thermal efficiency as a function of power output of various embodiments of gas-turbines described herein;

[0055] FIGS. **5**A and **5**B are schematic depictions of an embodiment of a gas-turbine including an embodiment of a 5-port valve where the valve is in two configurations allowing the gas-turbine to operate in a high-pressure operation mode and in a low-pressure operation mode, respectively;

[0056] FIGS. **6**A and **6**B are schematic depictions of an embodiment of a 6-port valve suitable for use with a gas-turbine in two configurations allowing the gas-turbine to operate in a high-pressure operation mode and in a low-pressure operation mode, respectively;

[0057] FIGS. **7**A and **7**B are schematic depictions of an embodiment of a gas-turbine including an embodiment of a 6-port valve of FIG. **6** where the valve is in two configurations so that the gas-turbine operates in a high-pressure operation mode and in a low-pressure operation mode, respectively;

[0058] FIGS. **8**A and **8**B are schematic depictions of an embodiment of a 6-port valve suitable for use with a gas-turbine in two configurations allowing the gas-turbine to operate in a high-pressure operation mode and in a low-pressure operation mode, respectively;

[0059] FIGS. **9**A and **9**B are schematic depictions of an embodiment of a gas-turbine including an embodiment of a 6-port valve of FIG. **8** where the valve is in two configurations so that the gas-turbine operates in a high-pressure operation mode and in a low-pressure operation mode, respectively;

[0060] FIG. **10** is a schematic depiction of an embodiment of a valve suitable for use with a gas-turbine, allowing the gas-turbine to operate in at least one intermediate pressure operation mode in addition to a low-pressure operation mode and a high-pressure operation mode;

[0061] FIG. **11** is a schematic depiction of an embodiment of a gas-turbine including an embodiment of a valve of FIG. **10**, where the valve is set so that the gas-turbine operates in an intermediate pressure operation mode;

[0062] FIG. **12** is a schematic depiction of an embodiment of a gas-turbine including an embodiment of a six-port valve similar to the valve depicted in FIG. **10**;

[0063] FIGS. **13**A and **13**B are schematic depictions of an embodiment of a 5-port valve useful for continuously varying the mass flow to the combustor of a gas-turbine in a high-pressure operation mode, in high and low-mass flow rate configurations, respectively;

[0064] FIGS. **14**A and **14**B are schematic depictions of an embodiment of a 5-port valve useful for continuously varying the mass flow to the combustor of a gas-turbine in a low-pressure operation mode, in high and low mass flow rate configurations, respectively;

[0065] FIGS. **15**A, **15**B and **15**C are schematic depictions of embodiments of valves useful for continuously varying the mass flow to the combustor of a gas-turbine high and low-pressure operation modes;

[0066] FIG. **16** is a gas-turbine including a valve suitable for switching the gas-turbine between at least two pressure level operation modes and useful for reducing NOx emissions of the gas-turbine when in low-pressure operation mode; and

[0067] FIGS. **17**A and **17**B are two embodiments of a permeable section in a multiport valve suitable for use in a gas turbine and useful for reducing NOx emissions of the gas-turbine as described herein.

DESCRIPTION OF SOME EMBODIMENTS OF THE INVENTION

[0068] Some embodiments of the invention relate to multiport valves that allow switching between high-pressure operation (Brayton cycle) and low-pressure operation (inverse Brayton cycle) modes of a gas-turbine.

[0069] Some embodiments of the invention relate to multiport valves that allow operation of a gas-turbine in high-pressure, low-pressure and intermediate pressure modes.

[0070] Some embodiments of the invention relate to multiport valves that allow operation of a gas-turbine at a variable power output in high-pressure modes and/or low-pressure modes at relatively high efficiency by varying the mass flow through the gas-turbine. Some embodiments of the invention relate to valves that allow simple and efficient varying of the pressure, mass flow and power output of a gas-turbine, that in some embodiments is substantially continuous.

[0071] Some embodiments of the invention relate to gas-turbines operating in a low-pressure mode (inverse Brayton mode) having reduced NOx emissions as well as valves useful for such gas-turbines.

[0072] The principles, uses and implementations of the teachings of the invention may be better understood with reference to the accompanying description and Figures. Upon perusal of the description and figures present herein, one skilled in the art is able to implement the teachings of the invention without undue effort or experimentation, including by consulting U.S. Pat. No. 6,526,757, which is included by reference as if fully set forth herein. In the Figures, like reference numerals refer to like parts throughout.

[0073] Before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not necessarily limited in its application to the details of construction and the arrangement of the components and/or methods set forth herein. The invention is capable of other embodiments or of being practiced or carried out in various ways. The phraseology and terminology employed herein are for descriptive purpose and should not be regarded as limiting.

[0074] As noted in the introduction, in U.S. Pat. Nos. 6,526,757 and 6,606,864 are disclosed gas-turbines provided with valving that allow the gas-turbines to switch between high-pressure operation with efficient high-power output and low-pressure operation with efficient low-power output. However, a problem with the gas-turbines as described in U.S. Pat. Nos. 6,526,757 and 6,606,864 is that of complexity: the valving system of a simplest embodiment includes six separate on-off valves that must be operated synchronously to toggle between the two modes. Furthermore, in order to achieve additional, intermediate pressure—and thus intermediate power—turbine operation modes, even more complex embodiments which include more than one spool and many separate valves, must be employed.

[0075] It has been found that it is possible to simplify the valving system necessary to allow a gas-turbine to switch between high-pressure and low-pressure operation.

[0076] Thus, according to an aspect of some embodiments of the invention, there is provided a gas-turbine configured to switch between a high-pressure operation mode according to a Brayton cycle and a low-pressure operation mode according to an inverse Brayton cycle, comprising:

[0077] a) a multiport valve including movable valve members and at least five ports of which at least two inlet ports and at least two outlet ports: a compressor-outlet inlet port, an ambient inlet port, a heat-exchanger cold-stream inlet outlet port, an exhaust outlet port, and a fifth port;

[0078] b) a compressor outlet of a compressor of the gas-turbine in fluid communication with the compressor-outlet inlet port; and

[0079] c) a heat-exchanger cold-stream inlet of a heat-exchanger of the gas-turbine in fluid communication with the heat-exchanger cold-stream inlet outlet port;

wherein during Brayton-cycle operation of the gas-turbine, a valve member blocks fluid communication between the compressor-outlet inlet port and the exhaust outlet port and a valve member blocks fluid communication between the ambient inlet port and the heat-exchanger cold-stream inlet outlet port; and during inverse Brayton-cycle operation of the gas-turbine, a valve member blocks fluid communication between the compressor-outlet inlet port and the heat-exchanger cold-stream inlet outlet port.

[0080] In some embodiments, the fifth port is a compressor-inlet outlet port in fluid communication with an inlet of the compressor of the gas-turbine, and during inverse Brayton-cycle operation of the gas-turbine, a valve member blocks fluid communication between the ambient inlet port and the compressor-inlet outlet port. In some such embodiments, the gas-turbine further comprises an additional valve functionally associated with the hot-stream outlet of the heat-exchanger, wherein during inverse Brayton-cycle operation of the gas-turbine, the additional valve allows fluid communication from the hot-stream outlet of the heat-exchanger to an inlet of the compressor. In some such embodiments, during Brayton-cycle operation of the gas-turbine, the additional valve allows fluid communication from the hot-stream outlet of the heat-exchanger to an exhaust outlet of the gas-turbine. An exemplary such embodiment is depicted in FIGS. **3**A and **3**B.

[0081] In some embodiments, the fifth port is a heat-exchanger hot-stream outlet inlet port in fluid communication with a hot-stream outlet of the heat-exchanger of the gas-turbine, and during inverse Brayton-cycle operation of the gas-turbine, a valve member blocks fluid communication between the heat-exchanger hot-stream outlet inlet port and the exhaust outlet port. In some such embodiments, the gas-turbine further comprises an additional valve functionally associated with a hot-stream outlet of the heat-exchanger of the gas-turbine, and during inverse Brayton-cycle operation of the gas-turbine, the additional valve allows fluid communication from the hot-stream outlet of the heat-exchanger to an inlet of the compressor. In some embodiments, during Brayton-cycle operation of the gas-turbine, the additional valve allows fluid communication from ambient to an inlet of the compressor. An exemplary such embodiment is depicted in FIGS. **5**A and **5**B.

[0082] In some embodiments, the multiport valve includes six ports, of which three are inlet ports and three are outlet ports.

[0083] In some such embodiments where the multiport valve includes six ports, the fifth port is a compressor-inlet outlet port in fluid communication with an inlet of the compressor, and during inverse Brayton-cycle operation of the gas-turbine a valve member blocks fluid communication between the ambient inlet port and the compressor-inlet outlet port; and the multiport valve further includes a sixth port, a heat-exchanger hot-stream outlet inlet port in fluid communication with a hot-stream outlet of the heat-exchanger of the gas-turbine.

[0084] In some embodiments including such a six-port valve, the gas-turbine further comprises an additional valve functionally associated with a hot-stream outlet of the heat-exchanger of the gas-turbine, and during inverse Brayton-cycle operation of the gas-turbine, the additional valve allows fluid communication from the hot-stream outlet of the heat-exchanger of the gas-turbine to an inlet of the compressor of the gas-turbine. In some such embodiments, during Brayton-cycle operation of the gas-turbine, the additional valve allows fluid communication from the hot-stream outlet of the heat-exchanger of the gas-turbine to an exhaust outlet of the gas-turbine through the heat-exchanger hot-stream outlet inlet port. In some such embodiments, the gas-turbine further comprises a component functionally associated with the heat-exchanger hot-stream outlet inlet port, allowing flow of fluid from the hot-stream outlet of the heat-exchanger through the heat-exchanger hot-stream outlet inlet port and blocking flow of fluid from the multiport valve to the hot-stream outlet of the heat-exchanger through the heat-exchanger hot-stream outlet inlet port. In some such embodiments, the component is a undirectional valve that is part of the multiport valve. An exemplary such embodiment is depicted in FIGS. **7**A and **7**B.

[0085] In some such embodiments where the multiport valve includes six ports, the multiport valve further comprising a bypass conduit bypassing the valve void, providing fluid communication between the heat-exchanger hot-stream outlet inlet port and the compressor-inlet outlet port, wherein during Brayton-cycle operation of the gas-turbine, a valve member blocks the fluid communication between the heat-exchanger hot-stream outlet inlet port and the compressor-inlet outlet port through the bypass conduit. An exemplary such embodiment is depicted in FIGS. **9**A and **9**B.

[0086] According to an aspect of some embodiments of the invention there is also provided a multiport valve suitable for use with a gas-turbine and allowing switching the mode of operation of a gas-turbine between a high-pressure mode according to a Brayton cycle and a low-pressure mode according to an inverse Brayton cycle, the valve comprising:

[0087] a) a valve body defining a void in the form of a plurality of fluid conduits;

[0088] b) at least five ports leading to the void of which at least two inlet ports and at least two outlet ports: a compressor-outlet inlet port, an ambient inlet port, a heat-exchanger cold-stream inlet outlet port, an exhaust outlet port and a fifth port;

[0089] c) a first valve member inside the valve body movable between at least two positions, a first position and a second position; and

[0090] d) a second valve member inside the valve body movable between at least two positions, a first position and a second position

where the position of the first valve member and the position of the second valve member (together) define fluid communication between the inlet ports and the outlet ports through the void.

[0091] In some embodiments, the first valve member and the second valve member are configured to cooperatively move between the first positions and the second positions. In some embodiments, the first valve member and the second valve member are configured to move independently between the first positions and the second positions.

[0092] In some embodiments, in the first position the first valve member is in contact with a first valve seat and in the second position in contact with a second valve seat. In some embodiments, in the first position the second valve member is in contact with a third valve seat and in the second position in contact with a third valve seat.

[0093] As detailed hereinbelow, in some embodiments, in a first or second position a given valve member blocks fluid communication between specific ports. By blocking fluid communication is meant that the fluid communication between the ports is blocked to a sufficient degree to achieve the desired purpose (e.g., operating an associated gas-turbine in a desired mode), although there may be some leakage, for example as described below. As detailed hereinbelow, in some embodiments, in a first or second position a given valve member contacts a specific valve seat. By contacting a valve seat is meant contacting to a sufficient degree to achieve a desired purpose as described immediately herein above, for example, in some embodiments is meant “sealing contact”.

[0094] In some embodiments, the first valve member in the first position blocks fluid communication (through the void) between the ambient inlet port and the heat-exchanger cold-stream inlet outlet port and in the second position blocks fluid communication (through the void) between the ambient inlet port and the fifth port, a compressor inlet outlet port; and the second valve member in the first position blocks fluid communication (through the void) between the compressor-outlet inlet port and the exhaust outlet port and in the second position blocks fluid communication (through the void) between the compressor-outlet inlet port and the heat-exchanger cold-stream inlet outlet port. An exemplary such embodiment is valve **100** depicted in FIGS. **2** and **3**.

[0095] In some embodiments, the first valve member in the first position blocks fluid communication (through the void) between the compressor-outlet inlet port and the exhaust outlet port and in the second position blocks fluid communication (through the void) between the fifth port, a heat-exchanger hot-stream outlet inlet port, and the exhaust outlet port; and the second valve member in the first position blocks fluid communication (through the void) between the ambient inlet port and the heat-exchanger cold-stream inlet outlet port and in the second position blocks fluid communication (through the void) between the compressor-outlet inlet port and the heat-exchanger cold-stream inlet outlet port. An exemplary such embodiment is depicted in FIG. **5**.

[0096] In some embodiments, the first valve member in the first position blocks fluid communication (through the void) between the ambient inlet port and the heat-exchanger cold-stream inlet outlet port and in the second position blocks fluid communication (through the void) between the ambient inlet port and the fifth port, a compressor inlet outlet port; and the second valve member in the first position blocks fluid communication (through the void) between a sixth port, a heat-exchanger hot-stream outlet inlet port, and the heat-exchanger cold-stream inlet outlet port and in the second position blocks fluid communication (through the void) between the compressor-outlet inlet port and the heat-exchanger cold-stream inlet outlet port. An exemplary such embodiment is depicted in FIGS. **6** and **7**. In some embodiments, the valve further comprises a component functionally associated with the heat-exchanger hot-stream outlet inlet port, allowing flow of fluid into the void through the heat-exchanger hot-stream outlet inlet port and blocking flow of fluid from the void out through the heat-exchanger hot-stream outlet inlet port. In some such embodiments the component is a unidirectional valve (e.g., a check valve, in some embodiments located inside the valve body) configured to allow fluid to flow into the void of the valve body through the heat-exchanger hot-stream outlet inlet port but to block the flow of fluid from the valve body out through the heat-exchanger hot-stream outlet inlet port.

[0097] In some embodiments, the valve further comprises a bypass conduit providing fluid communication bypassing the valve void between the heat-exchanger hot-stream outlet inlet port and the compressor inlet outlet port, and a third valve member inside the valve body movable between at least two positions, a first position and a second position, wherein in the first position the third valve member blocks fluid communication through the bypass conduit between the heat-exchanger hot-stream outlet inlet port and the compressor inlet outlet port through the bypass conduit and in the second position the third valve member blocks fluid communication through the void between the heat-exchanger hot-stream outlet inlet port and the exhaust outlet port. In some embodiments, in the first position the third valve member is in contact with a fifth valve seat and in the second position the third valve member is in contact with a sixth valve seat. An exemplary such embodiment is depicted in FIG. **8**. In some such embodiments, the first valve member, the second valve member and the third valve member are configured to cooperatively move between the first positions and the second positions. In some such embodiments, at least one of the first valve member, the second valve member and the third valve member is configured to move between the first position and the second position independently of at least one other of the valve members.

[0098] In some embodiments of the multiport valve at least one of the valve members is movable to at least one intermediate position between a respective first position and respective second position, thereby allowing fluid communication (through the void) between an inlet port and at least two outlet ports. In some such embodiments, at least one valve member is fashioned as an airfoil having an aerodynamic profile (generally predefined aerodynamic profile) configured to direct the flow of fluid as desired through the fluid conduits of the valve body.

[0099] In some embodiments, the second valve member is movable to at least one intermediate position, providing fluid communication (through the void) between the compressor-outlet inlet port and the heat-exchanger cold-stream inlet outlet port and the exhaust outlet port. Exemplary such embodiments include valve **100**, valve **102** and valve **103** depicted in FIGS. **10** and **11**. In some such embodiments, the second valve member is movable to a plurality of such intermediate positions, allowing variation of the relative size of the path between the compressor-outlet inlet port and the heat-exchanger cold-stream inlet outlet port to the relative size of the path between the compressor-outlet inlet port and the exhaust outlet port.

[0100] In some embodiments, the first valve member is movable to an intermediate position, providing fluid communication between the ambient inlet port and the heat-exchanger cold-stream inlet outlet port and the compressor-inlet outlet port. Exemplary such embodiments include valve **100**, valve **102** and valve **103** depicted in FIGS. **10** and **11**. In some such embodiments, the first valve member is movable to a plurality of such intermediate positions, allowing variation of the relative size of the path between the ambient inlet port and the heat-exchanger cold-stream inlet outlet port to the relative size of the path between the ambient inlet port and the compressor inlet outlet port.

[0101] In some embodiments comprising a third valve member, the third valve member is movable to an intermediate position, providing fluid communication between the heat-exchanger hot-stream outlet inlet port and the exhaust outlet port and the compressor-inlet outlet port. An exemplary such embodiment is valve **103** depicted in FIGS. **10** and **11**. In some such embodiments, the third valve member is movable to a plurality of such intermediate positions, allowing variation of the relative size of the path between the heat-exchanger hot-stream outlet inlet port and the exhaust outlet port to the relative size of the path between the heat-exchanger hot-stream outlet inlet port and the compressor-inlet outlet port.

[0102] In some embodiments, at least one valve member is configured to vary a size of a fluid path between an inlet port and an outlet port while the valve member in the first position and/or the second position.

[0103] In some embodiments, the second valve member is configured to vary a size of a fluid path between the compressor-outlet inlet port and the heat-exchanger cold-stream inlet outlet port when in the first position. An exemplary such embodiment is depicted in FIG. **13**.

[0104] In some embodiments, the first valve member is configured to vary a size of a fluid path between the ambient inlet port and the heat-exchanger cold-stream inlet outlet port when in the second position. An exemplary such embodiment is depicted in FIG. **14**.

[0105] In some embodiments, the multiport valve further comprises an additional valve member movable inside the valve body and, the additional valve member configured to vary a size of a fluid path between the compressor-outlet inlet port and the heat-exchanger cold-stream inlet outlet port. An exemplary such embodiment is depicted in FIGS. **15**A and **15**C.

[0106] In some embodiments, the multiport valve further comprises an additional valve member movable inside the valve body and configured to vary a size of a fluid path between the ambient inlet port and the heat-exchanger cold-stream inlet outlet port. An exemplary such embodiment is depicted in FIGS. **15**B and **15**C.

[0107] In some embodiments, the valve further comprises a permeable section between a first region and a second region of the void in the valve body, providing fluid communication between the first region and the second region. Such a permeable section may be implemented in any suitable way including a conduit, slits, pores and the like. The utility of such a permeable section is described hereinbelow. In some such embodiments, the first region is in proximity of the exhaust outlet port and in some such embodiments between the second valve member and the exhaust outlet port. In some such embodiments, the second region is in proximity of the heat-exchanger cold-steam inlet outlet port and in some such embodiments between the second valve member and heat-exchanger cold-stream inlet outlet port. In some such embodiments, the permeable section is unidirectional, allowing passage of fluid from the first region to the second region, and blocking passage of fluid from the second region to the first region. Such a unidirectional permeable section may be implemented in any suitable way including with the help of a unidirectional valve, a check valve (a unidirectional valve that functions automatically without an external control, e.g. variants of a swing check valve or reed valve) or a pump. In some embodiments, the permeable section is part of the second valve member.

[0108] According to an aspect of some embodiments of the invention, there is also provided a gas-turbine, configured to switch between a high-pressure operation mode according to a Brayton cycle and a low-pressure operation mode according to an inverse Brayton cycle, comprising a multiport valve as described herein. In some embodiments, the gas-turbine is also configured to switch to an intermediate pressure mode between the high-pressure operation mode and the low-pressure operation mode.

Embodiment of 5-Port Valve Suitable for Use with a Gas-Turbine

[0109] FIGS. **2**A and **2**B depict an embodiment of a valve **100**, suitable for use with a gas-turbine, in side cross-section. Valve **100** comprises a valve body **110** defining a single void in the form of a plurality of fluid conduits **120**. Valve **100** further includes two inlet ports and three outlet ports: an ambient inlet port **151**, a compressor-outlet inlet port **152**, a compressor-inlet outlet port **161**, a heat-exchanger cold-stream inlet outlet port **162** and an exhaust outlet port **163**, the five ports in fluid communication one with the other through fluid conduits **120**. Valve **100** further includes a first valve member **171** and a second valve member **181**. First valve member **171** is movable inside valve body **110** between at least two positions: a first position, depicted in FIG. **2**A, in contact with a first valve seat **172** in valve body **110** blocking fluid communication between ambient inlet port **151** and heat-exchanger cold-stream inlet outlet port **162** and a second position, depicted in FIG. **2**B, in contact with a second valve seat **173** in valve body **110** blocking fluid communication between ambient inlet port **151** and compressor-inlet outlet port **161**. Second movable valve member **181** is movable inside valve body **110** between at least two positions: a first position, depicted in FIG. **2**A, in contact with a third valve seat **182** in valve body **110** blocking fluid communication between compressor-outlet inlet port **152** and exhaust outlet port **163** and a second position, depicted in FIG. **2**B, in contact with a fourth valve seat **183** in valve body **110** blocking fluid communication between compressor-outlet inlet port **152** and heat-exchanger cold-stream inlet outlet port **162**.

[0110] First movable valve member **171** is movable between the first and second positions by rotating around a first valve member axis **174**. Second movable valve member **181** is movable between the first and second positions by rotating around a second valve member axis **184**.

[0111] When valve members **171** and **181** are in the respective first position depicted in FIG. **2**A (configuration “**1**”), valve **100** allows an associated gas-turbine to operate in high-pressure operation mode, as is described further below. When valve members **171** and **181** are in the respective second position depicted in FIG. **2**B (configuration "**2**"), valve **100** allows an associated gas-turbine to operate in low-pressure operation mode.

[0112] In some embodiments, valve members **171** and **181** are configured for cooperative movement, that is to say both valve members move together between the first position (FIG. **2**A) and the second position (FIG. **2**B). In some embodiments, valve members **171** and **181** are independently operable. For example, in such embodiments valve member **171** may be in contact with first valve seat **172** (first position, FIG. **2**A), while second movable valve member **181** is in contact with fourth valve seat **183** (second position, FIG. **2**B).

[0113] In some embodiments valve members **171** and **181** are configured for positioning in at least one intermediate position, between the first positions and the second positions, allowing fluid from a given inlet port to flow to two outlet ports. Specifically, a portion of the fluid entering valve **100** from ambient inlet port **151** is directed to compressor-inlet outlet port **161**, and another portion is directed to heat-exchanger cold-stream inlet outlet port **162**. Similarly, a portion of the fluid entering through compressor-outlet inlet port **152** is directed to heat-exchanger cold-stream inlet outlet port **162** and another portion is directed to exhaust outlet port **163**. The utility of some such intermediate positions is described hereinbelow.

Gas-Turbine with 5-Port Valve **100**

[0114] FIG. **3** schematically depict an exemplary embodiment of a gas-turbine **10**, comprising a valve **100** (as described above) operable in a Brayton cycle (FIG. **3**A) and in an inverse Brayton cycle (FIG. **3**B). Gas-turbine **10** further includes compressor **20** and turbine **22**, together mounted on a common rotatable shaft **24** constituting a spool, combustor **26** and heat-exchanger **52**. Gas-turbine **10** also includes a 3-way valve **220** having an inlet **224** and two outlets, **221** and **222**. Valve **220** may be positioned as depicted in FIG. **3**A to providing fluid communication between inlet **224** and outlet **221**, or as depicted in FIG. **3**B providing fluid communication between inlet **224** and outlet **222**.

[0115] Valve **100** is configured to switch gas-turbine **10** between a high-pressure operation mode (Brayton cycle) depicted in FIG. **3**A, and a low-pressure operation mode (inverse Brayton cycle) depicted in FIG. **3**B.

[0116] In FIG. **3**A (configuration "**1**") both valve members **171** and **181** of valve **100** are in a first position (as in FIG. **2**A) directing fluid entering through ambient inlet port **151** to compressor-inlet outlet port **161**, and fluid entering through compressor-outlet inlet port **152** to heat-exchanger cold-stream inlet outlet port **162**. Ambient air is drawn through ambient inlet port **151** past compressor-inlet outlet port **161** into compressor **20**, pass through compressor-outlet inlet port **152** and heat-exchanger cold-stream inlet outlet port **162** of valve **100** into cold-stream conduit **54** of heat-exchanger **52**, to combust in combustor **26**. The combusted gases expand through turbine **22**, and exit turbine **22** into hot-stream conduit **56** of heat-exchanger **52**. 3-way valve **220** is set so that the combusted gases exit gas-turbine **10** through exhaust outlet **30** after exiting heat-exchanger **52**.

[0117] In FIG. **3**B (configuration "**2**") both valve members **171** and **181** of valve **100** are in a second position (as in FIG. **2**B) directing fluid incoming through ambient inlet port **151** to heat-exchanger cold-stream inlet outlet port **162**, and fluid coming through compressor-outlet inlet port **152** to exhaust outlet port **163**. Ambient air is drawn through ambient inlet port **151** past heat-exchanger cold-stream inlet outlet port **162** into cold-stream conduit **54** of heat-exchanger **52** and combusts in combustor **26**. The combusted gases exit turbine **22** into hot-stream conduit **56** of heat-exchanger **52**. 3-way valve **220** is set to directing the combusted gases into compressor **20**. The combusted gases exit compressor **20** and pass through compressor-outlet inlet port **152** to exit gas-turbine **10** through exhaust outlet port **163** of valve **100**.

[0118] It is important to note that generally the flow directions through the various conduits including fluid conduits **120** of valve **100** are the same in both high-pressure operation mode and low-pressure operation mode, and do not change when switching gas-turbine **10** from one mode to the other.

[0119] In FIG. **4**, the relation of thermal efficiency as a function of power output for gas-turbine **10** configured with valve **100** as described above is illustrated. Curve **410** is the thermal efficiency of gas-turbine **10** operating in the low-pressure operation mode (FIG. **3**B) and curve **412** is the thermal efficiency of gas-turbine **10** operating in the high-pressure operation mode (FIG. **3**A).

Further Embodiments of Gas-Turbine with 5-Port Valve **100**

[0120] In some embodiments, a gas-turbine comprises an embodiment of a valve similar to valve **100** of FIGS. **2**A and **2**B, where the valve is integrated in the gas-turbine in "reverse". In such an embodiment, valve **100** includes three inlet ports and two outlet ports: an ambient inlet port **151**, a compressor-outlet inlet port **152**, a heat-exchanger hot-stream outlet inlet port **153**, a heat-exchanger cold-stream inlet outlet port **162** and an exhaust outlet port **163**. FIG. **5** depict an exemplary embodiment of a gas-turbine **11**, comprising a valve **100**, and operable according to a Brayton cycle (FIG. **5**A) and an inverse Brayton cycle (FIG. **5**B). Gas-turbine **11** further includes compressor **20** and turbine **22**, together mounted on common rotatable shaft **24**, combustor **26** and heat-exchanger **52**. Gas-turbine **11** also includes a 3-way valve **225** having two inlets, **226** and **227**, and an outlet **228**. Valve **225** may be positioned as depicted in FIG. **5**A providing fluid communication between inlet **226** and outlet **228**, or as depicted in FIG. **5**B providing fluid communication between inlet **227** and outlet **228**.

[0121] Valve **100** is configured to switch gas-turbine **11** between a high-pressure operation mode in configuration "**1**" depicted in FIG. **5**A, and a low-pressure operation mode in configuration "**2**" depicted in FIG. **5**B.

[0122] In configuration "**1**" (FIG. **5**A) both valve members **171** and **181** of valve **100** are in a first position directing fluid from compressor-outlet inlet port **152** to heat-exchanger cold-stream inlet outlet port **162** and from heat-exchanger hot-stream outlet inlet port **153** to exhaust outlet port **163**. Ambient air is drawn through inlet **28** of gas-turbine **11** and through inlet **226** and outlet **228** of valve **225** into compressor **20**, pass through compressor-outlet inlet port **152** to heat-exchanger cold-stream inlet outlet port **162** of valve **100** into cold-stream conduit **54** of heat-exchanger **52**, and combusts in combustor **26**. The combusted gases expand through turbine **22** and pass through hot-stream conduit **56** of heat-exchanger **52**. From heat-exchanger **52** the combusted gases pass through heat-exchanger hot-stream outlet inlet port **153** of valve **100**, and are discharged through exhaust outlet port **163** to the surroundings.

[0123] In configuration "**2**" (FIG. **5**B) both valve members **171** and **181** of valve **100** are in a respective second position. Ambient air is drawn through ambient inlet port **151** and heat-exchanger cold-stream inlet outlet port **162** of valve **100** into cold-stream conduit **54** of heat-exchanger **52**, and combusts in combustor **26**. The combusted gases expand through turbine **22**, exiting into hot-stream conduit **56** of heat-exchanger **52**. The combusted gases from heat-exchanger **52** pass through 3-way valve **225** to compressor **20**, pass through compressor-outlet inlet port **152** and through exhaust outlet port **163** to exit gas-turbine **11**.

Embodiment of 6-Port Valve Suitable for Use with Gas-Turbine

[0124] In some embodiments described above, exhaust exits gas-turbine **10** through two different outlets. In some embodiments described below the exhaust exits a gas-turbine through a single exhaust outlet.

[0125] FIGS. **6**A and **6**B depict a valve **102**, suitable for use with a gas-turbine, in side cross-section. Valve **102** comprises a valve body **110** defining a single void in the form of a plurality of fluid conduits **120**. Valve **102** further includes an ambient inlet port **151**, a compressor-outlet inlet port **152**, a heat-exchanger hot-stream outlet inlet port **153**, a compressor-inlet outlet port **161**, a heat-exchanger cold-stream inlet outlet port **162** and an exhaust outlet port **163**, the six ports being in fluid communication one with the other through fluid conduits **120**.

[0126] Valve **102** further includes a first valve member **171** and a second valve member **181**. First valve member **171** is movable inside valve body **110** having at least two positions: a first position, depicted in FIG. **6**A, in contact with a first valve seat **172** in valve body **110** blocking fluid communication between ambient inlet port **151** and heat-exchanger cold-stream inlet outlet port **162**; and a second position, depicted in FIG. **6**B, in contact with a second valve seat **173** in valve body **110** blocking fluid communication between ambient inlet port **151** and compressor-inlet outlet port **161**. Second movable valve member **181** is movable inside valve body **110** having at least two positions: a first position, depicted in FIG. **6**A, in contact with a third valve seat **182** in valve body **110** blocking fluid communication between compressor-outlet inlet port **152** and exhaust outlet port **163**; and a second position, depicted in FIG. **6**B, in contact with a fourth valve seat **183** in valve body **110** blocking fluid communication between compressor-outlet inlet port **152** and heat-exchanger cold-stream inlet outlet port **162**.

[0127] Valve **102** also includes a check valve **130** operable as a unidirectional valve and configured in valve body **110** to allow fluid flowing from heat-exchanger hot-stream outlet inlet port **153** to any of the outlet ports **161**, **162** or **163** of valve **102**, and to block fluid flowing from any of the outlet ports of valve **102** out through heat-exchanger hot-stream outlet inlet port **153**.

[0128] As discussed with reference to valve **100**, in some embodiments, valve members **171** and **181** of valve **102** are configured for cooperative movement, that is to say both valve members move together between the first position (FIG. **6**A) and the second position (FIG. **6**B). In some embodiments, valve members **171** and **181** are independently operable. For example, in such embodiments valve member **171** is in contact with first valve seat **172** (first position, FIG. **6**A), while second movable valve member **181** is in contact with fourth valve seat **183** (second position, FIG. **6**B).

[0129] As discussed with reference to valve **100**, in some embodiments valve members **171** and **181** of valve **102** are configured for positioning in at least one intermediate position, between the first positions and the second positions, thereby allowing fluid from a given inlet port to flow to two outlet ports. The utility of some such intermediate positions is described hereinbelow.

Gas-Turbine Comprising 6-Port Valve **102**

[0130] FIG. 7 depict an exemplary embodiment of a gas-turbine **12** comprising an embodiment of valve **102**, and operable in a Brayton cycle (FIG. 7A) and in an inverse Brayton cycle (FIG. 7B). Gas-turbine **12** also includes 3-way valve **220**. An outlet **221** of valve **220** is connected to heat-exchanger hot-stream outlet inlet port **153** of valve **102** so that exhaust gas is discharged through exhaust outlet port **163** of valve **102**.

[0131] Valve **102** is configured to switch gas-turbine **12** between a high-pressure operation mode depicted in FIG. 7A, and a low-pressure operation mode depicted in FIG. 7B

[0132] In FIG. 7A both valve members **171** and **181** of valve **102** are in a respective first position. Ambient air is drawn through ambient inlet port **151** and compressor-inlet outlet port **161** of valve **102** into compressor **20**, pass through compressor-outlet inlet port **152** and heat-exchanger cold-stream inlet outlet port **162** of valve **102** into cold-stream conduit **54** of heat-exchanger **52** to combust in combustor **26**. The combusted gases expand through turbine **22**, and exit turbine **22** into hot-stream conduit **56** of heat-exchanger **52**. The combusted gases are directed by 3-way valve **220** to heat-exchanger hot-stream outlet inlet port **153** of valve **102**. In valve **102**, the combusted gases pass through check valve **130** and are then discharged to the surroundings through exhaust outlet port **163**.

[0133] In FIG. 7B both valve members **171** and **181** of valve **102** are in a respective second position. Ambient air is drawn through ambient inlet port **151** and through heat-exchanger cold-stream inlet outlet port **162** of valve **102** into cold-stream conduit **54** of heat-exchanger **52** to combust in combustor **26**. The combusted gases expand through turbine **22** into hot-stream conduit **56** of heat-exchanger **52**. 3-way valve **220** directs the gases into compressor **20**, to exit compressor **20**, and pass through compressor-outlet inlet port **152** of valve **102** and exit gas-turbine **12** through exhaust outlet port **163** of valve **102**. Check valve **130** blocks the exhaust gases from flowing back through heat-exchanger hot-stream outlet inlet port **153** of valve **102** towards 3-way valve **220**.

Additional Embodiment of 6-Port Valve Suitable for Use with Gas-Turbine

[0134] FIGS. **8**A and **8**B depict a valve **103**, suitable for use with a gas-turbine, in side cross-section. Valve **103** comprises a valve body **110** defining a single void in the form of a plurality of fluid conduits **120**. Valve **103** further includes an ambient inlet port **151**, a compressor-outlet inlet port **152**, a heat-exchanger hot-stream outlet inlet port **153**, a compressor-inlet outlet port **161**, a heat-exchanger cold-stream inlet outlet port **162** and an exhaust outlet port **163**, the six ports being in fluid communication one with the other through fluid conduits **120**. Valve **103** further comprises a bypass conduit providing fluid communication between heat-exchanger hot-stream outlet inlet port and compressor-inlet outlet port.

[0135] Valve **103** further includes three valve members, **171**, **181** and **191**.

[0136] First valve member **171** is movable inside valve body **110** having at least two positions: a first position as depicted in FIG. **8**A in contact with a first valve seat **172** in valve body **110**, and a second position, depicted in FIG. **8**B, in contact with a second valve seat **173** in valve body **110**. In the first position first valve member **171** in said first position blocks fluid communication between ambient inlet port **151** and heat-exchanger cold-stream inlet outlet port **162** and in the second position (FIG. **8**B) blocks fluid communication between ambient inlet port **151** and compressor inlet outlet port **161**.

[0137] Second valve member **181** is movable inside valve body **110** having at least two positions: a first position, depicted in FIG. **8**A, in contact with a third valve seat **182** in valve body **110**, and a second position, depicted in FIG. **8**B, in contact with a fourth valve seat **183** in valve body **110**. In the first position (FIG. **8**A), second valve member **181** blocks fluid communication between heat-exchanger hot-stream outlet inlet port **153**, and heat-exchanger cold-stream inlet outlet port **162** and in the second position (FIG. **8**B) blocks fluid communication between compressor-outlet inlet port **152** and heat-exchanger cold-stream inlet outlet port **162**.

[0138] Third valve member **191** is movable inside valve body **110** having at least two positions: a first position, depicted in FIG. **8**A, in contact with a fifth valve seat **192** in valve body **110**, and a second position, depicted in FIG. **8**B, in contact with a sixth valve seat **193** in valve body **110**. In the first position (FIG. **8**A) third valve member **191** blocks fluid communication between heat-exchanger hot-stream outlet inlet port **153** and compressor inlet outlet port **161** through the bypass conduit and in the second position (FIG. **8**B) third valve member **191** blocks fluid communication between heat-exchanger hot-stream outlet inlet port **153** and exhaust outlet port **163**.

[0139] Analogously to the discussed above with reference to valves **100** and **102**, in some embodiments, two or three valve members **171**, **181** and **191** are configured for cooperative movement. Analogously to the discussed above with reference to valves **100** and **102**, in some embodiments, one or more valve members **171**, **181** and **191** are independently operable.

Gas-Turbine Comprising 6-Port Valve 103

[0140] FIG. **9** depict an exemplary embodiment of a gas-turbine **13** comprising an embodiment of a valve **103**, operable according to a Brayton cycle (FIG. **9**A) and according to an inverse Brayton cycle (FIG. **9**B)

[0141] Valve **103** is configured to switch gas-turbine **13** between a high-pressure operation mode depicted in FIG. **9**A, and a low-pressure operation mode depicted in FIG. **9**B.

[0142] In FIG. **9**A, valve members **171**, **181** and **191** of valve **103** are in a respective first position. Ambient air is drawn through ambient inlet port **151** and compressor-inlet outlet port **161** of valve **103** into compressor **20**, and pass through compressor-outlet inlet port **152** and heat-exchanger cold-stream inlet outlet port **162** of valve **103** into cold-stream conduit **54** of heat-exchanger **52** to combust in combustor **26**. The combusted gases expand through turbine **22** and exit through hot-stream conduit **56** of heat-exchanger **52** and through heat-exchanger hot-stream outlet inlet port **153**, to be discharged through exhaust outlet port **163** to the surroundings.

[0143] In FIG. **9**B all three valve members **171**, **181** and **191** of valve **103** are in a respective second position. Ambient air is drawn through ambient inlet port **151** and heat-exchanger cold-stream inlet outlet port **162** of valve **103** into cold-stream conduit **54** of heat-exchanger **52** to combust in combustor **26**. The combusted gases enter turbine **22** and exit turbine **22** into hot-stream conduit **56** of heat-exchanger **52**. Exiting hot-stream conduit **56**, the combusted gases are drawn through heat-exchanger hot-stream outlet inlet port **153**, through the bypass conduit to compressor-inlet outlet port **161** of valve **103** into compressor **20**. From compressor **20**, the combusted gases pass through compressor-outlet inlet port **152** of valve **103** to be discharged from gas-turbine **13** through exhaust outlet port **163** of valve **103**.

[0144] In general terms, in some embodiments a gas-turbine such as **13** is switched between a high-pressure operation mode and a low-pressure operation mode as is described above, using a six-port valve, having three inlet ports designated “X” (ambient inlet port **151**), “Y” (compressor-outlet inlet port **152**) and “Z” (heat-exchanger hot-stream outlet inlet port **153**), and three outlet ports designated “x” (compressor-inlet outlet port **161**), “y” (heat-exchanger cold-stream inlet outlet port **162**) and “z” (exhaust outlet port **163**). In a first configuration, the valve provides fluid communication exclusively between inlet port “X” and outlet port “x”, between inlet port “Y” and outlet port “y” and between inlet port “Z” and outlet port “z”. In a second configuration, the valve provides fluid communication exclusively between inlet port “X” and outlet port “y”, between inlet port “Y” and outlet port “z” and between inlet port “Z” and outlet port “x”. Providing flow communication exclusively between the specified pairs of inlet and outlet ports means that only fluid communication which is explicitly described between the specified ports is provided, and there is no fluid communication between the ports which is not explicitly described.

Multi-Power Single-Spool Gas-Turbine

[0145] Aspects of the invention relate to multiport valves suitable for use with gas-turbines that allow switching between high-pressure, low-pressure and at least one intermediate-pressure operation modes of a gas-turbine. According to such embodiments, a valve is configured and operable to be in at least one intermediate configuration, in addition to the high-pressure (Brayton cycle) configuration “**1**” and low-pressure (inverse Brayton cycle) configuration “**2**” discussed above, for example in FIGS. **8**A and **8**B. Such an intermediate configuration allows a gas-turbine to work in a pressure mode intermediate between the high and low-pressure operation modes.

[0146] FIG. **10** depicts an embodiment of a valve **103** in an exemplary intermediate configuration, valve members **171**, **181** and **191** being in an intermediate position, between the respective first position and second position. In such an intermediate configuration, fluid from a given inlet port is directed to flow to two outlet ports. Specifically, a portion of the fluid entering valve **103** from ambient inlet port **151** is directed to compressor-inlet outlet port **161**, and another portion to heat-exchanger cold-stream inlet outlet port **162**. Similarly, a portion of the fluid entering through compressor-outlet inlet port **152** is directed to heat-exchanger cold-stream inlet outlet port **162** and another portion is directed to exhaust outlet port **163**. A portion of the fluid entering valve **103** from heat-exchanger hot-stream outlet inlet port **153** is directed to exhaust outlet port **163** and another portion is directed to compressor-inlet outlet port **161**.

[0147] In some embodiments, a mixing region **126** within fluid conduits **120** is configured to function as jet pump ejector. In some embodiments, such configuration includes fashioning at least one of valve members **171**, **181** as an airfoil having a pre-defined aerodynamic profile. When mixing region **126** is configured as a jet pump ejector, the pressure of fluid flowing from compressor-outlet inlet port **152** to heat-exchanger cold-stream inlet outlet port **162** drops, producing a suction zone (for example, through the Bernoulli effect). The suction zone sucks fluid from ambient inlet port **151** into valve **103** and to heat-exchanger cold-stream inlet outlet port **162**.

[0148] FIG. **11** depicts an exemplary embodiment of a gas-turbine **13**, configured with a valve **103** and operable in an intermediate pressure operation mode in addition to a high-pressure operation mode (configuration “**1**”, FIG. **8**A) and a low-pressure operation mode (configuration “**2**”, FIG. **8**B). During operation in the intermediate pressure operation mode when valve members **171**, **181** and **191** are positioned as depicted in FIG. **10**, compressor **20** generates a low-pressure region around compressor-inlet outlet port **161** of valve **103**, so a portion of ambient air is drawn from ambient inlet port **151** into compressor-inlet outlet port **161**. Additionally, a portion of the gas coming from heat-exchanger **52** into heat-exchanger hot-stream outlet inlet port **153** is drawn into compressor **20** through compressor-inlet outlet port **161**.

[0149] Compressed fluid coming from compressor **20** flows into compressor-outlet inlet port **152** at high-pressure and is directed to both heat-exchanger cold-stream inlet outlet port **162** and to exhaust outlet port **163**, the exact ratio dependent, inter alia, on the position of valve member **181**.

[0150] Thus, in some embodiments when one or more of valve members **171**, **181** and **191** are positioned in an intermediate position, for example as depicted in FIG. **11**, a gas-turbine **13** is operable in a mode where the pressure is between the highest and lowest pressures and consequently the power output is between the highest and lowest power outputs. In such embodiments, in all three modes the thermal efficiency of the gas-turbine is relatively high (see curve **414** in FIG. **4**).

[0151] In some embodiments an intermediate pressure operation mode of a gas-turbine such as **13** is obtained by positioning only one valve member **171**, **181** or **191** in a respective intermediate position while the other two valve members are positioned in either a first or second position. In some embodiments, an intermediate pressure operation mode of gas-turbine **13** is obtained by positioning two valve members in a respective intermediate position, while the remaining valve member is positioned in either a first or a second position.

[0152] In some embodiments, a gas-turbine such as gas-turbine **13** comprising a valve with three valve members as described herein such as valve **103**, is switched to an intermediate pressure operation mode by positioning a first valve member **171** and a second valve member **181** in an intermediate position, substantially as is described above, and positioning a third valve member **191** in a first position or in a second position.

[0153] Analogously, in some embodiments, a gas-turbine such as gas-turbine **10** of FIG. **3** or gas-turbine **11** of FIG. **5**, comprising a valve with two valve members as described herein, such as valve **100**, is switched to an intermediate pressure operation mode by positioning a first valve member **171** and a second valve member **181** of the valve in an intermediate position. Similarly, in some embodiments a gas-turbine such as gas-turbine **12** of FIG. **7** is switched to an intermediate pressure operation mode by positioning a first valve member **171** and a second valve member **181** of a valve such as valve **102** in an intermediate position. In some such embodiments, a mixing region analogue to mixing region **126** of valve **103** is formed in the respective two-valve member valve (e.g., **100** or **102**) to function as jet pump ejector. In some embodiments of gas-turbines such as **10**, **11** and **12**, a continuity of intermediate pressure operation modes is obtained by positioning valve members **171** and **181** of respective valves such as **100** and **102** in a continuity of positions.

[0154] In some embodiments, the position of at least one valve member is not continuously variable. That is to say, one or a series of intermediate pressure operation modes of gas-turbine **13** is obtained by maintaining at least one valve member in a fixed position while varying the position of the remaining valve members. In some embodiments, valve members **171**, **181** and **191** are moveable between two endpoints, and may be maintained at a specific intermediate position between the endpoints. In such embodiments, valve **103** has at least three configurations, and gas-turbine **13** comprising valve **103** may be efficiently operated in at least three different pressure operation modes.

[0155] Returning to FIG. **4**, the relation of thermal efficiency as a function of power output for gas-turbine **13** including valve **103** as described above is schematically depicted, where curve **410** corresponds to a single spool gas-turbine operating in the low-pressure operation mode (as is described in FIG. 9B), curve **412** corresponds to gas-turbine **13** operating in a high-pressure operation mode (as is described in FIG. 9A), and curve **414** corresponds to gas-turbine **13** operating in one exemplary intermediate pressure operation mode as described above in FIG. **11**, where mixing region **126** is configured as a jet pump ejector.

Valves for Substantially Continuous Efficient Power Output

[0156] In some embodiments, a valving system is provided that allows high-pressure operation mode and/or low-pressure operation mode of a gas-turbine (including, inter alia, a combustor and a heat-exchanger) at a continuously varying power output at relative high efficiency. Such a valving system operates by reducing the mass flow of fluid to the combustor through the heat-exchanger. Such mass flow reduction is similar to the achieved by inlet throttling, for example with the use of variable inlet guide vanes.

[0157] In the art, variable inlet guide vanes are often used with large gas-turbines. Such guide vanes are unsuitable for use with small turbines due to high expense and technical complexity at small sized. Further, as there is a need for matching between the whirl caused by the guide vanes and the compressor blades, the guide vanes can be varied only by about 15% which allows a change of about 20% in power output at reasonable efficiencies.

[0158] FIG. **13** show an embodiment of a valve **104**, suitable for use with a gas-turbine, schematically depicted in side cross-section. In valve **104**, valve member **181** is configured to have a continuity of positions when in the first position in contact with valve seat **182**, allowing a gas-turbine including valve **104** and operating in a high-pressure operation mode to operate in a continuity of output power levels. Specifically, valve member **181** is relatively thick and valve seat **182** appropriately configured so that valve member **181** has a range of motion defining a continuity of positions in continuous contact with valve seat **182** thereby blocking fluid communication through valve seat **182**. Through the continuity of positions in the first position, the varying bulk of valve member **181** located in the fluid path between compressor-outlet inlet port **152** and heat-exchanger cold-stream inlet outlet port **162**, allows the size of the fluid path to be controllably varied.

[0159] FIGS. **13**A and **13**B show two exemplary such positions where valve member **181** is in the first position **1** in contact with valve seat **182**, but the exact position of valve member **181** varies the size of a fluid path **127** inside valve **104**, between compressor-outlet inlet port **152** and heat-exchanger cold-stream inlet outlet port **162**, thereby varying the gas-turbine output power level. For example, when valve member **181** is in position as depicted in FIG. **13**A, fluid path **127** is wide, allowing for a high flow rate of fluid from compressor-outlet inlet port **152** to heat-exchanger cold-stream inlet outlet port **162** so that the gas-turbine generates a relatively high output power level; and when valve member **181** is in a position as depicted in FIG. **13**B, fluid path **127** is narrow, allowing for a low flow-rate of fluid, so that the gas-turbine generates a relatively low output power level.

[0160] It is understood that valve **104** allows a gas-turbine to operate in a high-pressure operation mode in a continuity of configurations as described above, since valve member **181** is continuously in contact with valve seat **182**, in the described continuity of positions, substantially blocking flow of fluid from compressor-outlet inlet port **152** to exhaust outlet port **163**. Further, when valve **104** is in a high-pressure mode configuration as described above, valve member **171** is maintained in contact with valve seat **172**, substantially blocking flow from ambient inlet port **151** to heat-exchanger cold-stream inlet outlet port **162**.

[0161] Analogously to valve **100** as depicted in FIG. **2**B, valve **104** further allows an associated gas-turbine to operate in a low-pressure operation mode when valve members **171** and **181** are in a second position (not shown). Specifically, valve **104** is in a low-pressure mode configuration when valve members **171** and **181** are in contact with valve seats **173** and **183**, respectively. Thus, analogously to valve **100** in gas-turbine **10** of FIG. **3**, valve **104** is operable to switch a gas-turbine between a high-pressure operation mode according to a Brayton cycle and a low-pressure operation mode according to an inverse Brayton cycle, and in addition to varying the gas-turbine output power level in the high-pressure operation mode. Similarly, in a gas-turbine such as gas-turbine **11** depicted in FIG. **5**, multiport valve **104** is operable to switch the gas-turbine between a high-pressure operation mode according to a Brayton cycle and a low-pressure operation mode according to an inverse Brayton cycle, and in addition to varying the gas-turbine output power level in the high-pressure operation mode.

[0162] FIGS. **14**A and **14**B depict an embodiment of a valve **105**, suitable for use with a gas-turbine, schematically depicted in side cross-section. In valve **105**, valve member **171** is configured to have a continuity of positions when in the second position in contact with valve seat **173**, allowing a gas-turbine including valve **105** and operating in a low-pressure operation mode, to operate in a continuity of output power levels. Analogously to the described with reference to FIG. **13**, in FIG. **14** valve member **171** is relatively thick and valve seat **173** is appropriately configured so that valve member **171** has a range of motion defining a continuity of positions in continuous contact with valve seat **173** thereby blocking fluid communication through valve seat **173**. Through the continuity of positions in the second position, the varying bulk of valve member **171** located in the fluid path between ambient inlet port **151** and heat-exchanger cold-stream inlet outlet port **162**, allows the size of the fluid path to be controllably varied.

[0163] FIGS. **14**A and **14**B depict two exemplary such positions where valve member **171** is in the second position in contact with valve seat **173**, but the exact position of valve member **171** effects the gas-turbine output power level by varying the size of path **128** inside valve **105**, between ambient inlet port **151** and heat-exchanger cold-stream inlet outlet port **162**. For example, when valve member **171** is in position as depicted in FIG. **14**A, fluid path **128** is wide, allowing for a high flow rate of air from ambient inlet port **151** to heat-exchanger cold-stream inlet outlet port **162**, thereby generating a high output power level; and when valve member **171** is in position as depicted in FIG. **14**B, fluid path **128** is narrow allowing for a low flow rate of fluid so that the gas-turbine generates a low output power level.

[0164] It is understood that valve **105** allows a gas-turbine to operate in a low-pressure operation mode in a continuity of configurations as described above, since valve member **171** is continuously in contact with valve seat **173** in the described continuity of positions, substantially blocking flow of fluid from ambient inlet port **151** to compressor-inlet outlet port **161**. Further, when valve **105** is in such a low-pressure mode configuration as described above, valve member **181** is maintained in contact with valve seat **183**, substantially blocking flow from compressor-outlet inlet port **152** to heat-exchanger cold-stream inlet outlet port **162**.

[0165] Analogously to valve **100** as depicted in FIG. **2**A, valve **105** further allows an associated gas-turbine to operate in a high-pressure operation mode when valve members **171** and **181** are in a first position (not shown). Specifically, valve **105** is in a high-pressure mode configuration when valve members **171** and **181** are in contact with valve seats **172** and **182**, respectively. Thus, analogously to valve **100** in gas-turbine **10** of FIG. **3**, valve **105** is operable to switch a gas-turbine between a high-pressure operation mode according to a Brayton cycle and a low-pressure operation mode according to an inverse Brayton cycle, and in addition to varying the gas-turbine output power level in the low-pressure operation mode.

[0166] In some embodiments, a valve includes two separate valve members that allow both switching of an associated gas-turbine between a high-pressure and a low-pressure operation mode, and varying continuously the size of the path to the heat-exchanger. Referring to FIGS. **15**A, **15**B, and **15**C, valves **106**, **107** and **108**, respectively, are schematically depicted. Valves **106**, **107** and **108** are suitable for use with a gas-turbine and configured for switching a gas-turbine comprising valves **106**, **107** or **108** between a high-pressure and a low-pressure operation modes. Valves **106**, **107** and **108** are also configured for continuously varying output power level of an associated gas-turbine by allowing a continuous varying of the size of the fluid path to the heat-exchanger.

[0167] In valve **106** depicted in FIG. **15**A, a movable valve member **281** is rotatably moveable around valve member axis **184**, sharing an axis of rotation with valve member **181**. While valve member **171** maintains contact with valve seat **172** and valve member **181** maintains contact with valve seat **182** (so that valve **106** is in a high-pressure mode configuration) valve member **281** is moveable through a continuity of positions allowing variation of the size of fluid path **127**, thereby varying the output power level of the associated gas-turbine. Thus, analogously to valve **100** in gas-turbine **10** of FIG. **3**, valve **106** is operable to switch a gas-turbine between a high-pressure operation mode according to a Brayton cycle and a low-pressure operation mode according to an inverse Brayton cycle, and in addition to varying the gas-turbine output power level in the high-pressure operation mode.

[0168] A similar variation in the size of the fluid path is implementable in a multiport valve analogous to the depicted in FIG. **5**.

[0169] In valve **107** depicted in FIG. **15**B, a valve member **271** is movable around valve member axis **174** thereby operable to vary the size of fluid path **128** from ambient inlet port **151** to the heat-exchanger (not shown) through heat-exchanger cold-stream inlet outlet port **162**, while valve members **171** and **181** maintain contact with valve seats **173** and **183** respectively, so that valve **107** is in a low-pressure configuration. Thus, analogously to valve **100** in gas-turbine **10** of FIG. **3**, valve **107** is operable to switch a gas-turbine between a high-pressure operation mode according to a Brayton cycle and a low-pressure operation mode according to an inverse Brayton cycle, and in addition to varying the gas-turbine output power level in the low-pressure operation mode.

[0170] In valve **108** depicted in FIG. **15**C, two valve members, **171** and **271**, both movable around first valve member axis **174**, and two valve members **181** and **281**, both movable around second valve member axis **184**, allow the size of fluid paths **127** and **128**, respectively, to be continuously varied while valve **108** is set in high-pressure configuration and in low-pressure configuration. Analogously to valve **100** of FIG. **3**, valve **108** is operable to switch a gas-turbine between a high-pressure operation mode according to a Brayton cycle and a low-pressure operation mode according to an inverse Brayton cycle, and in addition to varying the gas-turbine output power level in the low-pressure operation mode and in the high-pressure operation mode. A similar variation in the size of the fluid path is implementable in a multiport valve analogous to the depicted in FIG. **5**.

[0171] Returning to FIG. **4**, the relationship of thermal efficiency to power output for a gas-turbine including a valve as described in FIGS. **13**A, **13**B, **14**A, **14**B, **15**A **15**B and **15**C is schematically depicted. Curve **412** corresponds to a gas-turbine operating in the high-pressure operation mode, for example with a valve **100** of FIG. **2**A, while curve **416** corresponds to a gas-turbine operating in high-pressure operation mode with a valve of FIGS. **12**A, **12**B **14**A or **14**C. Curve **410** corresponds to a gas-turbine operating in the low-pressure operation mode, for example with a valve **100** of FIG. **2**B, while curve **418** corresponds to the gas-turbine operating in low-pressure operation mode with a valve of FIGS. **14**A, **14**B **15**B or **15**C.

[0172] In the embodiments described above, the valve members are substantially plates configured to rotatably move between the different positions around a single axis close to or at an edge of the valve member. Generally, the teachings herein may be implemented using any suitable type of valve member. For example, in some embodiments valve members used include suitably-configured butterfly valves (especially tricentric butterfly valves), ball valves or rotary valves.

[0173] Gas-turbines using valves as described herein may be of any desired power capacity. That said, in some embodiments, a gas-turbine is configured for producing up to about 100 kW. In some embodiments, a gas-turbine is configured for producing from about 14 kW to about 40 kW of power. In some embodiments, a gas-turbine is configured for producing from about 7 kW to about 36 kW of power. Such low powers are useful, for example, for powering a small motor vehicle, such as a light truck or an automobile.

Reduced NOx Emission Inverse-Brayton Cycle Gas-Turbine

[0174] Aspects of the invention relate to gas-turbines operating in a low-pressure operation mode according to an inverse Brayton cycle that have reduced NOx emissions. Due to poor mixing and vaporization at low power operation which create local high temperature zones, gas-turbine NOx emissions are higher under partial load. In some embodiments of the invention, inlet air is mixed with a portion of exhaust and is directed into the combustor, thereby decreasing the oxygen content of the combustible mixture in the combustor, and as a result, reducing the amount of NOx emissions.

[0175] Thus, according to an aspect of some embodiments of the invention, there is provided a method of operating a gas-turbine according to an inverse Brayton cycle, comprising: a) providing a conduit allowing fluid communication between a compressor of the gas-turbine and a cold-stream inlet of a heat-exchanger of the gas-turbine; and b) during inverse Brayton cycle operation of the gas-turbine, directing fluid from the compressor to the heat-exchanger cold-stream inlet through the conduit so that a portion of the fluid entering the heat-exchanger cold-stream inlet is from the compressor. In some embodiments, between about 30% and about 70% (in some embodiments, between about 40% and about 60%, in some embodiments between about 45% and about 55%) by mass of the fluid entering the heat-exchanger cold-stream inlet is from the compressor. In one specific preferred embodiment, approximately 50% by mass of the fluid entering the heat-exchanger cold-stream inlet is from the compressor.

[0176] In some embodiments, the method further comprises: adjusting a size of the conduit so as to control an amount of fluid entering the cold-stream inlet from the compressor.

[0177] According to an aspect of some embodiments of the invention there is also provided a gas-turbine comprising, when operating according to an inverse Brayton cycle, a) an air inlet configured to direct fluid into a cold-stream conduit of a heat-exchanger through a cold-stream inlet; b) conduits to direct fluid from the cold-stream conduit to a combustor, from the combustor to a turbine, from the turbine to a hot-stream conduit of the heat-exchanger, from the hot-stream conduit to a compressor, and from the compressor to an exhaust outlet; and c) a conduit allowing passage of fluid from the compressor into the cold-stream inlet of the heat-exchanger.

[0178] In some embodiments, the gas-turbine is configured to operate only according to an inverse Brayton cycle.

[0179] In some embodiments the gas-turbine is configured to optionally operate according to a Brayton cycle, for example as described herein. In some such embodiments, the gas-turbine is configured so that during operation according to a Brayton cycle, the conduit is substantially blocked preventing passage of fluid between the compressor and the cold-stream inlet.

[0180] In some embodiments, the conduit allowing passage of fluid from the compressor into the cold-stream inlet is of fixed size.

[0181] In some embodiments, the size of the conduit allowing passage of fluid from the compressor into the cold-stream inlet is adjustable, for example allowing varying an amount of fluid passing from the compressor into the cold-stream inlet.

[0182] In some embodiments, the conduit allowing passage of fluid from the compressor into the cold-stream inlet is configured so that during operation according to an inverse Brayton cycle between about 30% and about 70% (in some embodiments, between about 40% and about 60%, in some embodiments 45% and about 55%) by mass of the fluid entering the heat-exchanger cold-stream inlet is from the compressor.

[0183] In some embodiments, the conduit allowing passage of fluid from the compressor into the cold-stream inlet of the heat-exchanger is passive, that is to say, occurs due to the pressure differential between the two regions without investment of any additional work. In some embodiments, the conduit is active, that is to say, comprises a component such as a pump that performs work to direct fluid from the compressor to the cold-stream inlet of the heat-exchanger.

[0184] FIG. **16** depicts an exemplary embodiment of a gas-turbine **19** including a valve **109** suitable for use with a gas-turbine and useful for reducing the amount of NOx emissions of the gas-turbine in low-pressure operation mode. In the embodiment depicted in FIG. **16**, valve **109** comprises five ports and two valve members in a configuration similar to valve **100** depicted in FIG. **2**. In the embodiment depicted in FIG. **16**, valve **109** further comprises a permeable section **140** of valve body **110** between regions **121** and **122** of fluid conduits **120**, allowing passage of fluid from region **121** to region **122**.

[0185] In the embodiment depicted in FIG. **16**, region **121** is up-stream from valve member **181**, between valve member **181** and exhaust outlet port **163** while region **122** is up-stream from valve member **181**, between valve member **181** and heat-exchanger cold-stream inlet outlet port **162**. Permeable section **140** is unidirectional, only allowing passage of fluid from region **121** to region **122** if the pressure in region **121** is higher than the pressure in region **122** (e.g., during inverse Brayton cycle operation of gas-turbine **19**), but blocking passage of fluid from region **122** into region **121** (e.g., during Brayton cycle operation of gas-turbine **19**).

[0186] Depending on the positions of valve members **171** and **181**, gas-turbine **19** may be set in configurations analagous to the configurations depicted in for gas-turbine **10** in FIGS. **3**A and **3**B. In FIG. **16**, gas-turbine **19** is depicted in a configuration analogous to configuration "**2**" (FIG. **2**B), consequently operating in a low-pressure operation mode according to an inverse Brayton cycle. As a result, the pressure in region **121** is higher than the pressure in region **122** so a portion of the exhaust gas passes from region **121** through permeable section **140** into region **122**. The portion of exhaust gas that passes through permeable section **140** to region **122** mixes with the ambient air coming into gas-turbine **19**, reducing oxygen content in the fluid entering the combustor and consequently reducing NO'x content in the combusted gas of turbine **19**.

[0187] Some such embodiments are superficially similar to reversed circulation methods implemented in internal combustion engines, where a significant amount of power is invested in recompressing exhaust into a high-pressure combustion chamber, reducing thermal efficiency but reducing NOx emissions. In contrast, in some embodiments of the invention advantage is taken of the fact that in a gas-turbine operating according to an inverse Brayton cycle the pressure in heat-exchanger cold-stream inlet is lower than at the compressor outlet, so that little if any power is used to bring the exhaust into the heat-exchanger cold-stream inlet. Additionally, in some embodiments, the thermal efficiency of the gas-turbine is increased by the mixing incoming ambient air with the hot exhaust.

[0188] FIG. **17**A depicts an exemplary embodiment of permeable section **140** in valve **109**, including a check valve **141**, operable as a unidirectional valve (e.g., a reed valve) and configured to allow fluid passage from region **121** to region **122** of fluid conduits **120** of valve **109**, and to block passage of fluid in the opposite direction from region **122** to region **121**.

[0189] FIG. **17**B depicts another exemplary embodiment of permeable section **140** of valve **109** integrated in valve member **181**.

[0190] Valve member **181** includes a unidirectional valve **186** (e.g., a reed valve) allowing fluid passage from region **121** to region **122** and to block fluid passage from region **121** to **122**. Specifically, valve member **181** comprises conduit **185** providing fluid communication from a face **188** to a face **189** of valve member **181**. Unidirectional valve **186** is disposed inside conduit **185**. When the pressure in region **122** is greater than the pressure in region **121**, valve **186** is closed, sealing conduit **185**. When the pressure in region **121** is greater than the pressure in region **122**, valve **186** opens allowing fluid (e.g., exhaust gas from compressor-outlet inlet port **152**) to pass from region **121** to region **122**.

[0191] Generally, the size of holes **185** determines the amount of exhaust gas mixed and therefore the oxygen content of the gas entering a combustor **26**. In some embodiments, the amount of exhaust gas mixed can be controlled, for example, by changing the number or size of holes. It is understood that embodiments of permeable section **140** are not limited to the examples described above and permeable section **140** can comprise holes, slits, pores and the like, allowing passage of fluid from region **121** to region **122** of fluid conduits **120** valve **109**.

[0192] The reduction of NOx emissions in a gas-turbine operating in low-pressure (inverse Brayton mode) is described with reference to embodiments depicted in FIGS. **16**, **17**A and **17**B where the conduit directing exhaust from the compressor outlet to mix with air entering the combustor of a gas-turbine is part of or associated with a valve as described herein that allows operation of a gas-turbine in both high and low-pressure modes.

[0193] In some embodiments any of the valves of the invention described herein, e.g. valve **100**, can be utilized to reduce NOx emission by permitting a portion of the oxygen-depleted exhaust gas to mix with incoming ambient air in low-pressure operation mode of a gas-turbine, by positioning valve member **181** close to, but not in contact with, valve seat **183**, when operating the gas-turbine in low-pressure operation mode. Thus, when valve member **181** allows for fluid passage between compressor-outlet inlet port **152** and heat-exchanger cold-stream inlet outlet port **162** in low-pressure operation mode, exhaust gas is forced into the flow of incoming ambient air, where the amount of such exhaust passage is controlled by the exact positioning of valve member **181** with respect to valve seat **183**.

[0194] In some embodiments, a gas-turbine configured for multipressure operation, e.g., such as described in U.S. Pat. Nos. 6,526,757 and 6,606,864, includes an additional valve (or an existing valve is modified) that allows passage of exhaust from the compressor outlet to mix with air entering the combustor during low-pressure (inverse Brayton) operation, thereby reducing NOx emissions.

[0195] In some embodiments, a gas-turbine configured for multipressure operation, e.g., such as described hereinabove, includes an additional valve (not associated with the valve that allows switching between high and low-pressure operation) defining a conduit that allows passage of exhaust from the compressor outlet to mix with air entering the combustor during low-pressure (inverse Brayton) operation, thereby reducing NOx emissions. In some embodiments, such an extra valve has two configurations: closed (blocking passage of exhaust) and open (allowing passage of exhaust) defining a fixed conduit size. In some embodiments, the valve is adjustable, allowing the size of the conduit to be adjusted to allow varying the amount of exhaust passing to mix with the air entering the combustor.

[0196] In some embodiments, a gas-turbine configured for low-pressure (inverse Brayton cycle) operation, e.g. such as known in the art, includes a valve defining a conduit that allows passage of exhaust from the compressor outlet to mix with air entering the combustor, thereby reducing NOx emissions. In some embodiments, such a valve has two configurations: closed (blocking passage of exhaust) and open (allowing passage of exhaust). In some embodiments, the valve is adjustable, allowing variation of the amount of exhaust passing to mix with the air entering the combustor.

[0197] In the above, oxygen-depleted exhaust is mixed with ambient air prior to entering the heat-exchanger of the gas-turbine. In some embodiments, the exhaust is mixed with the air after exiting the heat-exchanger cold-stream outlet and prior to entering the combustor. However, such embodiments are usually considered less advantageous as lowering combustor inlet temperature reduces thermal efficiency of the gas-turbine.

[0198] It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention, which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable subcombination or as suitable in any other described embodiment of the invention. Certain features described in the context of various embodiments are not to be considered essential features of those embodiments, unless the embodiment is inoperative without those elements.

[0199] Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all such alternatives, modifications and variations that fall within the scope of the appended claims.

[0200] Citation or identification of any reference in this application shall not be construed as an admission that such reference is available as prior art to the invention.

[0201] Section headings are used herein to ease understanding of the specification and should not be construed as necessarily limiting.

1. A gas-turbine configured for operation according to both Brayton-cycle and inverse-Brayton cycle, comprising:
- a) a multiport valve including movable valve members and at least five ports comprising: a compressor-outlet inlet port, an ambient inlet port, a heat-exchanger cold-stream inlet outlet port, an exhaust outlet port, and a fifth port;
- b) a compressor outlet of a compressor in fluid communication with said compressor-outlet inlet port; and
- c) a heat-exchanger cold-stream inlet of a heat-exchanger in fluid communication with said heat-exchanger cold-stream inlet outlet port;

wherein during Brayton-cycle operation of the gas-turbine:
- a valve member blocks fluid communication between said compressor-outlet inlet port and said exhaust outlet port, and
- a valve member blocks fluid communication between said ambient inlet port and said heat-exchanger cold-stream inlet outlet port;

and during inverse Brayton-cycle operation of the gas-turbine:
- a valve member blocks fluid communication between said compressor-outlet inlet port and said heat-exchanger cold-stream inlet outlet port.

2. The gas-turbine of claim **1**, wherein said fifth port comprises a compressor-inlet outlet port in fluid communication with an inlet of said compressor, wherein during inverse Brayton-cycle operation of the gas-turbine, a valve member blocks fluid communication between said ambient inlet port and said compressor-inlet outlet port.

3. The gas-turbine of claim **2**, further comprising an additional valve functionally associated with a hot-stream outlet of said heat-exchanger, wherein during inverse Brayton-cycle operation of the gas-turbine, said additional valve allows fluid communication from said hot-stream outlet of said heat-exchanger to an inlet of said compressor.

4. The gas-turbine of claim **3**, wherein during Brayton-cycle operation of the gas-turbine, said additional valve allows fluid communication from said hot-stream outlet of said heat-exchanger to an exhaust outlet of the gas-turbine.

5. The gas-turbine of claim **1**, wherein said fifth port comprises a heat-exchanger hot-stream outlet inlet port in fluid communication with a hot-stream outlet of said heat-exchanger, and wherein during inverse Brayton-cycle operation of the gas-turbine, a valve member blocks fluid communication between said heat-exchanger hot-stream outlet inlet port and said exhaust outlet port.

6. The gas-turbine of claim **5**, further comprising an additional valve functionally associated with a hot-stream outlet of said heat-exchanger, wherein during inverse Brayton-cycle operation of the gas-turbine, said additional valve allows fluid communication from said hot-stream outlet of said heat-exchanger to an inlet of said compressor.

7. The gas-turbine of claim **6**, wherein during Brayton-cycle operation of the gas-turbine, said additional valve allows fluid communication from ambient to an inlet of said compressor.

8. The gas-turbine of claim **1**, wherein said fifth port comprises a compressor-inlet outlet port in fluid communication with an inlet of said compressor, and wherein during inverse Brayton-cycle operation of the gas-turbine a valve member blocks fluid communication between said ambient inlet port and said compressor-inlet outlet port; and said multiport valve further includes a sixth port, a heat-exchanger hot-stream outlet inlet port in fluid communication with a hot-stream outlet of said heat-exchanger.

9. The gas-turbine of claim **8**, further comprising an additional valve functionally associated with a hot-stream outlet of said heat-exchanger, wherein during inverse Brayton-cycle operation of the gas-turbine, said additional valve allows fluid communication from said hot-stream outlet of said heat-exchanger to an inlet of said compressor.

10. The gas-turbine of claim **9**, wherein during Brayton-cycle operation of the gas-turbine, said additional valve allows fluid communication from said hot-stream outlet of a heat-exchanger to an exhaust outlet of the gas-turbine through said heat-exchanger hot-stream outlet inlet port.

11. The gas-turbine of claim **8**, further comprising a component functionally associated with said heat-exchanger hot-stream outlet inlet port, allowing flow of fluid from said hot-stream outlet of said heat-exchanger through said heat-exchanger hot-stream outlet inlet port and blocking flow of fluid from said multiport valve to said hot-stream outlet of said heat-exchanger through said heat-exchanger hot-stream outlet inlet port.

12. The gas-turbine of claim **11**, wherein said component comprises a undirectional valve that is part of said multiport valve.

13. The gas-turbine of claim **8**, said multiport valve further comprising a bypass conduit providing fluid communication between said heat-exchanger hot-stream outlet inlet port and said compressor-inlet outlet port, and wherein during Brayton-cycle operation of the gas-turbine, a said valve member blocks said fluid communication between said heat-exchanger hot-stream outlet inlet port and said compressor-inlet outlet port through said bypass conduit.

14. A multiport valve suitable for use with a gas-turbine allowing switching of a mode of gas-turbine operation between a Brayton cycle and an inverse Brayton cycle, comprising:
- a) a valve body defining a void in the form of a plurality of fluid conduits;
- b) at least five ports leading to said void comprising:
  - a compressor-outlet inlet port, an ambient inlet port, a heat-exchanger cold-stream inlet outlet port, an exhaust outlet port and a fifth port;
- c) a first valve member inside said valve body movable between at least two positions, a first position and a second position; and
- d) a second valve member inside said valve body movable between at least two positions, a first position and a second position,

where a position of said first valve member and a position of said second valve member together define fluid communication between said inlet ports and said outlet ports through said void.

15. The valve of claim **14**, said first valve member and said second valve member configured to cooperatively move between said first positions and said second positions.

16. The valve of claim **14**, said first valve member and said second valve member configured to move independently between said first positions and said second positions.

17. The valve of claim **14**, wherein:

said first valve member in said first position blocks fluid communication between said ambient inlet port and said heat-exchanger cold-stream inlet outlet port and in said second position blocks fluid communication between said ambient inlet port and said fifth port, a compressor inlet outlet port; and

said second valve member in said first position blocks fluid communication between said compressor-outlet inlet port and said exhaust outlet port and in said second position blocks fluid communication between said compressor-outlet inlet port and said heat-exchanger cold-stream inlet outlet port.

18. The valve of claim **14**, wherein:

said first valve member in said first position blocks fluid communication between said compressor-outlet inlet port and said exhaust outlet port and in said second position blocks fluid communication between said fifth port, a heat-exchanger hot-stream outlet inlet port, and said exhaust outlet port; and

said second valve member in said first position blocks fluid communication between said ambient inlet port and said heat-exchanger cold-stream inlet outlet port and in said second position blocks fluid communication between said compressor-outlet inlet port and said heat-exchanger cold-stream inlet outlet port.

19. The valve of claim **14**, wherein:

said first valve member in said first position blocks fluid communication between said ambient inlet port and said heat-exchanger cold-stream inlet outlet port and in said second position blocks fluid communication between said ambient inlet port and said fifth port, a compressor inlet outlet port and said second valve member in said first position blocks fluid communication between a sixth port, a heat-exchanger hot-stream outlet inlet port, and said heat-exchanger cold-stream inlet outlet port and in said second position blocks fluid communication between said compressor-outlet inlet port and said heat-exchanger cold-stream inlet outlet port.

20. The valve of claim **19**, further comprising a component functionally associated with said heat-exchanger hot-stream outlet inlet port, allowing flow of fluid into said void through said heat-exchanger hot-stream outlet inlet port and blocking flow of fluid from said void out through said heat-exchanger hot-stream outlet inlet port.

21. The valve of claim **20**, wherein said component comprises a unidirectional valve.

22. The valve of claim **19**, further comprising a bypass conduit providing fluid communication between said heat-exchanger hot-stream outlet inlet port and said compressor inlet outlet port, and a third valve member inside said valve body movable between at least two positions, a first position and a second position, wherein

in said first position said third valve member blocks fluid communication between said heat-exchanger hot-stream outlet inlet port and said compressor inlet outlet port through said bypass conduit; and

in said second position said third valve member blocks fluid communication between said heat-exchanger hot-stream outlet inlet port and said exhaust outlet port.

23. The valve of claim **22**, said first valve member, said second valve member and said third valve member configured to cooperatively move between said first positions and said second positions.

24. The valve of claim **22**, wherein at least one of said first valve member, said second valve member and said third valve member is configured to move between said first position and said second position independently of at least one other said valve member.

25. The valve of claim **14**, wherein at least one of said valve members is movable to at least one intermediate position between a respective said first position and respective said second position, thereby allowing fluid communication between a said inlet port and at least two said outlet ports.

26. The valve of claim **14**, wherein at least one valve member is fashioned as an airfoil having an aerodynamic profile.

27. The valve of claim **25**, wherein said second valve member is movable to at least one said intermediate position, providing fluid communication between said compressor-outlet inlet port and said heat-exchanger cold-stream inlet outlet port and said exhaust outlet port.

28. The valve of claim **25**, wherein said first valve member is movable to a said intermediate position, providing fluid communication between said ambient inlet port and said heat-exchanger cold-stream inlet outlet port and a compressor outlet port.

29. The valve of claim **25**, comprising a said third valve member, wherein said third valve member is movable to a said intermediate position, providing fluid communication between a heat-exchanger hot-stream outlet inlet port and said exhaust outlet port and a compressor-inlet outlet port.

30. The valve of claim **14**, wherein at least one valve member is configured to vary a size of a fluid path between a said inlet port and a outlet port while said valve member in a said first position and/or a second position.

31. The valve of claim **30**, wherein said second valve member is configured to vary a size of a fluid path between said compressor-outlet inlet port and said heat-exchanger cold-stream inlet outlet port when in said first position.

32. The valve of claim **30**, wherein said first valve member is configured to vary a size of a fluid path between said ambient inlet port and said heat-exchanger cold-stream inlet outlet port when in said second position.

33. The valve of claim **30**, further comprising an additional valve member movable inside said valve body and configured to vary a size of a fluid path between said compressor-outlet inlet port and said heat-exchanger cold-stream inlet outlet port.

34. The valve of claim **14**, further comprising an additional valve member movable inside said valve body and configured to vary a size of a fluid path between said ambient inlet port and said heat-exchanger cold-stream inlet outlet port.

35. The valve of claim **14**, further comprising a permeable section between a first region and a second region of said void, providing fluid communication between said first region and said second region.

36. The valve of claim **35**, wherein said permeable section is unidirectional, allowing passage of fluid from said first region to said second region, and blocking passage of fluid from said second region to said first region.

37. A gas-turbine configured to switch between a high-pressure operation mode according to a Brayton cycle and a low-pressure operation mode according to an inverse Brayton cycle, comprising a valve of claim **14**.

38. The gas-turbine of claim **37**, further configured to switch to an intermediate pressure mode between said high-pressure operation mode and said low-pressure operation mode.

39. A method of operating a gas-turbine according to an inverse Brayton cycle, comprising:

a. providing a conduit allowing fluid communication between a compressor of the gas-turbine and a cold-stream inlet of a heat-exchanger of the gas-turbine; and

b. during inverse Brayton cycle operation of the gas-turbine, directing fluid from said compressor to said heat-exchanger cold-stream inlet through said conduit so that a portion of the fluid entering said heat-exchanger cold-stream inlet is from said compressor.

40. The method of claim **39**, further comprising: adjusting a size of said conduit so as to control an amount of fluid entering said cold-stream inlet from said compressor.

41. The method of claim **39**, wherein between about 30% and about 70% by mass of the fluid entering the cold-stream inlet is from said compressor.

42. A gas-turbine comprising, when operating according to an inverse Brayton cycle,

a. an air inlet configured to direct fluid into a cold-stream conduit of a heat-exchanger through a cold-stream inlet;

b. conduits to direct fluid from said cold-stream conduit to a combustor, from said combustor to a turbine, from said turbine to a hot-stream conduit of said heat-exchanger, from said hot-stream conduit to a compressor, and from said compressor to an exhaust outlet; and

c. a conduit allowing passage of fluid from said compressor into said cold-stream inlet of said heat-exchanger.

43. The gas-turbine of claim **42**, wherein said conduit allowing passage of fluid from said compressor into said cold-stream inlet is of fixed size.

44. The gas-turbine of claim **42**, wherein a size of said conduit allowing passage of fluid from said compressor into said cold-stream inlet is adjustable.

45. The gas-turbine of claim **42**, wherein said conduit allowing passage of fluid from said compressor into said cold-stream inlet is configured so that during operation of the gas-turbine according to an inverse Brayton cycle between about 30% and about 70% by mass of the fluid entering said cold-stream inlet is from said compressor.

* * * * *