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(54) **METHODS AND APPARATUS FOR POWER GENERATION**

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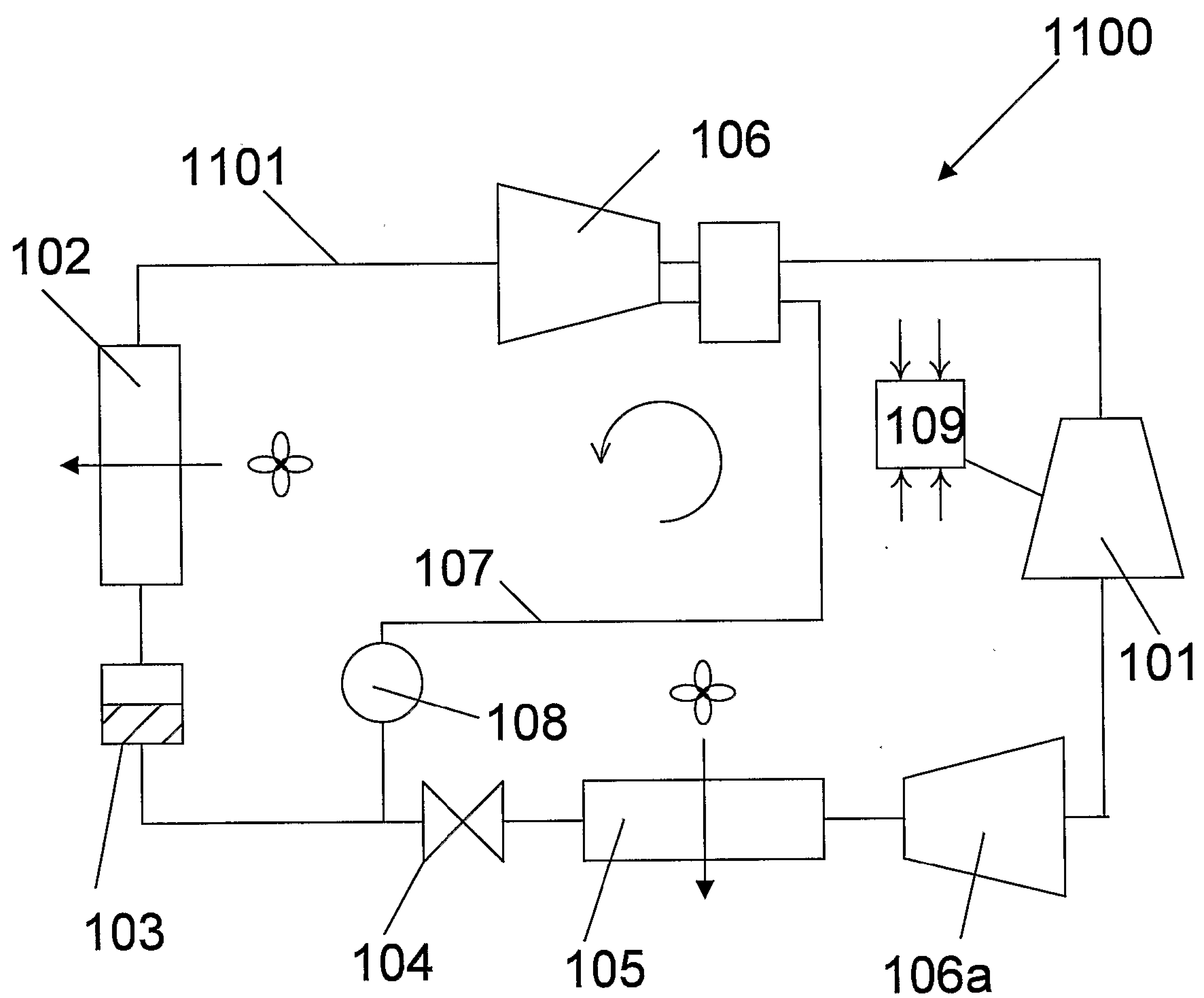
(57) **ABSTRACT**

A refrigeration apparatus (**7200**) includes a heat pump circuit (**7201**) and a power generation circuit (**7100**). The power generation circuit (**7100**) includes an evaporator (**701**) including a first and a second heat exchanger (**710***a*, **710***b*), a turbine (**702**), a condenser (**703**) and a pump (**704**). The first heat exchanger (**710***a*) absorbs heat rejected from the heat pump circuit (**7201**) into a power generation circuit (**7100**) while the second heat exchanger (**710***b*) further heats the fluid. The power generation circuit (**7100**) includes a bypass (**707**) which allows a portion of working liquid to enter the turbine (**702**) without passing through the evaporator (**701**). A heat pump (**704**) with similar bypass is also disclosed. Also disclosed are dual stage turbine design and a nozzle (**10300**) for a turbine which includes two fluid paths (**1011**, **1014**) that adapted to receive and mix the liquid and vapour streams of working fluid, so that the liquid working fluid is vaporized by the heat from the vapour working fluid.



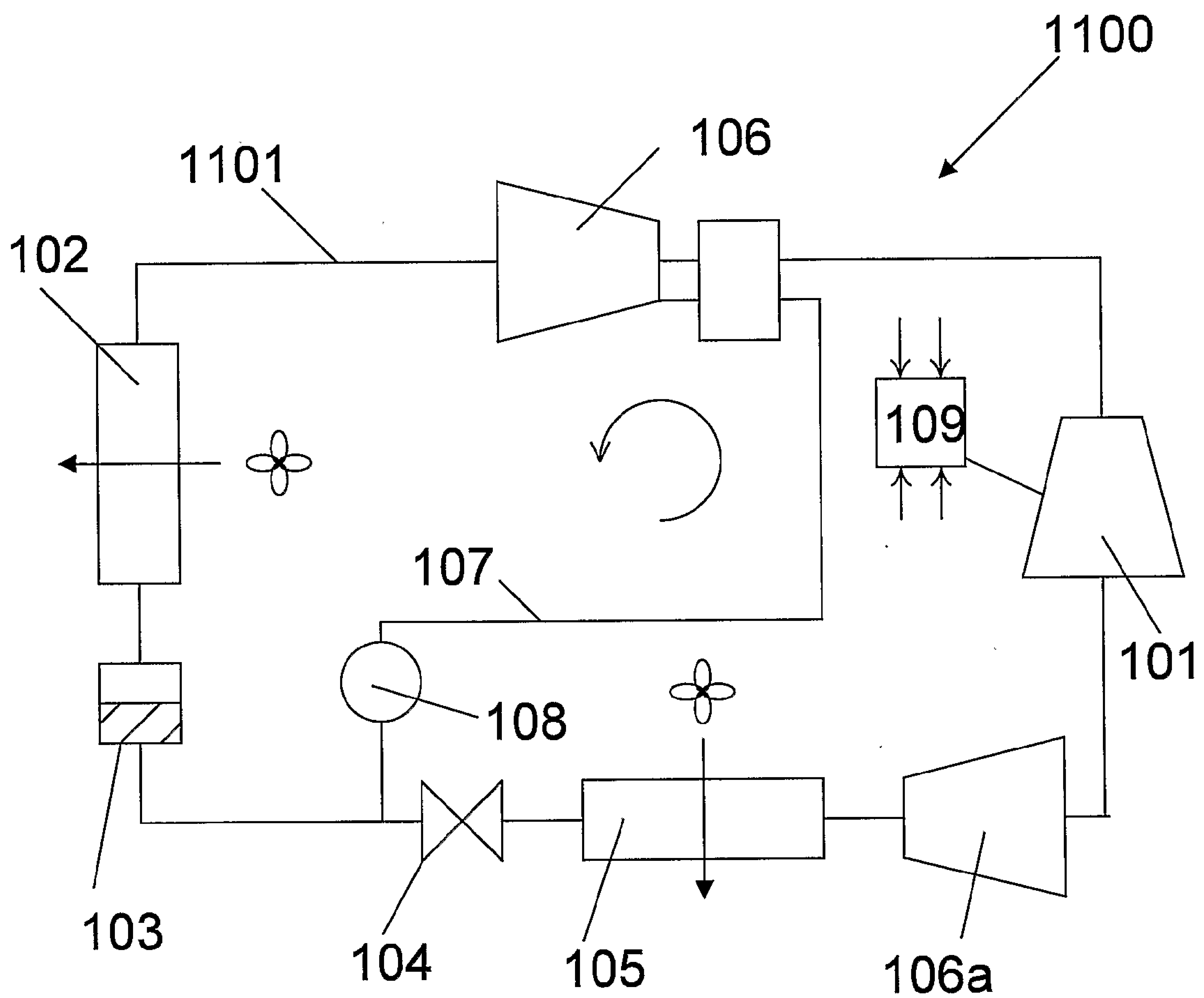
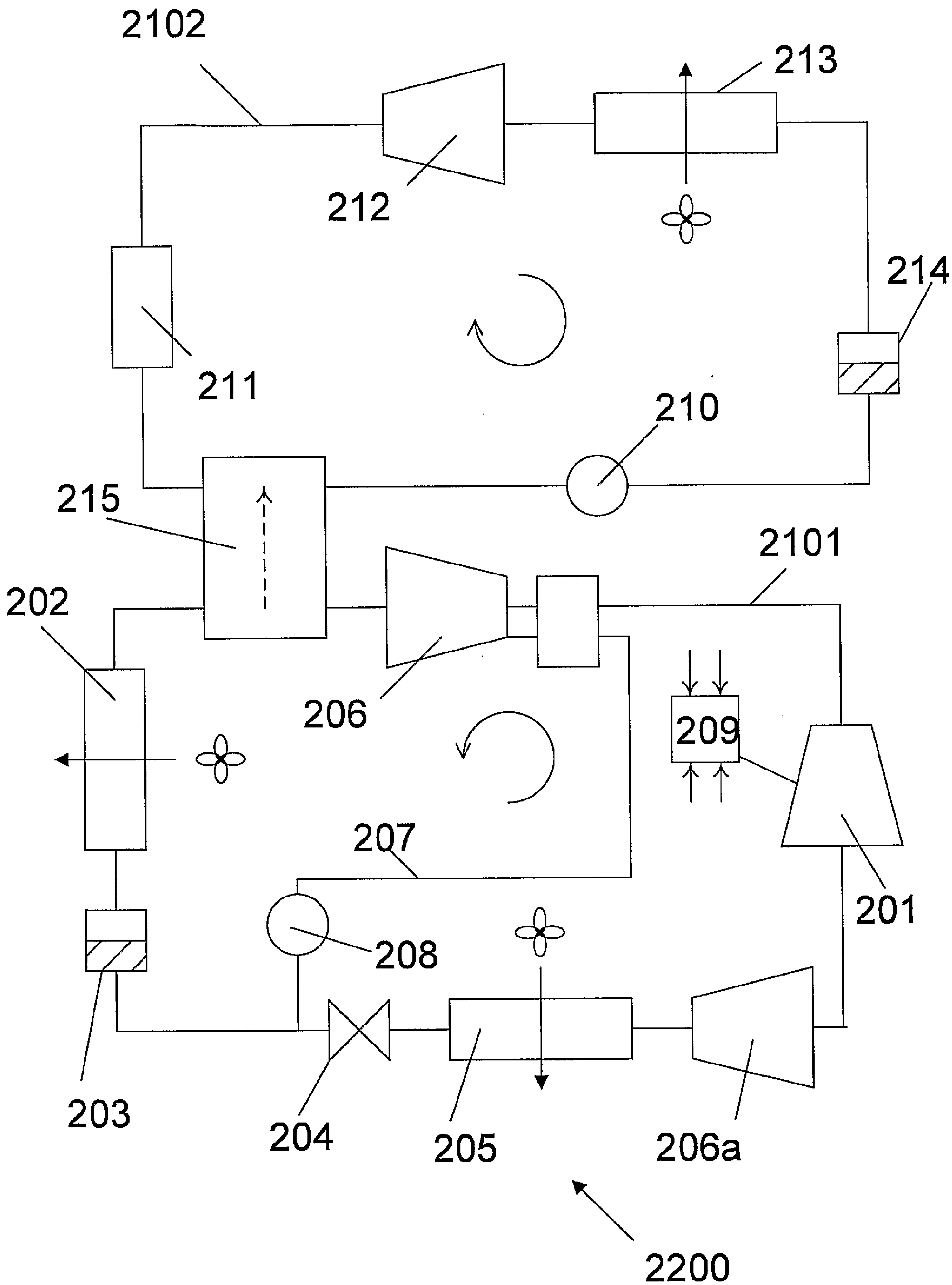


FIGURE 1


2102
213
212
214
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2200

FIGURE 2

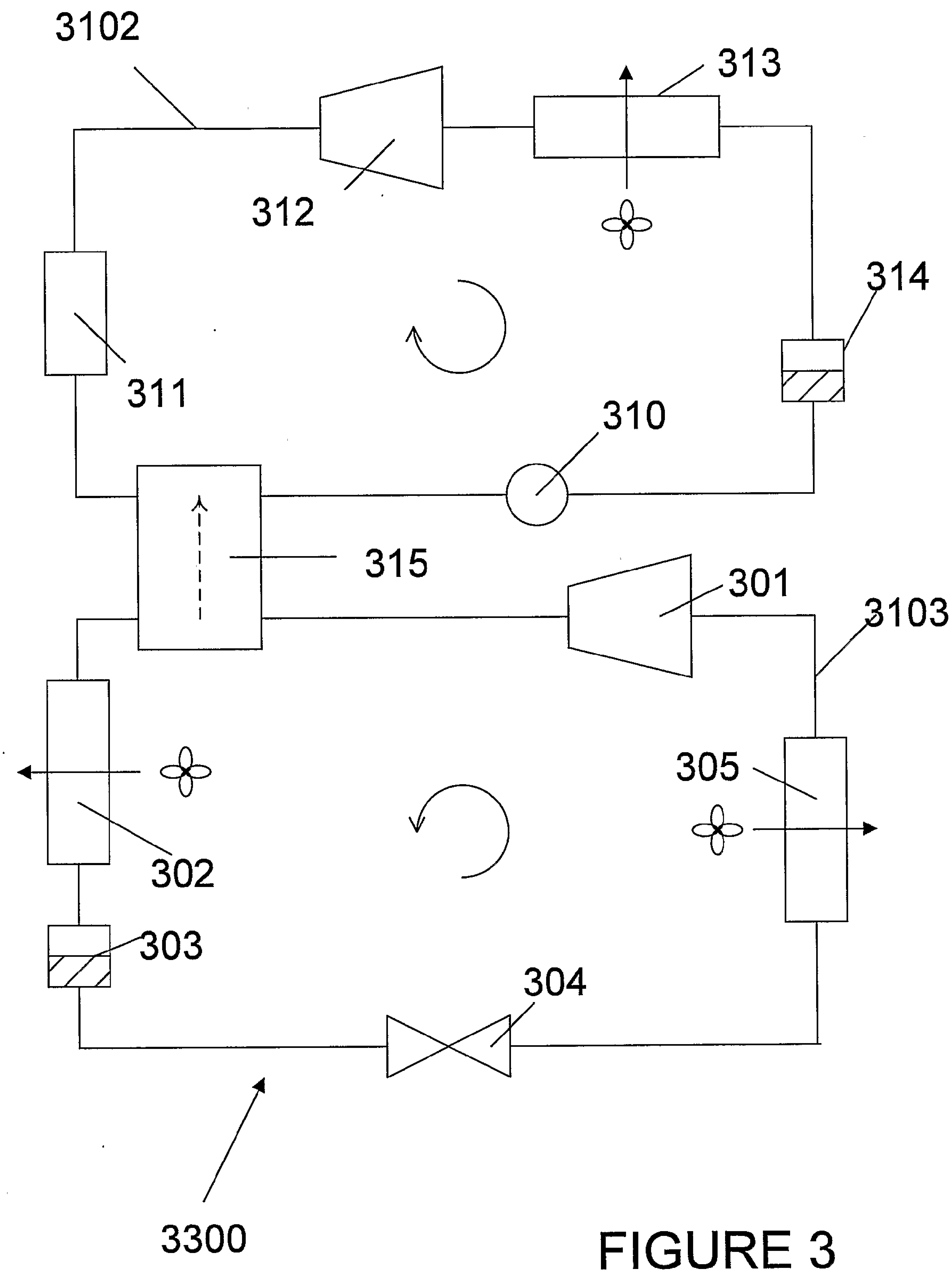


FIGURE 3

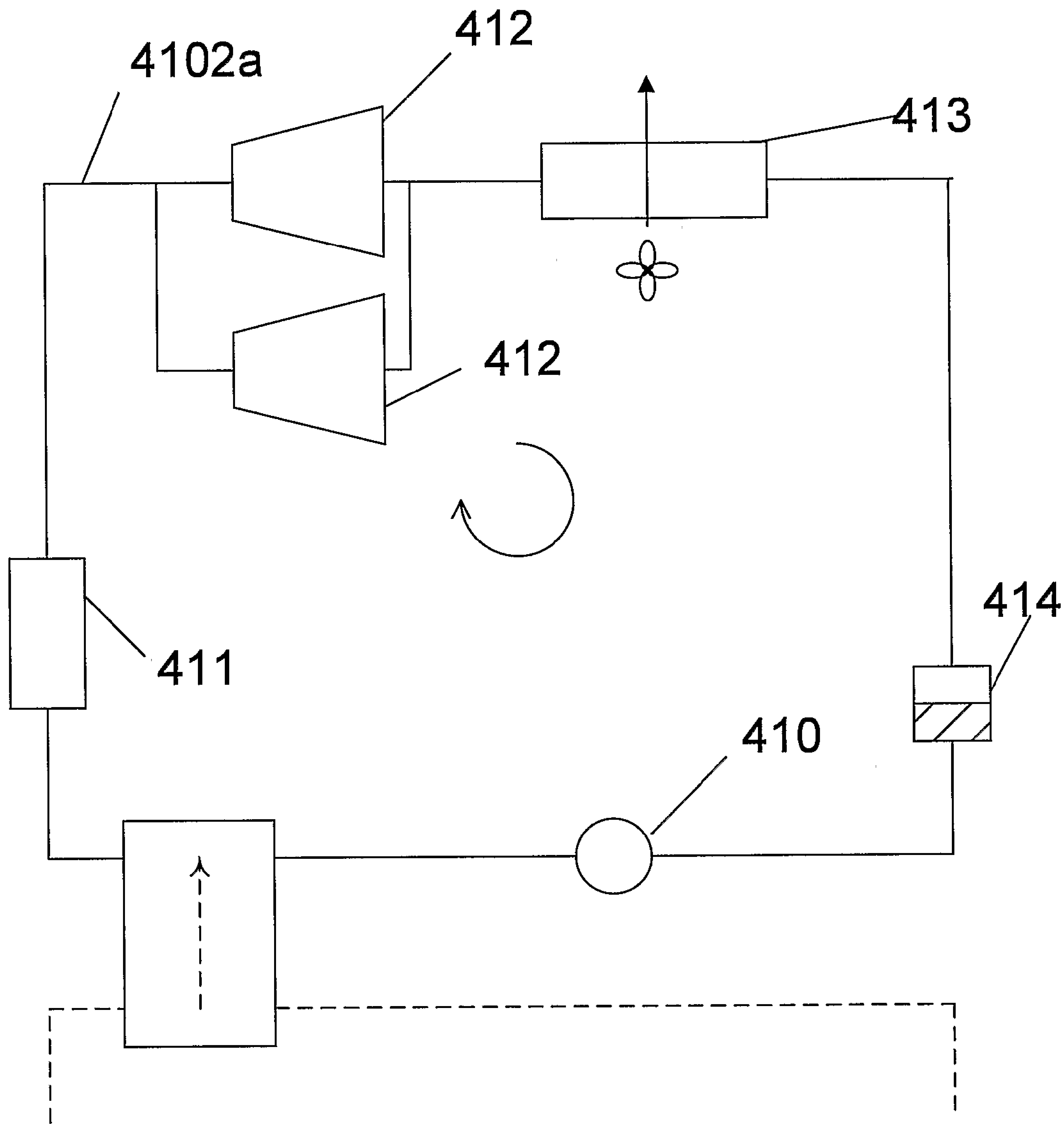


FIGURE 4

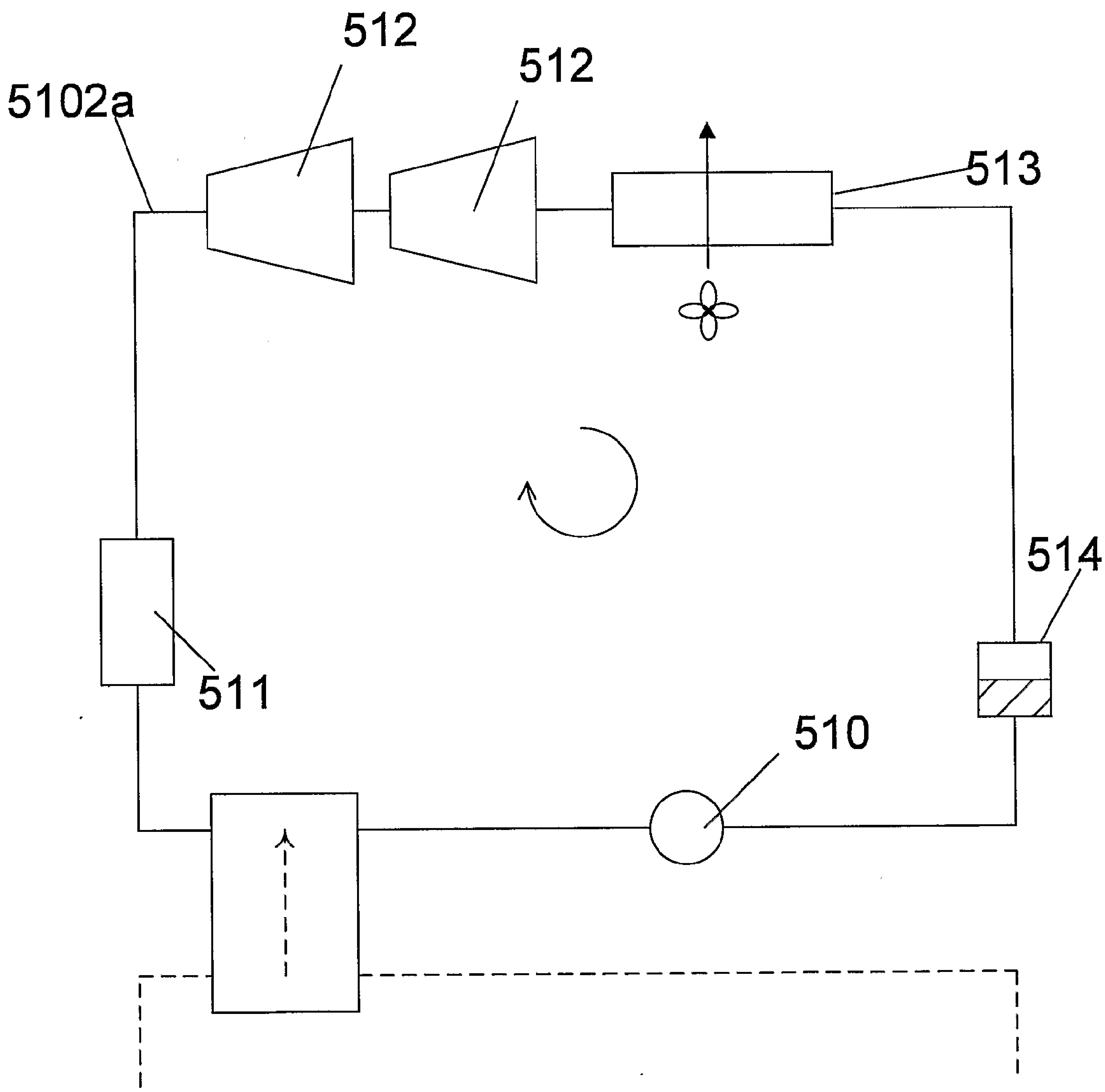


FIGURE 5

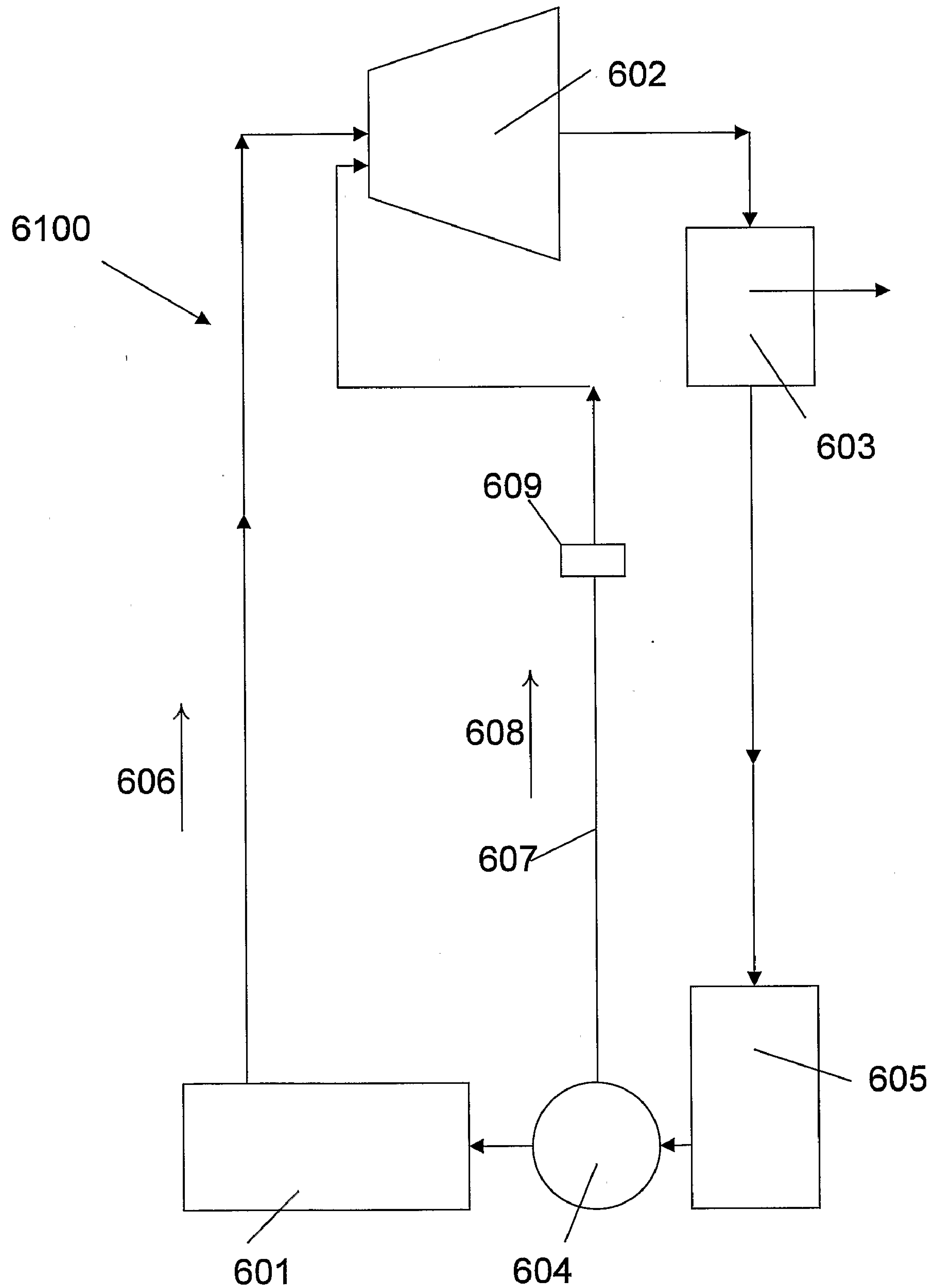
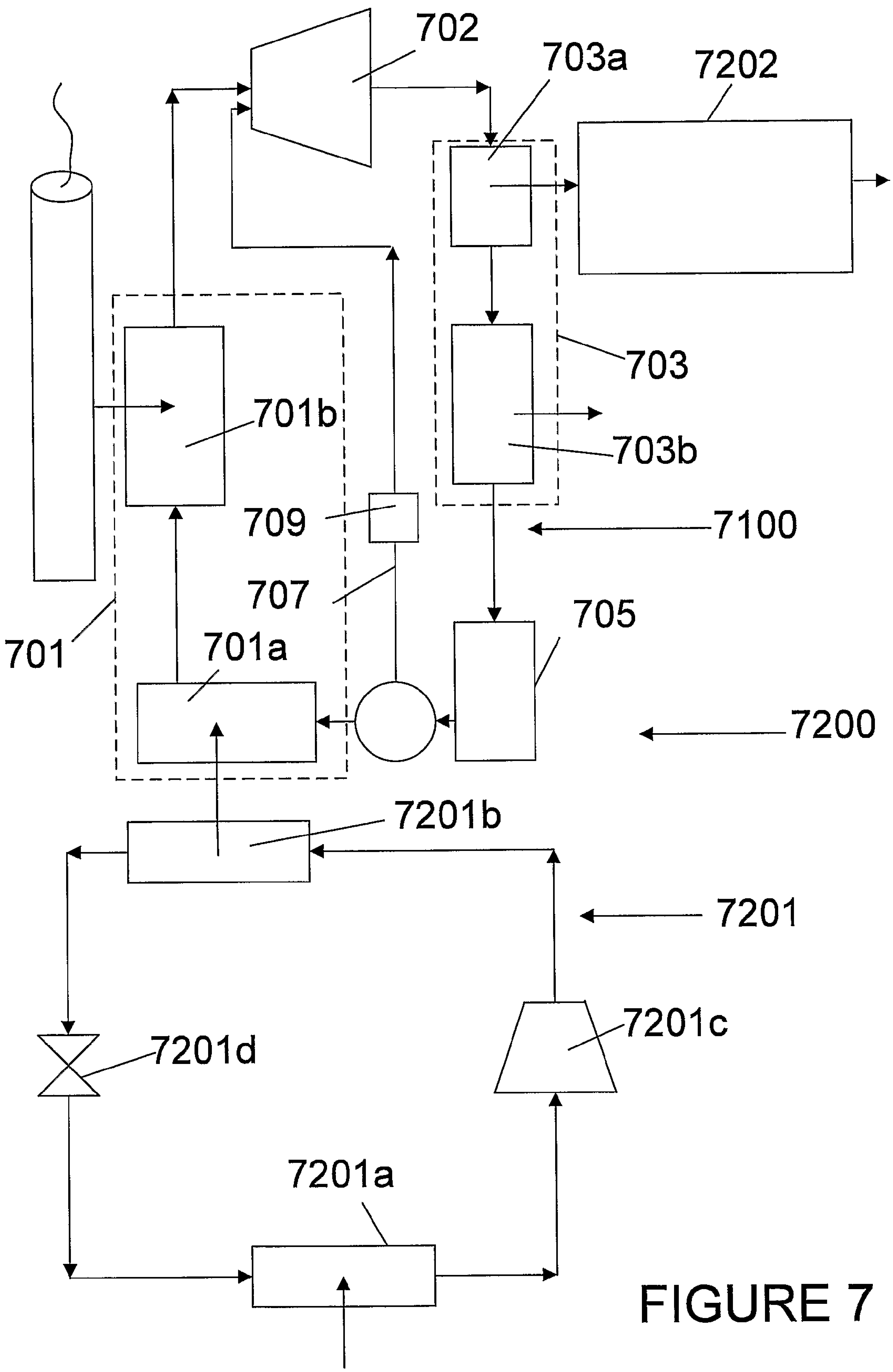


FIGURE 6


702
703a
7202
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701b
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709
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707
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7200
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7201c
7201a

FIGURE 7

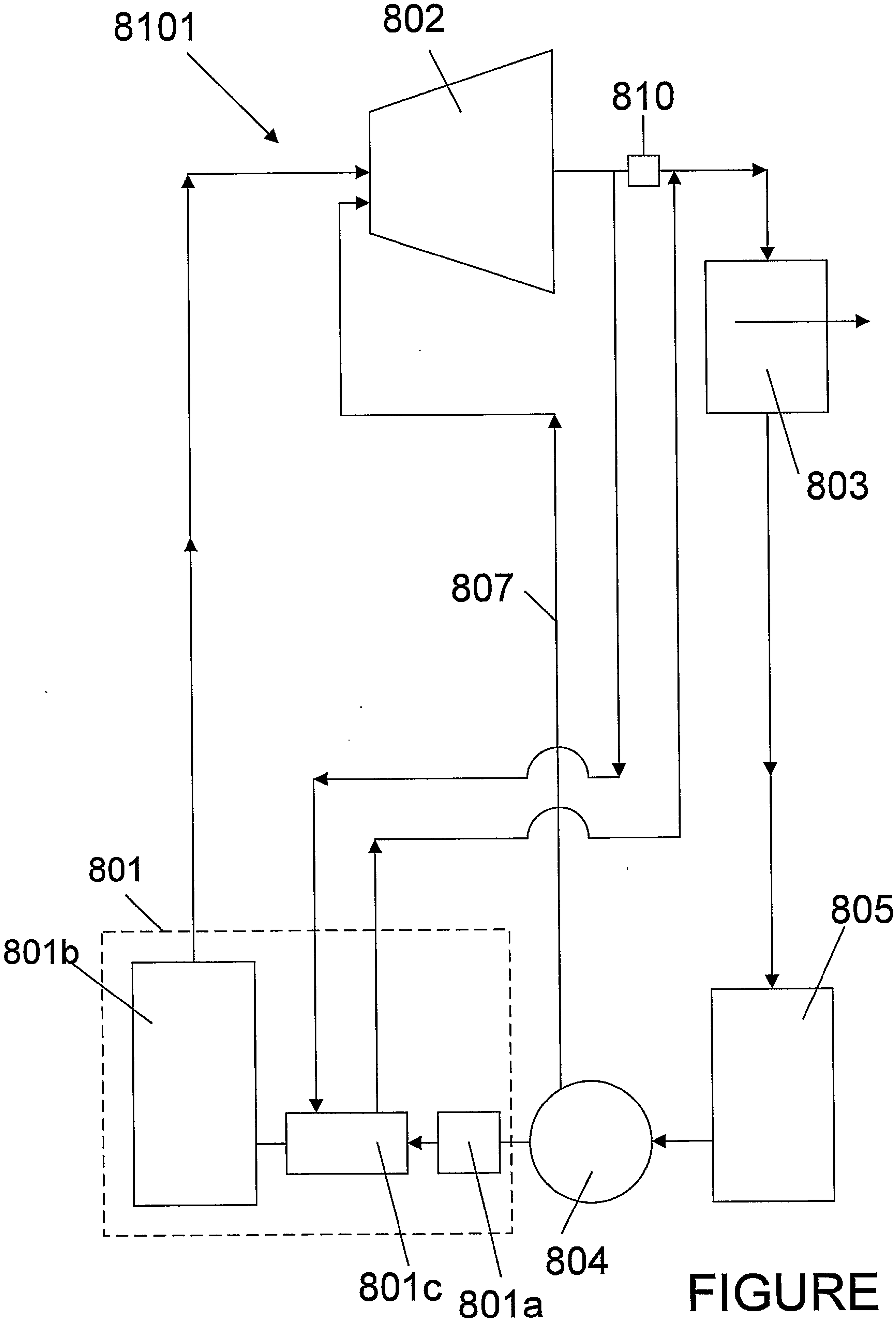


FIGURE 8

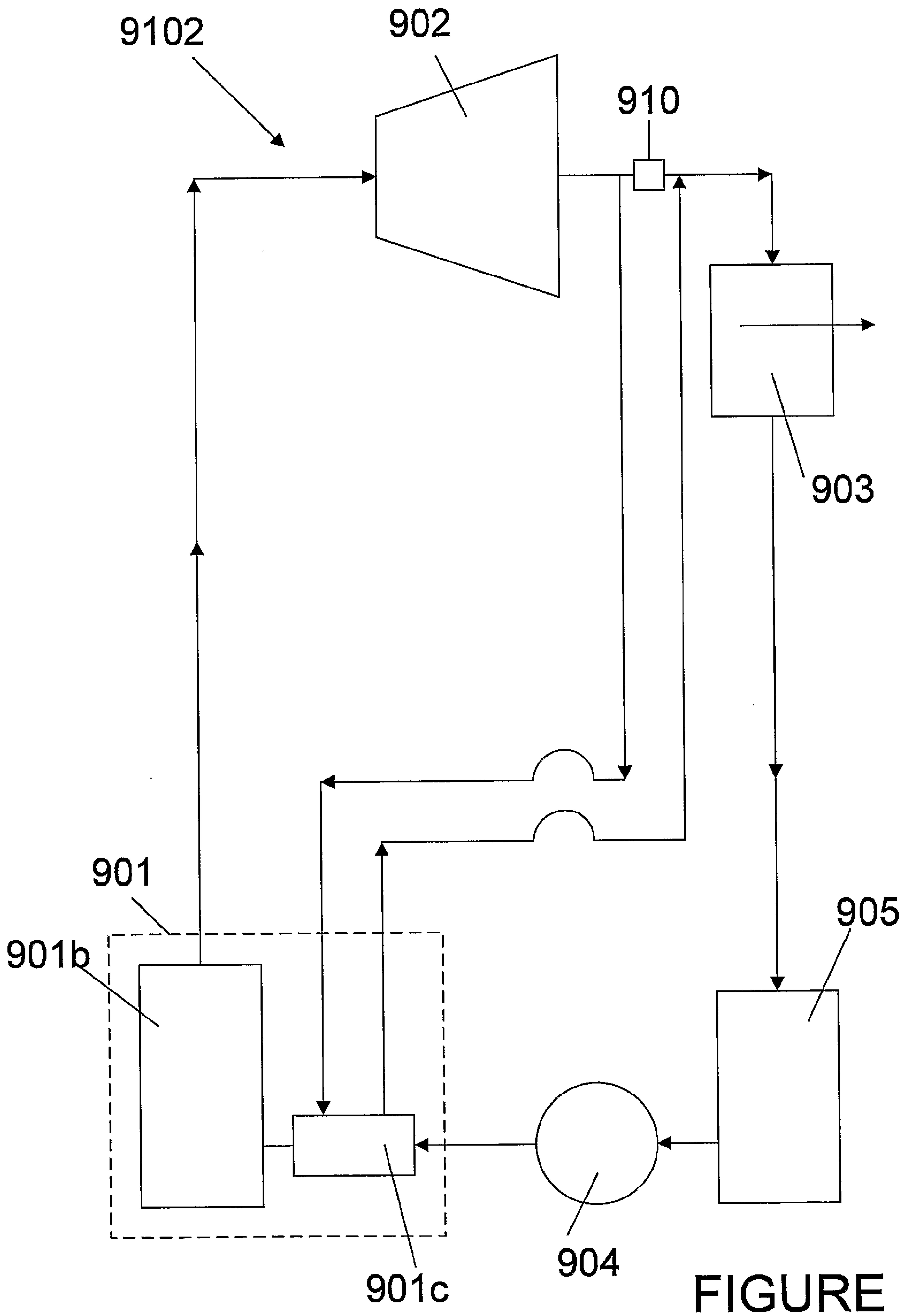


FIGURE 9

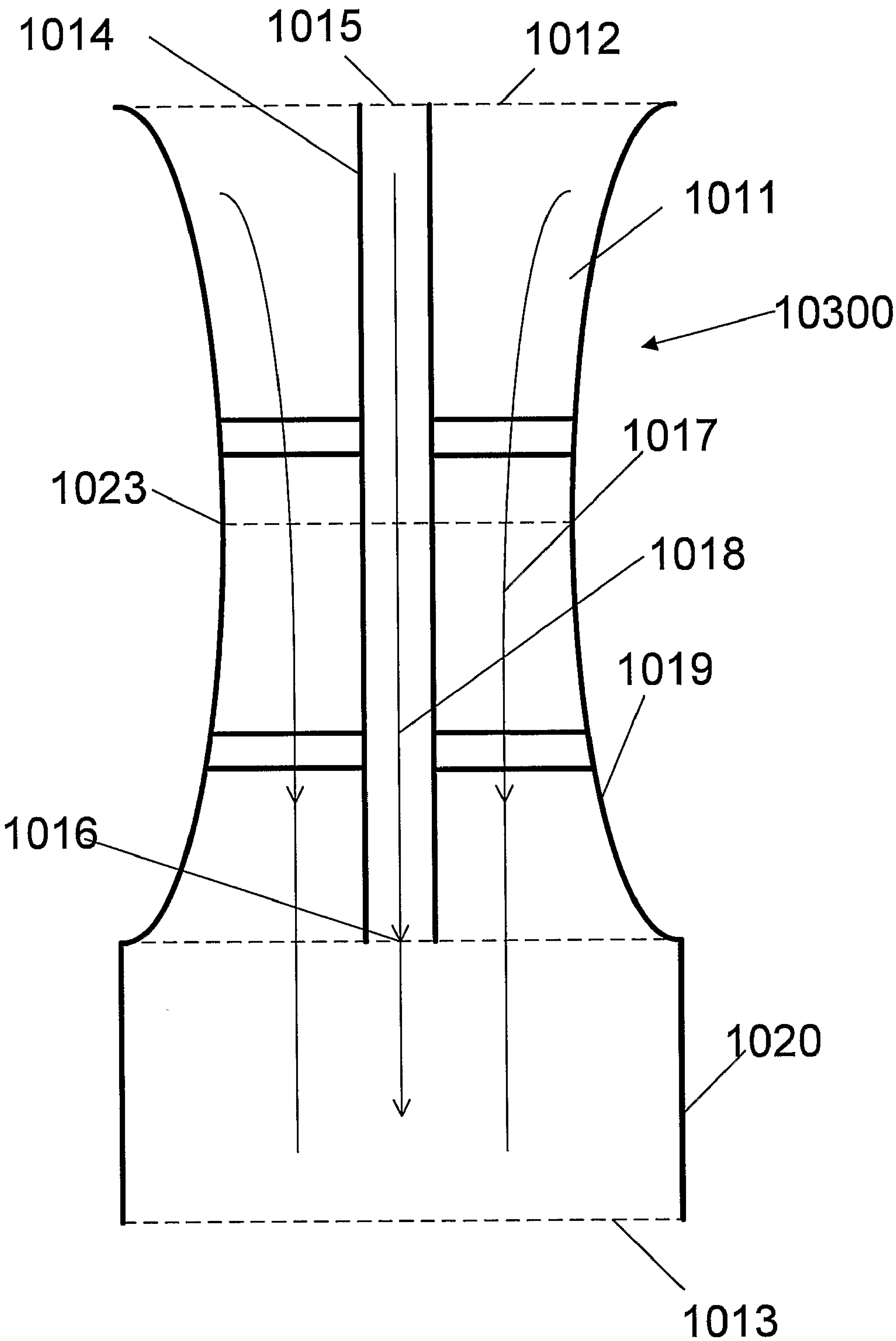
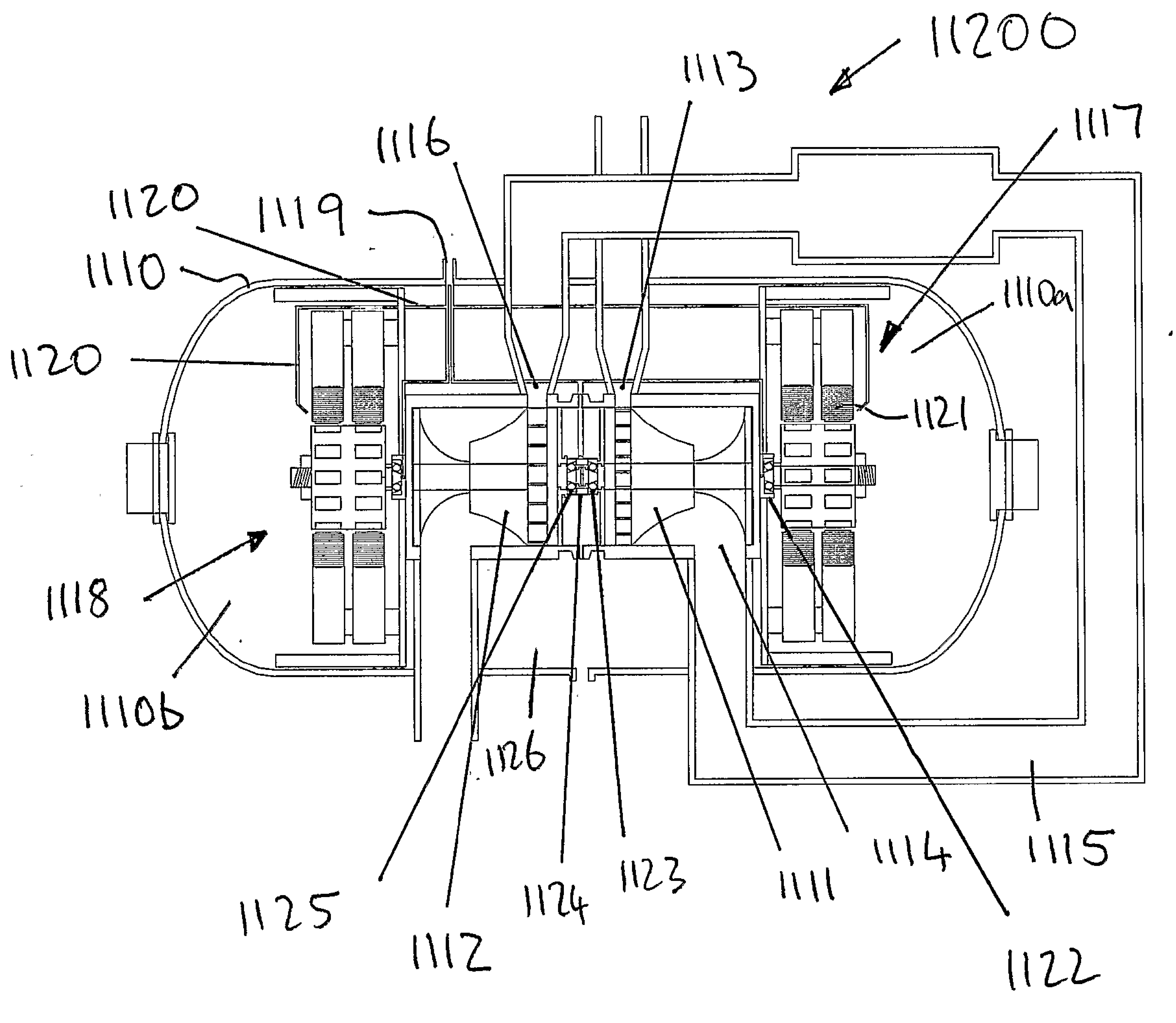


FIGURE 10


11200
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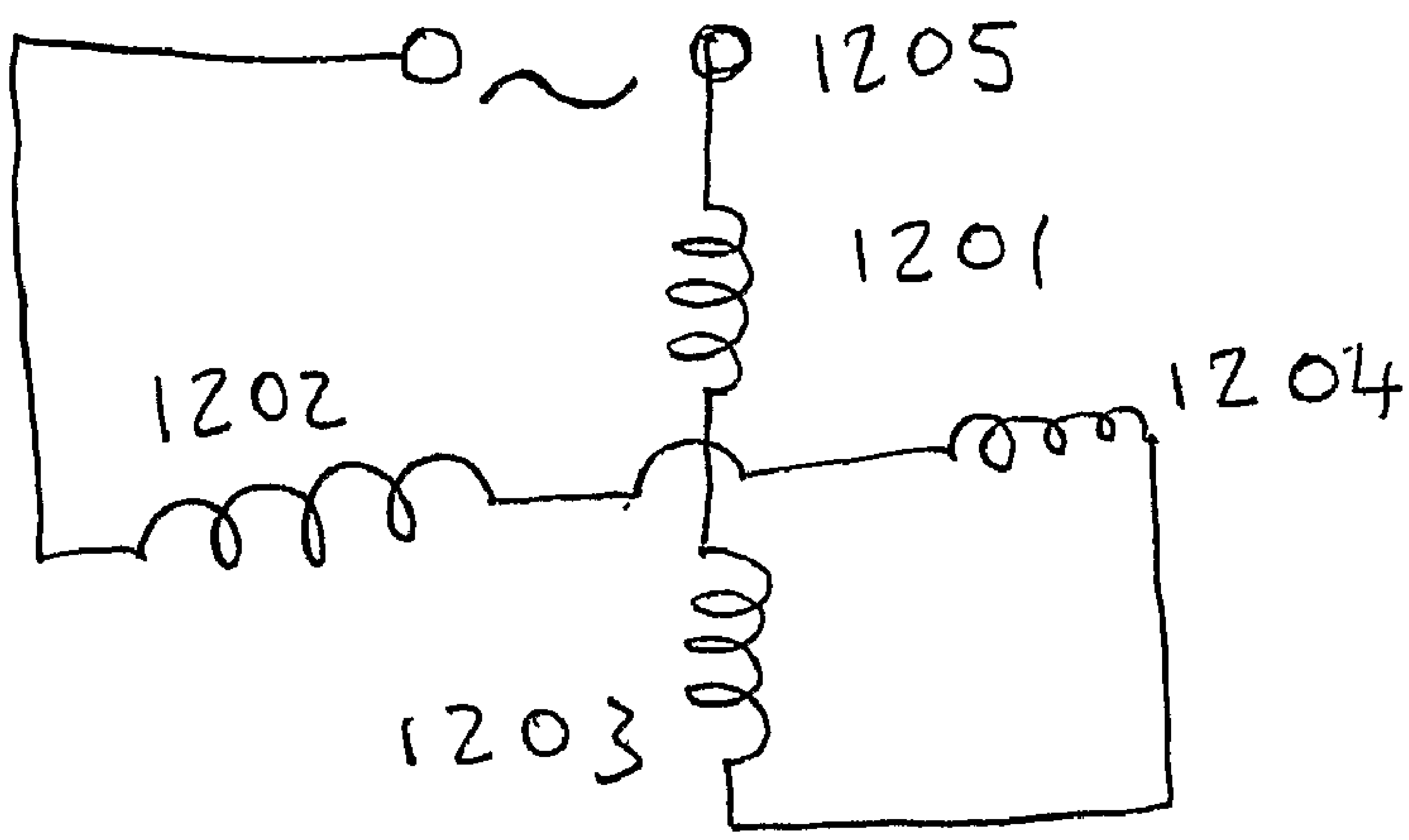
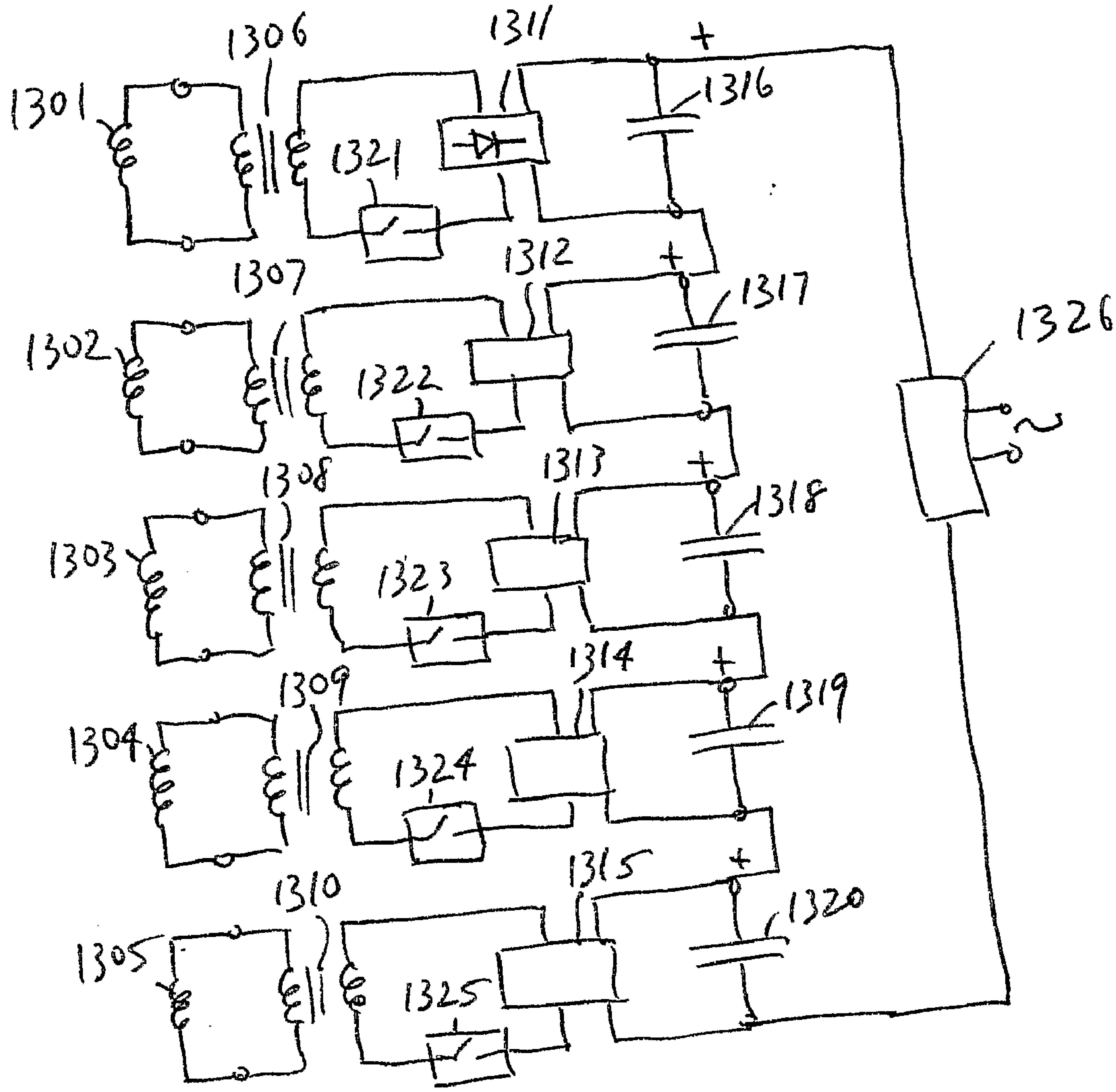
1123
1111
1114
1115
1122

Figure 11



1205
1201
1202
1204
1203

Fig 12



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1303
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1304
1324
1310
1315
+
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1305
1325

FIG 13

METHODS AND APPARATUS FOR POWER GENERATION

FIELD OF THE INVENTION

[0001] The present invention relates to methods and apparatus for utilizing heat which would otherwise be rejected to the environment, and in particular, but not exclusively to methods and apparatus for generating power from a Rankine type cycle and/or at least reducing the net power consumed by a heat pump apparatus.

BACKGROUND TO THE INVENTION

[0002] It is well known that almost every practical thermodynamic system rejects some heat to the environment. In times of cheap energy production this has not been viewed as a problem. However, in recent times energy availability has dwindled, and the cost of energy has begun to rise. Accordingly, a need has been recognized around the world to ensure that any energy consumed is used as efficiently as possible.

[0003] Two well known examples of systems which reject a relatively high proportion of the energy they consume as heat are refrigeration cycles and Rankine cycles.

[0004] It would be beneficial to develop systems and methods which utilize some of the heat which these apparatus would traditionally waste by rejecting it to the environment.

OBJECT OF THE INVENTION

[0005] It is an object of a preferred embodiment of the present invention to provide a method and/or an apparatus for power generation which will overcome or ameliorate problems with such methods and/or apparatus, or to at least provide a useful choice.

[0006] Further aspects of the invention, which should be considered in all its novel aspects, will become apparent from the following description given by way of example of possible embodiments of the invention.

SUMMARY OF THE INVENTION

[0007] According to one aspect of the present a turbine nozzle includes a first fluid path which includes a first inlet adapted to receive a first working fluid vapour stream, and a first outlet adapted to communicate a jet of said working fluid to a rotor of a turbine, the nozzle further including a second fluid path which includes a second inlet adapted to receive a second substantially liquid working fluid stream and a second outlet adapted to communicate a jet of said second working fluid to the rotor of said turbine, wherein the nozzle is adapted to mix the jets of working fluid so that at least part of the liquid working fluid is vaporised by heat from the working fluid vapour.

[0008] Preferably, said first working fluid stream and said second working fluid stream are from a common working fluid circuit.

[0009] Preferably, substantially all of the substantially liquid working fluid vapour is vaporised by heat from the substantially vapour working fluid jet.

[0010] Preferably, the first and second fluid paths are substantially circular or annular in cross-section.

[0011] Preferably, the second outlet is concentric with the first fluid path.

[0012] Preferably, the first fluid path has a converging/diverging section adapted to accelerate the stream of working fluid vapour to a mean velocity above the local speed of sound.

[0013] Preferably, a section of the first fluid path immediately downstream of the converging/diverging section has a substantially constant cross-section.

[0014] Preferably, the second outlet is in the substantially constant cross-section section of the first fluid path.

[0015] According to a further aspect of the present invention a turbine means includes at least one rotor and at least one nozzle as described in any of the eight immediately preceding paragraphs for supplying working fluid to the at least one rotor.

[0016] Preferably, the second working fluid is substantially completely vapourized before impinging on the rotor.

[0017] According to a further aspect of the present invention there is provided a dual stage turbine including a housing including a first chamber provided with a first inlet nozzle for supplying a working fluid to a first turbine rotor rotatably connected to the housing within the first chamber, the first chamber including a first outlet adapted to receive working fluid exiting the first turbine rotor, the first outlet connected to a second inlet nozzle provided in a second chamber, the second nozzle supplying a working fluid to a second turbine rotor which is rotatably connected to the housing, the housing further including a second outlet adapted to receive fluid exiting the second turbine rotor, wherein the first and second turbine rotors are independently rotatable.

[0018] Preferably, said first and second turbine rotors may be substantially identical.

[0019] Preferably, the working fluid from the first nozzle is radially incident on the first rotor.

[0020] Preferably, the working fluid from the second nozzle is radially incident on the second rotor.

[0021] Preferably, said working fluid exits each said turbine rotor substantially axially.

[0022] Preferably, each said turbine rotor is operably connected to an electrical energy generation means.

[0023] Preferably, said first inlet nozzle is the turbine nozzle described above.

[0024] According to a further aspect of the present invention a heat pump includes a working fluid circuit including, in order, a compressor, a condenser, a receiver, a throttling means, an evaporator, and a first turbine, wherein the circuit further includes a bypass means operable to transfer a proportion of a working fluid within said working fluid circuit from upstream of said throttling means to said first turbine without passing through the throttling means or said evaporator.

[0025] Preferably, said bypass means includes working fluid pumping means.

[0026] Preferably, said working fluid circuit rejects heat to a second working fluid in a second working fluid circuit via first heat exchanger means.

[0027] Preferably, said second working fluid circuit includes a second turbine.

[0028] Preferably, said second working fluid circuit includes second heat exchanger means operable to add further heat to said second working fluid.

[0029] Preferably, said first turbine is a turbine as described above.

[0030] According to a further aspect of the present invention a power generation apparatus includes a working fluid circuit including, in order of fluid flow, an evaporator means, a turbine means, a condenser means and a pumping means, wherein the working fluid circuit is adapted to allow a first portion of a working fluid exiting the condenser means to pass through the evaporator means before entering the turbine means, and a second portion of the working fluid to enter the turbine means without passing through the evaporator means.

[0031] Preferably, said first turbine is the turbine means described above.

[0032] Preferably, the working fluid circuit may include valve means for controlling the ratio of the first portion of working fluid to second portion of working fluid entering the turbine.

[0033] Preferably, the working fluid may be a refrigerant.

[0034] According to a further aspect of the present invention a refrigeration apparatus includes a heat pump means including an evaporator for cooling a medium to be cooled and a condenser, wherein the condenser rejects heat to an evaporator means of a power generation apparatus as described above.

[0035] Preferably, the condenser means of the power generation apparatus may reject heat to an evaporator of a second heat pump.

[0036] According to a further aspect of the present invention a method of supplying working fluid to a turbine means having a rotor means includes the steps of:

directing a jet of substantially vapour working fluid towards the rotor;

directing a jet of substantially liquid working fluid towards the rotor,

mixing the jets prior to the substantially liquid working fluid jet impinging on the rotor so that at least part of the substantially liquid working fluid vapour is vaporised by heat from the substantially vapour working fluid jet.

[0037] Preferably, substantially all of the substantially liquid working fluid vapour is vaporised by heat from the substantially vapour working fluid jet.

[0038] Preferably, the method includes directing the jet of working fluid vapour through a fluid path having a converging section.

[0039] Preferably, the method includes directing the jet of working fluid vapour through a fluid path having a converging/diverging section.

[0040] According to a further aspect of the present invention a heat pump includes a working fluid circuit including, in order, a compressor, a condenser, a receiver, a throttling valve, and an evaporator, the heat pump further including heat exchanger means for rejecting heat to a second working fluid cycle.

[0041] According to a further aspect of the present invention there is provided a method of generating power using a pre-existing refrigeration circuit, the method including inserting a heat exchanger upstream of a condenser in the pre-existing refrigeration circuit whereby heat is transferred from the pre-existing refrigeration circuit to working fluid in a heat pump circuit, the heat pump circuit including an evaporator or boiler downstream of the heat exchanger, a turbine downstream of the evaporator or boiler, a condenser downstream of the turbine and means to circulate the working fluid about said heat pump circuit.

[0042] According to a further aspect of the present invention there is provided a method for generating alternating current electric power from an energy recovery system using a source of waste heat, the system including a turbine unit and a generator having a plurality of windings, the generator being operably associated with the turbine, comprising the steps of

[0043] generating a first alternating current from at least a first of a the plurality of windings, and a second alternating current from at least another from the plurality of windings,

[0044] increasing the voltage of each alternating current using a transformer, rectifying the output of the transformers to produce a first direct current output and a second direct current output,

[0045] cumulatively adding the first direct current output to the second direct current output to produce a cumulative direct current output, and

[0046] inverting the cumulative direct current output to produce alternating current electric power.

[0047] Preferably the first and second alternating currents are each produced from a plurality of phase synchronised windings.

[0048] Preferably the step of rectifying the output of the transformers includes using a bridge rectifier and filtering the output of the bridge rectifier.

[0049] Apparatus for generating alternating current electric power in an energy recovery system from waste heat, the apparatus including a turbine unit and a generator operably associated with the turbine, the generator having a plurality of windings arranged to produce a first alternating current and a second alternating current, a first transformer to increase the voltage of the first alternating current and in the second transformer to increase the voltage of the second alternating current, a first and second rectifying means to rectify the output of each transformer, and the rectified outputs being cumulatively added together to produce a cumulative direct current output, and an inverter means to invert the cumulative direct current output to alternating current electric power.

[0050] A method for generating alternating current electric power in an energy recovery system from waste heat, the system including two turbine rotors, each turbine rotor adapted to operate at a different speed, a generator operably associated with each turbine rotor, comprising the steps of:

[0051] generating a first alternating current using each generator,

[0052] increasing the alternating current output of each generator using a transformer,

[0053] rectifying the output of each transformer to produce a direct current output,

[0054] cumulatively adding the direct current outputs together, and

[0055] inverting the cumulative direct current output to produce alternating current power.

[0056] Apparatus for generating alternating current electric power in a energy recovery system from waste heat, the apparatus including two turbine rotors adapted operate independently, each turbine rotor operably associated with a generator, each generator producing an alternating current which is provided to a transformer, each transformer being operable to increase the voltage of each of the alternating currents, rectifying means to rectify the output of each transformer to produce a first direct current output and a second direct current output, the first and second direct current outputs being cumulatively combined, and an inverter means to invert the cumulative direct current output to provide alternating current electric power.

BRIEF DESCRIPTION OF THE FIGURES

[0057] FIG. **1**: Is a schematic diagram of a heat pump.

[0058] FIG. **2**: Is a schematic diagram of an alternative embodiment of a heat pump.

[0059] FIG. **3**: Is a schematic diagram of a further alternative embodiment of a heat pump.

[0060] FIG. **4**: Is a schematic diagram of a second working fluid circuit with two turbines in parallel.

[0061] FIG. **5**: Is a schematic diagram of a second working fluid circuit with two turbines in series.

[0062] FIG. **6**: Is a simplified schematic diagram of a power generation apparatus according to a preferred embodiment of the invention.

[0063] FIG. **7**: Is a schematic diagram of a refrigeration apparatus of the present invention, incorporating the power generation apparatus of FIG. **6**.

[0064] FIG. **8**: Is a schematic diagram of an alternative embodiment of the power generation apparatus of FIG. **6**.

[0065] FIG. **9**: Is a schematic diagram of an alternative power generation apparatus according to one embodiment of the present invention.

[0066] FIG. **10**: Is a diagrammatic cross-section of a turbine nozzle according to the present invention.

[0067] FIG. **11** Is a diagrammatic cross section of a dual stage turbine of the present invention.

[0068] FIG. **12** Is a simplified circuit diagram of four generator windings connector in a phase synchronised manner.

[0069] FIG. **13** Is a simplified circuit diagram of five groups of windings connected as shown in FIG. **12** together with transformer, rectifier and inverter apparatus arranged to provide a required alternating current output.

BEST MODES FOR PERFORMING THE INVENTIONS

[0070] The term "fluid" is used here in to denote a liquid, gas, or a mixture of liquid and gas.

[0071] The term "working fluid" is used herein to denote any fluid suitable for use with the associated working fluid circuit, whether in a liquid or gaseous state.

[0072] The term "heat pump" is used to describe apparatus which are capable of transferring heat from a first medium to a relatively warmer a second medium, for example a phase change heat pump. The term includes embodiments in which heat is, in practice, transferred from a higher temperature medium to a lower temperature medium.

[0073] The term "turbine" is used to describe a turbomachine which converts energy from a working fluid vapour to useful power. Where the context requires it, the term "turbine" includes devices which incorporate means to generate electrical power.

[0074] The terms "upstream" and "downstream" are used to indicate a direction relative to the normal flow of working fluid.

[0075] Referring first to FIG. **1**, a heat pump according to one possible embodiment of the present invention is generally referenced **1100**.

[0076] The heat pump **1100** includes a first closed working fluid circuit **1101** which includes, in order according to the flow of working fluid, a compressor **101**, a condenser **102**, a receiver **103**, a throttling or Tx valve **404** and an evaporator **105**. A first turbine **106** is provided between the compressor **101** and condenser **102**. A second turbine **106***a* may optionally be included between the evaporator **105** and the compressor **101**.

[0077] The working fluid circuit **1101** further includes a bypass **107** which allows liquid working fluid to pass from upstream of the Tx valve **104** to the turbine **106** without passing through the compressor **101**. A pump **108** may be provided in the bypass **107** to pump the liquid working fluid to the turbine **106**.

[0078] A control means **109** may monitor one or more operating parameters of the heat pump **1100**, for example heat transfer from the evaporator **105** and/or required power from the turbine **106**, and may adjust the speed of the compressor **101** and the flow rate through the bypass **107**, for example by varying the speed of the pump **108**, so as to minimise the net power consumed by the heat pump **1100**, while keeping one or more of said operating parameters within predetermined limits.

[0079] The working fluid which flows through the bypass **107** exchanges heat with and is warmed by the working fluid exiting the compressor **101**, and flashes to vapour prior to entering the turbine **106**. Turbine **106** may be a turbine such as that described below with reference to FIG. **10** or **11**.

[0080] In some embodiments the heat transferred out of the circuit **1101** by the condenser **102** and/or into the circuit **1101** by the evaporator **105** may also be controlled by the control means **109**, for example by varying the flow of the cooling/heating medium. Both the heating and cooling mediums may be ambient air.

[0081] Those skilled in the art will appreciate pumping the working fluid in its liquid state is substantially more efficient than moving the fluid at the same flow rate with a compressor. Therefore, by allowing a portion of the working fluid to bypass the compressor, the flow rate around the cycle may be substantially maintained while reducing the energy consumed by the system.

[0082] Referring next to FIG. **2** a heat pump apparatus according to another embodiment of the present invention is generally referenced **2200**.

[0083] The heat pump **2200** includes a first closed working fluid circuit **2101** which is substantially identical to the working fluid circuit **1100** described above, and a second working fluid circuit **2102** which includes, in order, a pump **210**, an evaporator/boiler **211**, a turbine **212**, a condenser **213** and a receiver **214**. A non return valve (not shown) is preferably provided immediately upstream of the evaporator/boiler.

[0084] Heat is exchanged from the first working fluid circuit **2101** to the second working fluid circuit **2102** via a heat exchanger **215** which is located upstream of the evaporator/boiler **211** in the second working fluid circuit **2101**. The heat exchanger is preferably positioned between the turbine **206** and Tx valve **204** of the first working fluid cycle **2101**.

[0085] The evaporator/boiler **211** receives preheated working fluid from the heat exchanger **215** and heats it further until it is a vapour at a suitable temperature and pressure for introduction into the turbine **212**. The heat input for the evaporator/boiler **211** may be obtained from any suitable source, for example waste steam, external combustion of fossil fuels and/or solar heating. In some embodiments it may be possible to substantially vapourise the working fluid using heat from ambient air.

[0086] In a preferred embodiment the evaporator/boiler is a heat exchanger.

[0087] Heat balance in the second refrigerant circuit **2102** is maintained by the condenser **213**. As with the condenser **102** and evaporator **105** of the first circuit **1101**, the heat rejected by the condenser **213** may be controlled by controlling the flow of cooling medium over the condenser **213**. This is preferably controlled by a control means **209**.

[0088] Use of a second circuit **2102** may further decrease the net energy required by the heat pump **2200** due to the additional power generated by the turbine **212**.

[0089] Referring next to FIG. **3**, in an alternative embodiment a heat pump apparatus **3300** may be based on a substantially standard refrigeration circuit **3103** including a compressor **301**, a condenser **302**, a receiver **303**, a throttling or Tx valve **304**, and an evaporator **305**. The refrigerant circuit **3103** may replace the refrigerant circuit **2102** of the heat pump **2200**. The heat exchanger **315** may be the only component in the working fluid circuit which is not found in a standard vapour compression refrigeration cycle.

[0090] This embodiment is preferably based on a pre-existing air-conditioning installation and may allow the use of the heat rejected from the circuit **3103** with the minimum of modification to the original refrigeration equipment. Control means (not shown) may be used to control the speed of the compressor **301** as described above with reference to control of compressors **101** and **201**.

[0091] Referring next to FIG. **4**, in one embodiment the second circuit **2102**, **3102** may be replaced by an alternative second working fluid circuit **4102***a*, which may differ from those shown in FIGS. **2** and **3** in that it includes multiple turbines **412** in parallel connection between the evaporator/boiler **411** and the condenser **413**. Higher efficiencies may be realised by using multiple turbines with reduced wire length in each generator, as the decreased load electrical load on each turbine may allow the rotors of each turbine to rotate at a higher, and therefore more efficient, speed, than would be achieved by a single turbine attached to a generator having the same total wire length.

[0092] Referring next to FIG. **5**, in some embodiments a still further alternative second circuit **5102***a* may be provided with more than one turbine **512** in series. The applicant envisages that in one embodiment six turbines **512** may be utilised in series, although more or fewer than this may be used as required, for example two as illustrated.

[0093] Turbines in parallel may be preferred where the mass flow rate of working fluid provided by the pump is greater than the preferred mass flow rate through a single turbine. Turbines in series may be preferred when the pump is capable of creating a greater pressure drop than can be most efficiently utilised by a single turbine.

[0094] In a still further embodiment (not shown) a combination of series and parallel turbines may be used as required.

[0095] Referring next to FIG. **6** a power generation apparatus is generally referenced **6100**. The apparatus **6100** includes a working fluid circuit which includes, in order of flow of the working fluid, an evaporator/boiler means **601**, a turbine means **602**, a condenser means **603** and a pumping means **604**. A receiver **605** is preferably also provided in order to ensure that the working fluid entering the pumping means **604** is in a substantially liquid phase. The turbine means **602** preferably includes a nozzle substantially as described below with reference to FIG. **10**.

[0096] The evaporator means **601** may absorb heat from any suitable source, or from more than one source. In one embodiment the evaporator means **601** may include a heat exchanger for absorbing low temperature heat, such as heat rejected from a refrigeration/airconditioning circuit such working fluid circuits **1101** or **3103**, or those described below, and a second heat exchanger for absorbing higher temperature heat, for example from waste steam. In some embodiments the low temperature heat may not evaporate the working fluid, but may merely preheat it, while in other embodiments the working fluid may be evaporated or vaporized by the low temperature heat and may be superheated by the higher temperature heat. Those skilled in the art will appreciate that the evaporation temperature of the working fluid will be a function of the working fluid selected and the pressure it is held at. Preferred embodiments use refrigerant as the working fluid, with R245 and R406 being preferred options.

[0097] Similarly the condenser **603** may also include one or more heat exchanger means as required.

[0098] A first portion of the working fluid exits the condenser **603** and flows through the receiver **605** if provided, the pumping means **604**, the evaporator means **601** and then to the turbine means **602**, as generally indicated by arrow **606**. However, a second portion of the working fluid exiting the condenser **603** travels through a bypass **607** and enters the turbine means **602** without passing through the evaporator **601**, as generally indicated by arrow **608**. The flow of working fluid which does not flow through the evaporator means **601** may be controlled by a suitable valve means **609**.

[0099] In some embodiments a small capacity pump (not shown) may be provided upstream of the receiver **605** in addition to the main pump downstream of the receiver.

[0100] At least some of the liquid second portion **608** is vaporised by heat from the vapour portion **606** before it impinges on a rotor (not shown) of the turbine **602**, for example by use of the nozzle described further below.

[0101] FIG. **7** shows one preferred embodiment of a refrigeration apparatus, generally referenced **7200** which includes a power generation apparatus **7100** substantially the same as the power generation apparatus **6100** described above.

[0102] The refrigeration apparatus **7200** includes a heat pump generally referenced **7201** with a second evaporator means **7201***a* to absorb heat from a medium to be cooled and a second condenser means **7201***b* which rejects heat. The heat pump **7201** is preferably a standard refrigeration or air conditioning apparatus and further includes a compressor means **7201***c* and a throttling valve **7201***d*.

[0103] The evaporator means **701** includes a first heat exchanger **701***a* for preheating the working fluid with heat rejected from a first standard refrigeration/air conditioning cycle **7201**, and a second heat exchanger **701***b* which heats the working fluid to a superheated vapour with waste heat from a suitable process, for example heat from a boiler or waste steam. A non-return valve (not shown) may be used immediately upstream of the second heat exchanger **701***b*. In one embodiment oil may be used as a medium to transfer heat from the process to the heat exchanger **701***b*. However, in a preferred embodiment the second heat exchanger **701***b* includes a conduit through which the medium carrying the waste heat flows. A plurality of tubes carry the working fluid extend into the conduit so as to be in contact with the heating medium. The working fluid tubes may be arranged in substantially straight parallel rows or may be helical in shape. In one embodiment the second heat exchanger **701***b* forms part of a flue from a boiler.

[0104] The heat exchangers **701***a* and **701***b* may be in a common housing, or may be separate.

[0105] The condenser means **703** preferably includes a heat exchanger **703***a* which rejects heat to a suitable heat absorption means, for example a heat pump **7202**, and at least partially condenses the working fluid. A further heat exchanger **703***b* may also be provided, if required, to further cool the working fluid. The further heat exchanger **703***b* may be air or water cooled as required.

[0106] The heat exchangers **703***a*, **703***b* may be in a common housing or may be separate. In a preferred embodiment at least one of the heat exchangers **703***a*, **703***b* may have one or more thermoelectric generators (not shown) embedded in the partition between the hot and cold fluids.

[0107] The thermoelectric generators generate electricity from a temperature differential, typically using the well known Seebeck effect. The working fluid exiting the turbine heats the hot junction of the thermoelectric generator and the cold junction is cooled using any suitable cooling means.

[0108] In some embodiments the heat rejected through the thermoelectric generators may be sufficient to maintain the heat balance in the system, and further heat exchangers may not be required.

[0109] A first portion of the working fluid exiting the condenser **703** flows through the receiver **705**, if provided, the pumping means **704**, the evaporator means **701** and then to the turbine means **702**. However, a second portion of the working fluid exiting the condenser **703** travels through a bypass **707** and enters the turbine means **702** without passing through the evaporator **701**. In one embodiment (not shown) a power generation apparatus may have the same components as the power generation apparatus **7100**, but may omit the bypass between the pump and the turbine.

[0110] A control means (not shown) may monitor the power generated by the turbine **702**, the power used by the pump **704** and/or other suitable variables such as the rate of heat being absorbed by the second evaporator **7201***a* of the heat pump **7201**, and may vary the setting of the valve means **709** and/or the amount of heat input into or rejected by the apparatus **7100**, for example by controlling the speed of cooling fans (not shown) operating on the second evaporator **7201***a* to optimise a selected variable, for example power consumption, or heat absorbed by the second evaporator **7201***a*.

[0111] FIG. **8** shows an alternative embodiment of the power generation apparatus **7100** of FIG. **7**, and is generally referenced **8101**. In this embodiment a portion of the fluid exiting the turbine **802**, but upstream of the pump **804**, flows through a further heat exchanger **801***c* downstream of the pump **804**, but upstream of the turbine **802**. In a preferred embodiment the further heat exchanger **801***c* is between the first heat exchanger **801***a* and second heat exchanger **801***b* which receives higher temperature heat, for example waste heat as described above with reference to FIG. **6**. The position of the further heat exchanger **801***c* may be selected so that the fluid downstream of the pump **804** is being heated, rather than cooled, by the fluid exiting the turbine **802**.

[0112] A valve means **810** may be used to vary the flow through of working fluid through the further heat exchanger **801***c*, although in other embodiments substantially all of the flow from the turbine **802** may flow to the further heat exchanger **801***c*. A control means may control the flow through the valve means **810**.

[0113] Referring next to FIG. **9**, another power generation apparatus **9102** is shown, which could be substituted for the power generation apparatus **7100** shown in FIG. **7**. Apparatus **9102** has substantially the same features as the power generation apparatus **8101** shown in FIG. **8**, but does not a have a bypass to allow working fluid to be directed to the turbine **902** without passing through the evaporator **901**.

[0114] FIG. **10** shows a turbine nozzle, generally referenced **10300**, which may be used with any of the apparatus **1100**, **2200**, **6100**, **7200**, or **8100** described above. The nozzle may be used with any suitable turbine and turbine rotor configuration.

[0115] The turbine nozzle **10300** defines a first fluid path **1011** having a first inlet **1012** and a first outlet **1013** and a second fluid path **1014** having a second inlet **1015** and a second outlet **1016**.

[0116] A first fluid **1017** passes through the first fluid path **1011** and is preferably substantially gaseous. A second fluid **1018** passes through the second fluid path **1014** and is preferably substantially liquid. The first and second fluid paths **1011**, **1014** are preferably substantially circular or annular in cross-section, and in a particularly preferred embodiment are substantially coaxial, with the first fluid path **1011** substantially surrounding the second fluid path **1014**.

[0117] The nozzle **10300** is adapted to mix the two streams of working fluid before they impinge on a rotor of a turbine. In the embodiment shown the mixing is achieved by turbulence in the two fluid streams.

[0118] By mixing the streams, the heat from the working fluid vapour stream **1017** heats vaporises at least part of the substantially liquid vapour stream **1018**. Some turbines may require that substantially all of the liquid working fluid is vaporised prior to impinging on the blades.

[0119] The volume flow rate of the second fluid **1018** is preferably much lower than that of the first fluid **1017**. In a preferred embodiment the cross-sectional area of the second fluid path **1014** is much smaller than that of the first fluid path **1011**.

[0120] The first fluid path **1011** of the nozzle **10300** illustrated in FIG. **10** has a converging/diverging cross-section suitable for accelerating the first fluid **1017** beyond the local speed of sound. However, this is not essential, and in embodiments where subsonic fluid flows are required the diverging section **1019** may be omitted. If a converging/diverging section is used then a further section **1020** having a substantially constant cross-section is preferably provided immediately downstream of the diverging section **1019**. The exit **1016** of the second fluid path is preferably provided within or at the entrance to the constant cross-section area section **1020**.

[0121] By mixing liquid working fluid with gaseous working fluid, the mass flow exiting the nozzle **10300** may be increased and the combined density of the first and second fluids may be greater than that of the first fluid alone.

[0122] It is envisaged that in some cases a turbine, in conjunction with the nozzle **10300**, may reduce the temperature and pressure of the gas sufficiently that they can be used to replace the throttling or Tx valve in heat pump apparatus such as a refrigeration or air conditioning cycle. In some embodiments the turbine may remove sufficient energy from the stream of gas and liquid that the fluid is mainly liquid at its outlet. In these embodiments the turbine may also perform the function of a condenser, although some further heat rejection may be required in order to maintain heat balance in the cycle.

[0123] In some embodiments sensors (not shown) may be positioned at suitable points in the nozzle to provide feedback on the conditions of the working fluid, in order to allow a control means to monitor whether the required flow rates and velocities are being achieved. In one embodiment sensors measuring temperature and pressure may be provided at the inlets **1012**, **1015** outlets **1013**, **1016**, and in the case of a converging/diverging nozzle, the throat **1023**. The control means may vary the conditions at one or both of the inlets **1012**, **1015** in order to keep the flow at the outlets **1013**, **1016** within a required range. In one embodiment the size of the nozzle throat may be varied. Alternatively the turbine may be provided with a plurality of nozzles (not shown), each having different geometry, and the control means may direct the working fluid to the nozzle which provides the best performance.

[0124] Referring next to FIG. **11**, a turbine is generally referenced **11200**.

[0125] The turbine includes a housing **1110** divided into a first chamber **1110***a* and a second chamber **1110***b*. A first rotor **1111** is rotatably connected to the first chamber **1110***a* and is rotatable independently of a second rotor **1112** which is rotatably connected to the second chamber **1110***b*. The rotors **1111**, **1112** are preferably substantially identical.

[0126] The housing **1110** is provided with at least one first inlet nozzle **1113** for supplying a working fluid (not shown) to the first rotor **1111**. The working fluid exits the housing **1110** via at least one outlet **1114** and moves through a conduit **1115** to a second nozzle **1116** which supplies fluid to the second rotor **1112**.

[0127] The turbine rotors **1111**, **1112** may be of any suitable design, and are preferably radial flow turbine rotors. The working fluid from the nozzles **1113**, **1116** preferably approaches the respective rotor **1111**, **1112** substantially radially and exits the rotor **1111**, **1112** substantially axially.

[0128] Each turbine rotor **1111**, **1112** is connected to a separate electrical energy generator means such as a generator **1117**, **1118**, an alternator or the like. Because the rotors **1111**, **1112** are independently rotatable they are able to operate at different rotational speeds. This may provide a more efficient use of the pressure available than if the two rotors were constrained to rotate at the same speed.

[0129] In some embodiments nozzle **10300** may be used as the first nozzle **1113**.

[0130] In a preferred embodiment the turbine **11200** is provided with a lubrication circuit and cooling circuit. Cool liquid refrigerant, which contains lubricating oil in accordance with normal air conditioning/refrigeration practice, is supplied to a lubrication system inlet **1119**. Capillary tubes **1120** run from the inlet **1119** to positions immediately adjacent the generator windings **1121**, outer bearings **1122** and the first rotor inner bearing. When the liquid refrigerant reaches the end of the capillary tubes **1120** it flashes to vapour, carrying oil with it. This spray cools and lubricates the bearings and windings, and in particular the magnets. Some of the oil on the outer bearings **1122** is thrown off by centrifugal force and assists in cooling the generators **1117**, **1118**.

[0131] Oil and refrigerant from the inner bearing **1123** bleeds through a small orifice in a plate **1124** which separates the first rotor **1111** from the second rotor **1112** and assists in lubricating the cooling the second rotor inner bearing **1125**.

[0132] Any refrigerant which does not flash is collected in a sump **1126** and is drained to the accumulator.

[0133] In a preferred embodiment, each generator **1117**, **1118** includes two sets of ten stationary windings positioned side by side so as to be energised by rare earth magnets which are mounted on the shaft of each turbine rotor so as to rotate with the turbine. The alternating current outputs from each of the 20 coils of each generator are grouped into five sets of four coils (which are hereinafter referred to as quads). Each quad is connected in a phase synchronised pattern as shown in FIG. **12**. Each coil is paired with a diametrically opposite coil on the other set of windings. Referring to FIG. **12**, four selected coils **1201**, **1202**, **1203** and **1204** are connected in a phase synchronised manner so as to generate an alternating current across outputs **1205**. It will be seen that other quad combinations, or even individual coils, may be selected so as to provide an alternating current output.

[0134] Turning now to FIG. **13** each quad (substantially according to FIG. **12**) is shown as a single winding marked **1301** to **1305** respectively. As mentioned above, individual windings or other combinations of windings may be used rather than the quad arrangement illustrated in FIG. **13**. The alternating current output of each quad is provided to a step up transformer **1306** to **1310** respectively. In a preferred embodiment, each step up transformer has a turns ratio of approximately 1:5. This increases the voltage of the AC output, having the advantage of providing a more manageable voltage as will be described further below for inversion to produce an alternating current output which is viable for provision to the mains power supply. The transformers also have the advantage of providing a means of power matching the generator output to its load, and providing isolation between quads.

[0135] The output of each transformer is rectified, preferably using a bridge rectifier **1301** to **1305** respectively and filtered using one or more capacitors **1316** to **1320**. In a preferred embodiment a circuit breaker **1321** to **1325** is also provided in case an overload condition occurs.

[0136] The rectified outputs i.e. the outputs from each quad, are cumulatively connected together so that the output voltage adds cumulatively i.e. they are connected in series rather than parallel, so that the voltage of each output is cumulatively combined to produce a cumulative DC output voltage which is then inverted by an inverter unit **1326** to provide alternating current electric power, being three phase alternating current in the preferred embodiment. This alternating output may then be provided to a mains supply, or be used for other purposes. In a preferred embodiment, the inversion unit comprises of variable speed drive with a regenerative front end, manufactured by Control Techniques Ltd of the United Kingdom. Those skilled in the art to which the invention relates will appreciate that other suitable apparatus may be used.

[0137] The AC to DC interface used with the invention has a number of advantages. The use of direct current simplifies the phasing problem between generator coils and produces an output which is independent of any speed variations or differences between the turbines or turbine stages. The direct current output produces a higher voltage output per ampere-turn on the generator windings and therefore lowers the number ampere-turns required to provide a given voltage output. The DC output is also easily summed to produce a higher voltage output. It will be seen that each generator can be used to provide a separate DC output, and the output of each generator can be cumulatively combined to provide an overall DC output which can then be inverted to produce a required alternating current output. Furthermore, the direct current output means that known inverter apparatus can be used to provide a range of different alternating current outputs at varying voltages as required.

[0138] Where in the foregoing description, reference has been made to specific components or integers of the invention having known equivalents, then such equivalents are herein incorporated as if individually set forth.

[0139] Although this invention has been described by way of example and with reference to possible embodiments thereof, it is to be understood that modifications or improvements may be made thereto without departing from the spirit or scope of the appended claims.

1.-**32**. (canceled)

33. (canceled)

34.-**40**. (canceled)

41. A heat pump including a first working fluid circuit including, a compressor, a first condenser downstream of the compressor, a first receiver downstream of the first condenser, a throttling valve downstream of the first condenser, and an evaporator downstream of the throttling valve, the heat pump further including heat exchanger means for rejecting heat to a second working fluid cycle, the second working fluid cycle including a boiler, a turbine downstream of the boiler, a second condenser downstream of the turbine, a second receiver downstream of the second condenser and a pump downstream of the second condenser, wherein the heat rejected from the first working fluid cycle preheats the working fluid vapour entering the boiler of the second working fluid cycle.

42. The heat pump of claim **41**, wherein the heat exchanger is provided between the first compressor and the first condenser.

43. The heat pump of claim **41**, wherein the heat exchanger is provided between the pump and the boiler.

44. The heat pump of claim **41**, wherein the turbine is provided with a rotor and a nozzle, the nozzle including a first fluid path which includes a first inlet adapted to receive a first working fluid vapour stream, and a first outlet adapted to communicate a jet of said working fluid to the rotor, the nozzle further including a second fluid path which includes a second inlet adapted to receive a second substantially liquid working fluid stream and a second outlet adapted to communicate a jet of said second working fluid to the rotor, wherein the nozzle is adapted to mix the jets of working fluid so that at least part of the liquid working fluid is vaporized by heat from the working fluid vapour.

45. The heat pump of claim **44**, wherein substantially all of the substantially liquid working fluid vapour is vaporized by heat from the substantially vapour working fluid jet before impinging on the rotor.

46. The heat pump of claim **44**, wherein the first and second fluid paths are substantially circular or annular in cross-section.

47. The heat pump of claim **46**, wherein the second outlet is concentric with the first fluid path.

48. The heat pump of claim **44**, wherein the first fluid path has a converging/diverging section adapted to accelerate the stream of working fluid vapour to a mean velocity above the local speed of sound.

49. The heat pump of claim **48**, wherein a section of the first fluid path immediately downstream of the converging diverging section has a substantially constant cross-section.

50. The heat pump of claim **49**, wherein the second outlet is in the substantially constant cross-section section of the first fluid path.

51. The heat pump of claim **41**, wherein the turbine is provided with a generator having a plurality of windings arranged to produce a first alternating current and a second alternating current, a first transformer to increase the voltage of the first alternating current and in the second transformer to increase the voltage of the second alternating current, a first and second rectifying means to rectify the output of each transformer, and the rectified outputs being cumulatively added together to produce a cumulative direct current output, and an inverter means to invert the cumulative direct current output to alternating current electric power.

52. A method of generating power using a pre-existing refrigeration circuit, the method including inserting a heat exchanger upstream of a condenser in the pre-existing refrigeration circuit whereby heat is transferred from the pre-existing refrigeration circuit to working fluid in a heat pump circuit, the heat pump circuit including an evaporator or boiler downstream of the heat exchanger, a turbine generator downstream of the evaporator or boiler, a condenser downstream of the turbine generator and means to circulate the working fluid about said heat pump circuit.

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