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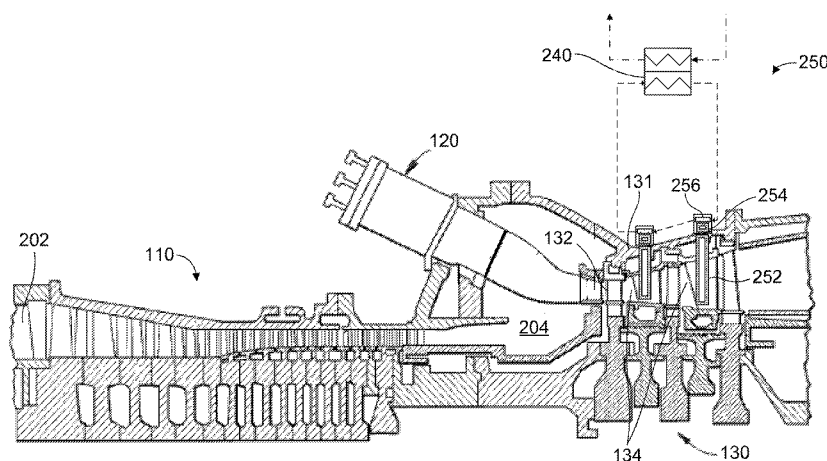


FIG. 2

(57) Abstract: A turbomachine includes a compressor configured to compress air received at an intake portion to form a compressed airflow that exits into an outlet portion. A combustor is operably connected with the compressor, and the combustor receives the compressed airflow. A turbine is operably connected with the combustor. The turbine receives combustion gas flow from the combustor. The turbine has a plurality of rotor blades and a plurality of nozzles, and a turbine casing forms an outer shell of the turbine. A cooling system is operably connected to the turbine. The cooling system includes a plurality of heat pipes located in at least a portion of the plurality of nozzles. The heat pipes are operatively connected to the manifolds. The heat pipes and the manifolds are configured to transfer heat from the nozzles to one or more heat exchangers.



## HEAT PIPE NOZZLE TEMPERATURE MANAGEMENT SYSTEM FOR A TURBOMACHINE

### BACKGROUND OF THE INVENTION

[0001] Exemplary embodiments of the present invention relate to the art of turbomachines and, more particularly, to a heat pipe cooling system and nozzle temperature management system for a turbomachine.

[0002] Turbomachines include a compressor operatively connected to a turbine that, in turn, drives another machine such as, a generator. The compressor compresses an incoming airflow that is delivered to a combustor to mix with fuel and be ignited to form high temperature, high pressure combustion products. The high temperature, high pressure combustion products are employed to drive the turbine. Due to the high temperature of the combustion products, gas turbine nozzles require cooling. Known materials have their limits and cooling has allowed nozzles to operate at these high temperatures. This cooling is most commonly accomplished with air extracted from the compressor and less commonly with steam. However, negative attributes of compressor air cooling are a reduction in cycle output capacity and efficiency while the negative attributes of steam cooling includes the additional component cost due to complexity. As such, there is a need for alternative turbine nozzle cooling methods.

### BRIEF DESCRIPTION OF THE INVENTION

[0003] In an aspect of the present invention, a turbomachine includes a compressor configured to compress air received at an intake portion to form a compressed airflow that exits into an outlet portion. A combustor is operably connected with the compressor, and the combustor receives the compressed airflow. A turbine is operably connected with the

combustor. The turbine receives combustion gas flow from the combustor. The turbine has a plurality of rotor blades and a plurality of nozzles, and a turbine casing forms an outer shell of the turbine. A cooling system is operatively connected to the turbine. The cooling system includes a plurality of heat pipes located in at least a portion of the plurality of nozzles. The plurality of heat pipes are operatively connected to one or more manifolds. The plurality of heat pipes and the one or more manifolds are configured to transfer heat from the plurality of nozzles to one or more heat exchangers.

[0004] In another aspect of the present invention, a cooling system for a turbomachine is provided. The turbomachine has a compressor configured to compress air received at an intake portion to form a compressed airflow that exits into an outlet portion. A combustor is operably connected with the compressor, and the combustor receives the compressed airflow. A turbine is operably connected with the combustor, and the turbine receives combustion gas flow from the combustor. The turbine has a plurality of rotor blades and a plurality of nozzles. A turbine casing forms an outer shell of the turbine. The cooling system is operatively connected to the turbine. The cooling system has a plurality of heat pipes located in at least a portion of the plurality of nozzles. The plurality of heat pipes are operatively connected to one or more manifolds. The plurality of heat pipes and the one or more manifolds are configured to transfer heat from the plurality of nozzles to one or more heat exchangers.

[0005] In yet another aspect of the present invention, a method of transferring heat from a turbomachine is provided. The method includes a passing step that passes combustion gases through a turbine. The turbine has a plurality of nozzles, and a turbine casing that forms an outer shell of the turbine. An extracting step extracts heat from the plurality of nozzles by thermally conducting the heat to a plurality of heat pipes. The plurality of heat pipes are in thermal communication with one or more heat exchangers. A conducting

step conducts heat from the plurality of heat pipes to a heat pipe heat exchanger. The heat pipe heat exchanger is configured to transfer heat to a fuel heating heat exchanger. A heating step heats fuel with the fuel heating heat exchanger.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1 is a simplified schematic diagram of a turbomachine.

[0007] FIG. 2 is a partially schematic, axial sectional view through a portion of the turbomachine, according to an aspect of the present invention.

[0008] FIG. 3 illustrates a cross-sectional view of the cooling system, according to an aspect of the present invention.

[0009] FIG. 4 illustrates a cross-sectional view of the cooling system, according to an aspect of the present invention.

[0010] FIG. 5 illustrates a cross sectional shape of a circular or cylindrical heat pipe, according to an aspect of the present invention.

[0011] FIG. 6 illustrates a cross sectional shape of an oval heat pipe, according to an aspect of the present invention.

[0012] FIG. 7 illustrates a cross sectional shape of a polygonal heat pipe, according to an aspect of the present invention.

[0013] FIG. 8 illustrates a cross sectional shape of a rectangular with rounded corners heat pipe, according to an aspect of the present invention.

[0014] FIG. 9 illustrates a cross sectional shape of a circular or cylindrical heat pipe with a plurality of fins, according to an aspect of the present invention.

[0015] FIG. 10 illustrates a partially schematic and radial cross-sectional view of the cooling system, according to an aspect of the present invention.

[0016] FIG. 11 illustrates a schematic view of a turbomachine incorporating the cooling and fuel heating system, according to an aspect of the present invention.

[0017] FIG. 12 illustrates a method for extracting heat from a turbine nozzle, according to an aspect of the present invention.

## DETAILED DESCRIPTION OF THE INVENTION

[0018] One or more specific aspects/embodiments of the present invention will be described below. In an effort to provide a concise description of these aspects/embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with machine-related, system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

[0019] When introducing elements of various embodiments of the present invention, the articles "a," "an," and "the" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. Any examples of operating parameters and/or environmental conditions are not exclusive of other parameters/conditions of the disclosed embodiments. Additionally, it should be understood that references to "one embodiment", "one aspect" or "an embodiment" or "an aspect" of the present invention are not intended to be interpreted as excluding the existence of additional embodiments or aspects that also incorporate the recited features.

[0020] FIG. 1 illustrates a simplified diagram of a turbomachine 100. The turbomachine includes a compressor 110 operably connected to a combustor 120, and the combustor 120 is operably connected to a turbine 130. The turbine's exhaust may be operably connected to a heat recovery steam generator (HRSG) 140. The HRSG 140 generates steam that is directed into a steam turbine 150. In this example, all the individual turbomachines are arranged in a single shaft configuration, and the shaft 160 drives a generator 170. It is to be understood that the term turbomachine includes compressors, turbines or combinations thereof.

[0021] FIG. 2 is a partially schematic, axial sectional view through a portion of the turbomachine, according to an aspect of the present invention. The turbomachine 100 includes a compressor 110 having an intake portion 202 and an outlet portion 204. The compressor compresses air received at the intake portion 202 and forms a compressed airflow that exits from/into the outlet portion 204. The combustor 120 is operably connected with the compressor 110, and the combustor 120 receives the compressed airflow. The turbine 130 is operably connected with the combustor 120, and the turbine 130 receives combustion gas flow from the combustor 120. The turbine 130 includes a turbine casing 131. The turbine casing 131 forms an outer shell of the turbine 130. The turbine also includes a plurality of rotor blades 132 and a plurality of nozzles 134.

[0022] A cooling system 250 is operatively connected to the turbine 130. For example, the cooling system includes a plurality of heat pipes 252 that are located in at least a portion of the nozzles 134. The heat pipes 252 are in thermal communication with the nozzles and the heat pipes may also be in thermal communication with turbine casing 131. Heat absorbed from the nozzles 134 and subsequently into the heat pipes 252 is transferred to a second group of heat pipes 254, which may be contained within the turbine casing or attached to the turbine casing. The heat from the heat pipes is conducted to manifold 256.

This heat may then be transferred to a heat pipe heat exchanger 240. The heat pipes 252, 254 may be circumferentially located around the turbine and/or located in one or more turbine nozzles.

[0023] As the turbine 130 operates, combustion gases generate heat, and some of this heat is transferred to the nozzles 134. This heat may be harvested by the heat pipes 252, 254. The heat pipes 252, 254 transfer this heat to the manifold 256 and subsequently to one or more heat exchangers. As non-limiting examples, the heat pipes may be located inside the nozzles 134, or located in the nozzles and within the turbine casing 131. In the latter case, the heat pipes are configured to maintain thermal communication with the turbine casing 131. In other embodiments, the heat pipes 252, 254 may be partially embedded in the turbine casing, or the heat pipes may extend external to the turbine casing. The heat pipes 250 may be located in nozzles between (and including) the first through last stages of the turbine, or in any individual nozzle stage as desired in the specific application.

[0024] FIG. 3 illustrates a cross-sectional and schematic view of the cooling system 250, according to an aspect of the present invention. The heat pipe 252 is located in the nozzle 134 and is in thermal communication with heat pipe 254. A plurality of heat pipes 252 (e.g., a first group of heat pipes) are located in a plurality of nozzles, for example there may be one heat pipe in one nozzle. The heat pipes 254 (e.g., a second group of heat pipes) may be contained within the turbine casing or attached to the turbine casing. The manifold 256 is thermally connected to multiple heat pipes 254, and the heat pipes 254 may be arranged circumferentially about the turbine casing/shell 131. The manifold 256 includes a coolant/heat transfer medium, such as water, steam, glycol or oil. The manifold 256 is thermally connected to a heat pipe heat exchanger 240. A conduit 310 connects the heat pipe heat exchanger 240 to a plurality of other heat exchangers. For example, the other heat exchangers may be a fuel heating heat exchanger 241, a fuel pre-heating heat exchanger 242,

a HRSG heat exchanger 243 and any other desired heat exchanger 244. The heat pipe heat exchanger 240 transfers the heat from the manifold(s) 256 to the heat transfer medium in conduit 310. As examples only, the conduit's heat transfer medium may be water, glycol, oil, steam or any other suitable fluid or gas. A pump 320 may be used to force the fluid through the conduit 310 and the heat exchangers. The heat exchangers may also include valve controlled bypass lines 360 (only one is shown for clarity). A valve 361 can be operated so that it directs flow around the heat exchanger (e.g., 242) via bypass line/conduit 360. This feature may be desirable if specific heat exchangers are to be "removed" (possibly temporarily) from the flow along conduit 310. The valves 361 can be manually controlled or remotely controlled.

[0025] The heat pipes 252, 254 include a heat transfer medium 253 which may be a liquid metal, molten salt or Qu material. As examples only, the heat transfer medium may be one or combinations of, aluminum, beryllium, beryllium-fluorine alloy, boron, calcium, cesium, cobalt, lead-bismuth alloy, liquid metal, lithium-chlorine alloy, lithium-fluorine alloy, manganese, manganese-chlorine alloy, mercury, molten salt, potassium, potassium-chlorine alloy, potassium-fluorine alloy, potassium-nitrogen-oxygen alloy, rhodium, rubidium-chlorine alloy, rubidium-fluorine alloy, sodium, sodium-chlorine alloy, sodium-fluorine alloy, sodium-boron-fluorine alloy, sodium nitrogen-oxygen alloy, strontium, tin, zirconium-fluorine alloy. As one specific example, the heat transfer medium 253 may be a molten salt comprising potassium, sodium or cesium. The outer portion of the heat pipes 252, 254 may be made of any suitable material capable of serving the multiple purposes of high thermal conductivity, high strength and high resistance to corrosion from the heat transfer medium.

[0026] The heat pipes 252, 254 may also be formed of a "Qu-material" having a very high thermal conductivity. The Qu-material may be in the form of a multi-layer coating

provided on the interior surfaces of the heat pipes. For example, a solid state heat transfer medium may be applied to the inner walls in three basic layers. The first two layers are prepared from solutions which are exposed to the inner wall of the heat pipe. Initially the first layer which primarily comprises, in ionic form, various combinations of sodium, beryllium, a metal such as manganese or aluminum, calcium, boron, and a dichromate radical, is absorbed into the inner wall to a depth of 0.008 mm to 0.012 mm. Subsequently, the second layer which primarily comprises, in ionic form, various combinations of cobalt, manganese, beryllium, strontium, rhodium, copper, B-titanium, potassium, boron, calcium, a metal such as aluminum and the dichromate radical, builds on top of the first layer and forms a film having a thickness of 0.008 mm to 0.012 mm over the inner wall of the heat pipe. Finally, the third layer is a powder comprising various combinations of rhodium oxide, potassium dichromate, radium oxide, sodium dichromate, silver dichromate, monocrystalline silicon, beryllium oxide, strontium chromate, boron oxide, B-titanium and a metal dichromate, such as manganese dichromate or aluminum dichromate, which evenly distributes itself across the inner wall. The three layers are applied to the heat pipe and are then heat polarized to form a superconducting heat pipe that transfers thermal energy with little or no net heat loss.

[0027] FIG. 4 illustrates a cross-sectional and schematic view of the cooling system 450, according to another aspect of the present invention. The heat pipe 452 is located in the nozzle 134 and extends through the turbine casing 131. The heat pipe 452 is in thermal communication with manifold 456. The manifold 456 is thermally connected to multiple heat pipes 452, and the manifold 456 may be arranged circumferentially about the turbine casing/shell 131. Heat from the nozzle 134 is transferred from the heat pipe 452 to the manifold 456.

[0028] FIG. 5 illustrates a cross sectional shape of a circular or cylindrical heat pipe 252, according to an aspect of the present invention. A cylindrical heat pipe is easy to

manufacture and install with conventional tools. FIG. 6 illustrates a cross sectional shape of an oval heat pipe 652, according to an aspect of the present invention. The oval heat pipe 652 may have improved heat transfer characteristics compared to the cylindrical heat pipe. FIG. 7 illustrates a cross sectional shape of a polygonal heat pipe 752, according to an aspect of the present invention. The polygonal shape may include rectangular, hexagonal, square or any other suitable polygonal shape. FIG. 8 illustrates a cross sectional shape of a rectangular with rounded corners heat pipe 852. The rectangular with rounded corners shape may have improved heat transfer characteristics over the oval heat pipe 652, due to increased surface area. FIG. 9 illustrates a cross sectional shape of a circular or cylindrical heat pipe 952 with a plurality of fins 953, according to an aspect of the present invention. The fins 953 are configured to increase the heat transfer capability of the heat pipe, may be arranged axially as shown or radially, and may be comprised of a material having high thermal conductivity, such as copper or aluminum.

[0029] FIG. 10 illustrates a partially schematic and radial cross-sectional view of the cooling system 250, according to an aspect of the present invention. The heat pipes 252 are located in at least a portion of nozzles 134. The heat pipes 254 are circumferentially located and distributed around the turbine casing 131. The manifold 256 is connected in a circuit represented by line 1010. For example, the manifold 256 would form a generally continuous flow loop around the turbine 130. A portion of this flow loop is interrupted and routed to the heat pipe heat exchanger 240, and the outlet therefrom is routed back the manifold 256. In this way, heat generated by the nozzles 134 and heat pipes 252, 254 can be transferred or conducted to the heat exchanger 240.

[0030] FIG. 11 illustrates a schematic view of a turbomachine 1100 incorporating the cooling system, according to an aspect of the present invention. The turbomachine 1100 includes a compressor 1110, combustor 1120 and turbine 1130. The cooling system includes

a plurality of heat pipes (not shown for clarity) connected to a manifold 1156. The manifold 1156 is connected to a heat pipe heat exchanger 1140. A pump 1155 circulates a coolant through a conduit system and a plurality of heat exchangers. The heat pipe heat exchanger 1140 is connected to a fuel gas pre-heater heat exchanger 1142. Fuel gas 1160 is input and travels to the combustor 1120. The fuel gas pre-heater heat exchanger is connected to a heat recovery steam generator (HRSG) heat exchanger 1144. Water 1170 is input to the heat exchanger 1144 and heated to an elevated temperature or steam, and is output to the HRSG economizer (not shown). Each heat exchanger may include a bypass line 1180 and valve 1181 to selectively bypass the respective heat exchanger. Only one such bypass line is identified in FIG. 11 for clarity. A primary fuel heater heat exchanger 1146 may be fed by steam 1190 from the HRSG (not shown), and the resultant heated fuel is delivered to combustor 1120.

[0031] The valves 1181 and bypass lines 1180 (if connected on all heat exchangers) allow for improved control over fuel heating and machine efficiency. For example, heat exchangers 1140 and 1144 may be connected in a loop to only heat the water input to the HRSG. Heat exchangers 1140 and 1142 may be connected in a loop to pre-heat the fuel supply. This configuration may greatly reduce or eliminate the steam withdrawn from the HRSG, and will permit more steam to be directed into a steam turbine (not shown). As another example, heat exchangers 1140, 1142 and 1144 could be connected in a loop. This configuration will pre-heat fuel 1160 and heat water 1170 going into the HRSG. Heat exchangers 1140, 1142 and 1146 may be connected in a loop and this will maximize the fuel heating potential. Alternatively, all heat exchangers may be connected in a loop so that all heat exchangers will benefit from the heat removed from the compressor discharge airflow.

[0032] FIG. 12 illustrates a method 1200 for transferring heat from a turbomachine. The method includes a step 1210 of passing combustion gases through a turbine 130. An

extracting step 1220 extracts heat from a plurality of nozzles 134 by conducting heat to a plurality of heat pipes 252, 254. The heat pipes 252, 254 may include a molten salt heat transfer medium, such as, potassium, sodium, cesium, liquid metal or combinations thereof. The heat pipes 252, 254 are in thermal communication with one or more heat exchangers 240. A conducting step 1230 conducts heat from the heat pipes 252, 254 to the heat exchanger 240. A heating step 1240 heats fuel in a fuel heating heat exchanger.

[0033] The cooling system 250 of the present invention provides a number of advantages. Turbomachine efficiency may be improved which results in improved combined cycle heat rate. The turbine section buckets, wheels and combustion gas transition pieces may have improved lifespans due to the cooler combustion flow. There is also a reduced demand for steam heating the fuel heating heat exchanger, and this steam can be directed to a steam turbine for improved efficiency.

[0034] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

## CLAIMS

1. A turbomachine comprising:

a compressor configured to compress air received at an intake portion to form a compressed airflow that exits into an outlet portion;

a combustor operably connected with the compressor, the combustor receiving the compressed airflow;

a turbine operably connected with the combustor, the turbine receiving combustion gas flow from the combustor, the turbine having a plurality of rotor blades and a plurality of nozzles, and a turbine casing forming an outer shell of the turbine; and

a cooling system operatively connected to the turbine, the cooling system including a plurality of heat pipes located in at least a portion of the plurality of nozzles, the plurality of heat pipes operatively connected to one or more manifolds, the plurality of heat pipes and the one or more manifolds are configured to transfer heat from the plurality of nozzles to one or more heat exchangers.

2. The turbomachine of claim 1, the plurality of heat pipes further comprising a heat transfer medium including one or combinations of:

aluminum, beryllium, beryllium-fluorine alloy, boron, calcium, cesium, cobalt, lead-bismuth alloy, liquid metal, lithium-chlorine alloy, lithium-fluorine alloy, manganese, manganese-chlorine alloy, mercury, molten salt, potassium, potassium-chlorine alloy, potassium-fluorine alloy, potassium-nitrogen-oxygen alloy, rhodium, rubidium-chlorine alloy, rubidium-fluorine alloy, sodium, sodium-chlorine alloy, sodium-fluorine alloy, sodium-boron-fluorine alloy, sodium nitrogen-oxygen alloy, strontium, tin, zirconium-fluorine alloy.

3. The turbomachine of claim 1, the plurality of heat pipes further comprising a molten salt heat transfer medium including one or combinations of, potassium, sodium or cesium.
4. The turbomachine of claim 1, the plurality of heat pipes located in nozzles between a first through a last stage of the turbine.
5. The turbomachine of claim 1, wherein the plurality of heat pipes have a cross-sectional shape, the cross sectional shape generally comprising at least one of:
  - circular, oval, rectangular with rounded corners, or polygonal.
6. The turbomachine of claim 5, the plurality of heat pipes further comprising a plurality of fins, the plurality of fins configured to increase the heat transfer capability of the plurality of heat pipes.
7. The turbomachine of claim 1, the plurality of heat pipes comprising:
  - a first group of heat pipes contained within the plurality of nozzles;
  - a second group of heat pipes contained within the turbine casing or attached to the turbine casing; and
  - wherein the first group of heat pipes is configured to transfer heat to the second group of heat pipes, and the second group of heat pipes is configured to transfer heat to a heat pipe heat exchanger.
8. The turbomachine of claim 1, the one or more heat exchangers including a heat pipe heat exchanger operably connected to the plurality of heat pipes and the one or more manifolds, and the heat pipe heat exchanger also operably connected to:
  - a fuel heating heat exchanger; or
  - a heat recovery steam generator heat exchanger; or
  - a fuel heating heat exchanger and a heat recovery steam generator heat exchanger.

9. A cooling system for a turbomachine, the turbomachine having a compressor configured to compress air received at an intake portion to form a compressed airflow that exits into an outlet portion, a combustor operably connected with the compressor, the combustor receiving the compressed airflow, and a turbine operably connected with the combustor, the turbine receiving combustion gas flow from the combustor, the turbine having a plurality of rotor blades and a plurality of nozzles, and a turbine casing forming an outer shell of the turbine, the cooling system operatively connected to the turbine, the cooling system comprising:

a plurality of heat pipes located in at least a portion of the plurality of nozzles, the plurality of heat pipes operatively connected to one or more manifolds, the plurality of heat pipes and the one or more manifolds are configured to transfer heat from the plurality of nozzles to one or more heat exchangers.

10. The cooling system of claim 9, the plurality of heat pipes further comprising a heat transfer medium including one or combinations of:

aluminum, beryllium, beryllium-fluorine alloy, boron, calcium, cesium, cobalt, lead-bismuth alloy, liquid metal, lithium-chlorine alloy, lithium-fluorine alloy, manganese, manganese-chlorine alloy, mercury, molten salt, potassium, potassium-chlorine alloy, potassium-fluorine alloy, potassium-nitrogen-oxygen alloy, rhodium, rubidium-chlorine alloy, rubidium-fluorine alloy, sodium, sodium-chlorine alloy, sodium-fluorine alloy, sodium-boron-fluorine alloy, sodium nitrogen-oxygen alloy, strontium, tin, zirconium-fluorine alloy.

11. The cooling system of claim 9, the plurality of heat pipes further comprising a molten salt heat transfer medium including one or combinations of, potassium, sodium or cesium.

12. The cooling system of claim 11, the plurality of heat pipes located in nozzles between a first through a last stage of the turbine.
13. The cooling system of claim 12, wherein the plurality of heat pipes have a cross-sectional shape, the cross sectional shape generally comprising at least one of:  
circular, oval, rectangular with rounded corners, or polygonal.
14. The cooling system of claim 13, the plurality of heat pipes further comprising a plurality of fins, the plurality of fins configured to increase the heat transfer capability of the plurality of heat pipes.
15. The cooling system of claim 13, the plurality of heat pipes comprising:  
a first group of heat pipes contained within the plurality of nozzles;  
a second group of heat pipes contained within the turbine casing or attached to the turbine casing; and  
wherein the first group of heat pipes is configured to transfer heat to the second group of heat pipes, and the second group of heat pipes is configured to transfer heat to a heat pipe heat exchanger.
16. The cooling system of claim 15, the one or more heat exchangers including a heat pipe heat exchanger operably connected to the plurality of heat pipes and the one or more manifolds, and the heat pipe heat exchanger also operably connected to:  
a fuel heating heat exchanger; or  
a heat recovery steam generator heat exchanger; or  
a fuel heating heat exchanger and a heat recovery steam generator heat exchanger.
17. A method of transferring heat from a turbomachine, the method comprising:  
passing combustion gases through a turbine, the turbine having a plurality of nozzles and a turbine casing that forms an outer shell of the turbine;

extracting heat from the plurality of nozzles by thermally conducting the heat to a plurality of heat pipes, the plurality of heat pipes in thermal communication with one or more heat exchangers;

conducting heat from the plurality of heat pipes to a heat pipe heat exchanger, the heat pipe heat exchanger configured to transfer heat to a fuel heating heat exchanger; and

heating fuel with the fuel heating heat exchanger.

18. The method of claim 17, the plurality of heat pipes further comprising a molten salt heat transfer medium including one or combinations of, potassium, sodium or cesium.

19. The method of claim 18, the plurality of heat pipes comprising:

a first group of heat pipes contained within the plurality of nozzles;

a second group of heat pipes contained within the turbine casing or attached to the turbine casing; and

wherein the first group of heat pipes is configured to transfer heat to the second group of heat pipes, and the second group of heat pipes is configured to transfer heat to the heat pipe heat exchanger.

20. The method of claim 18, the heat pipe heat exchanger operably connected to a heat recovery steam generator heat exchanger.

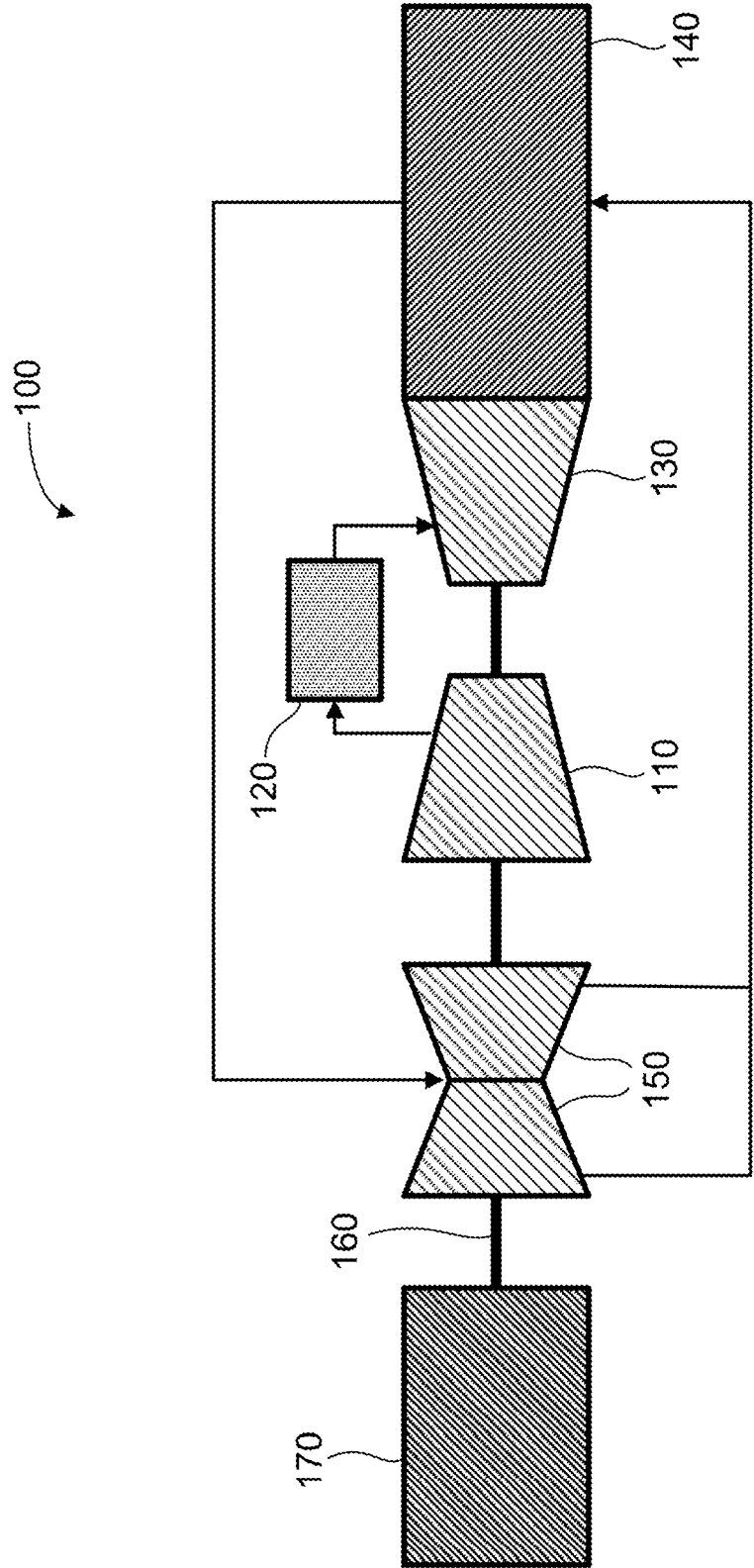


FIG. 1

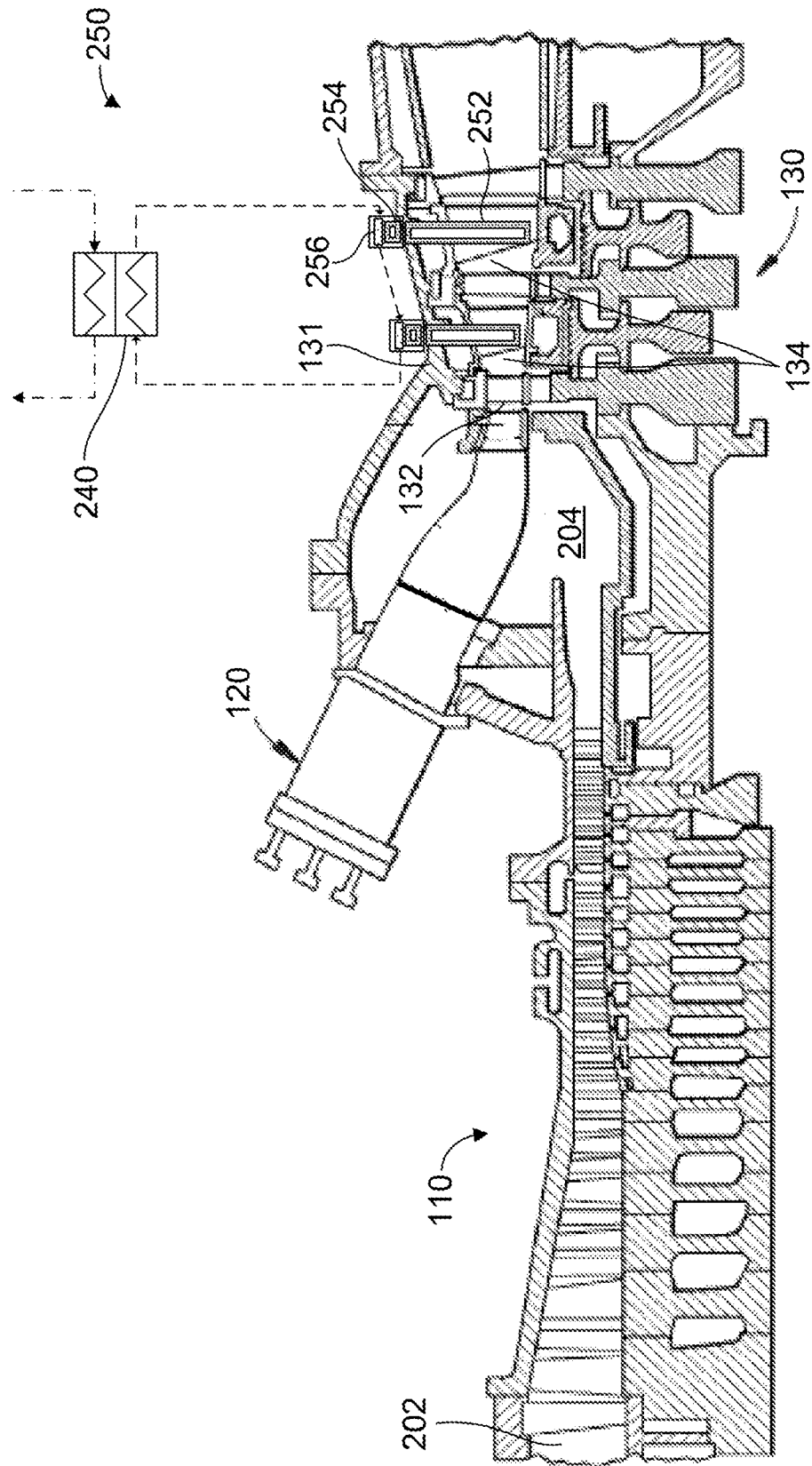


FIG. 2

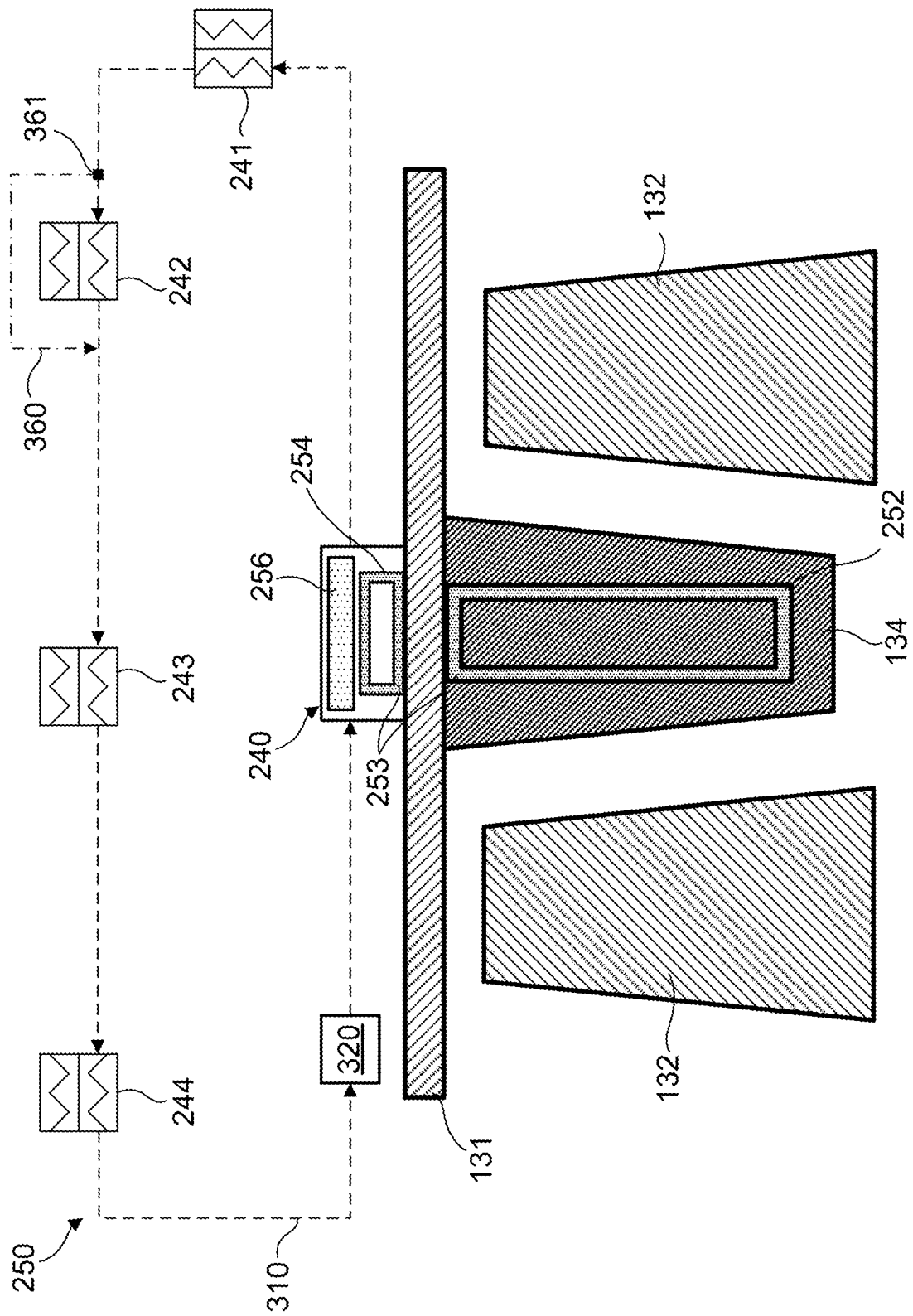


FIG. 3

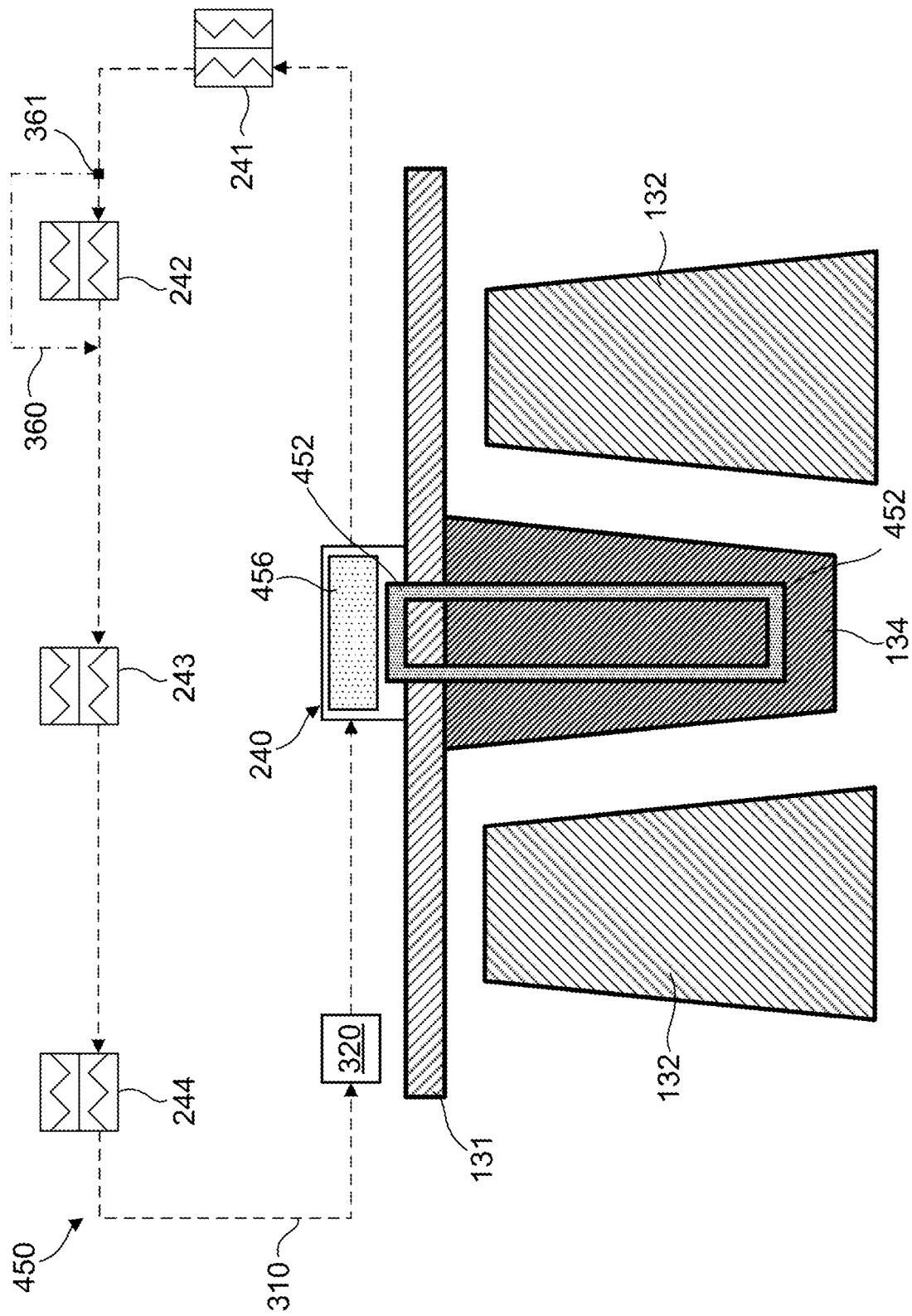


FIG. 4

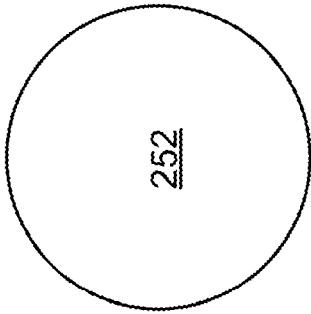


FIG. 5



FIG. 6

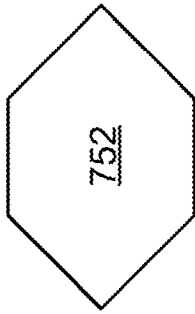


FIG. 7



FIG. 8

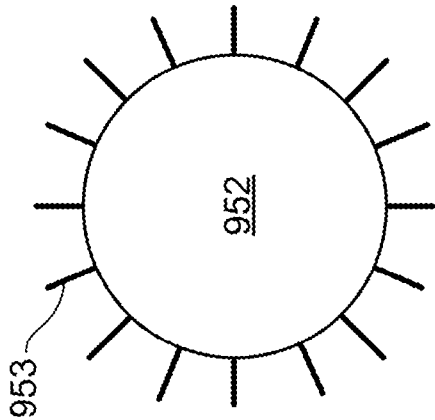


FIG. 9

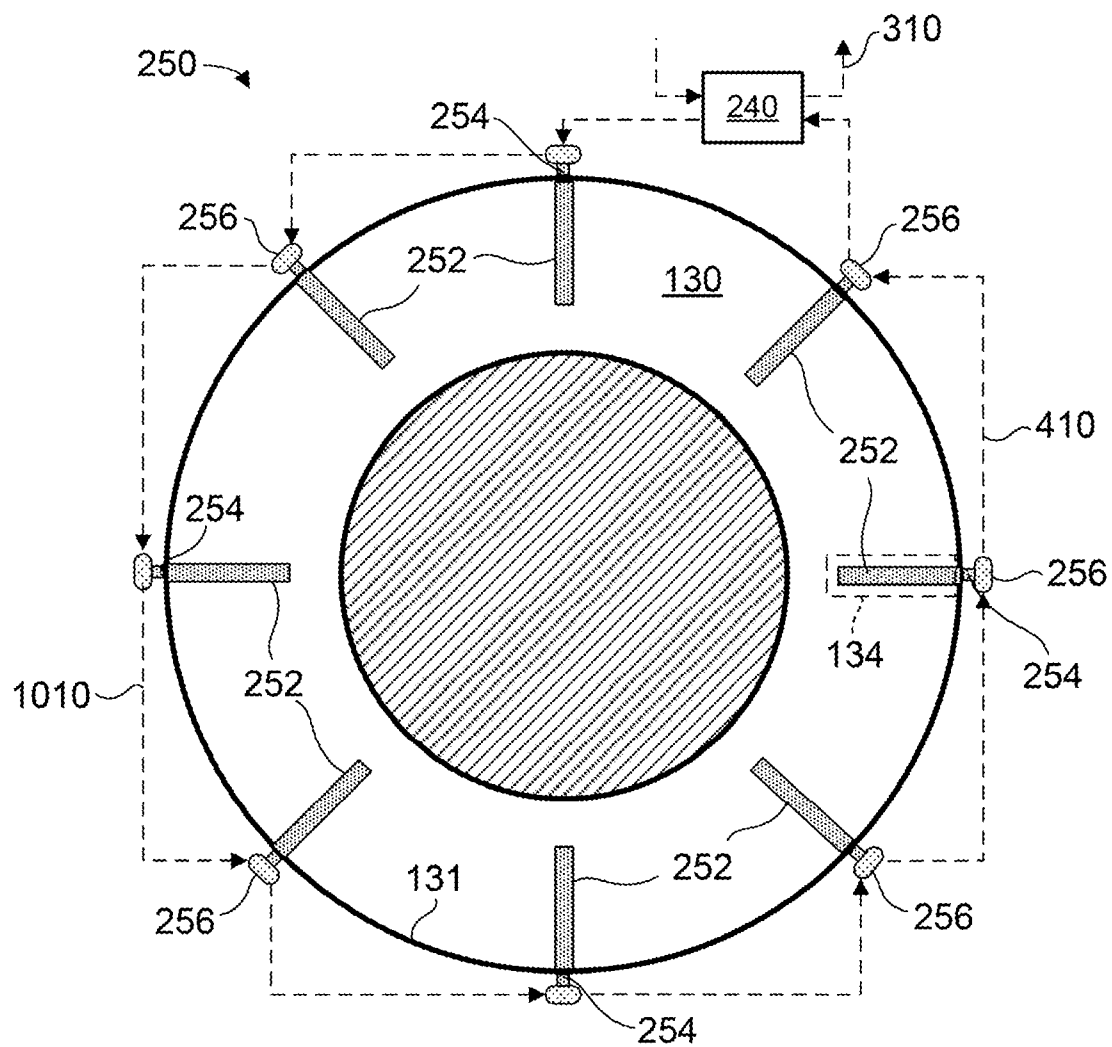


FIG. 10

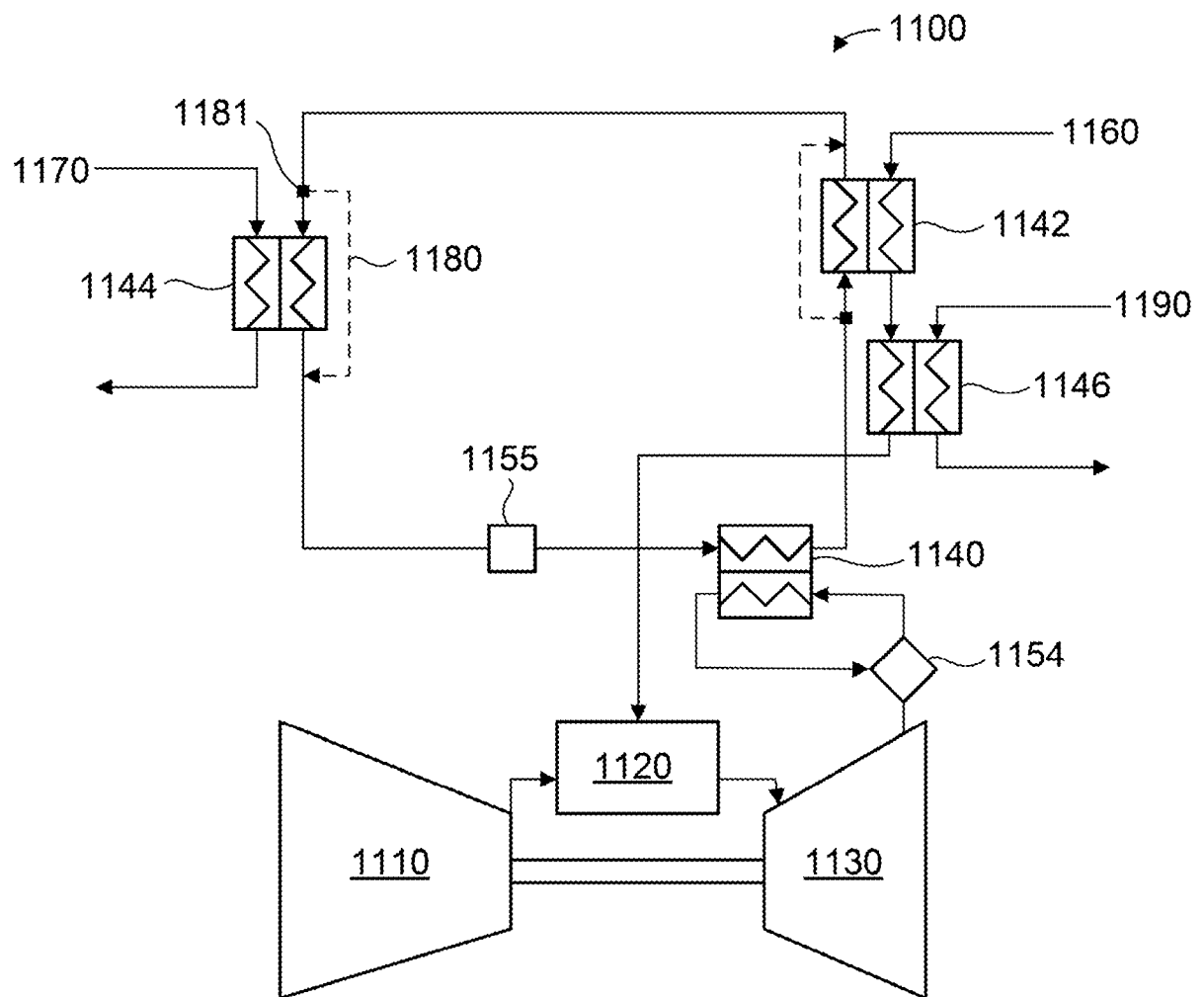


FIG. 11

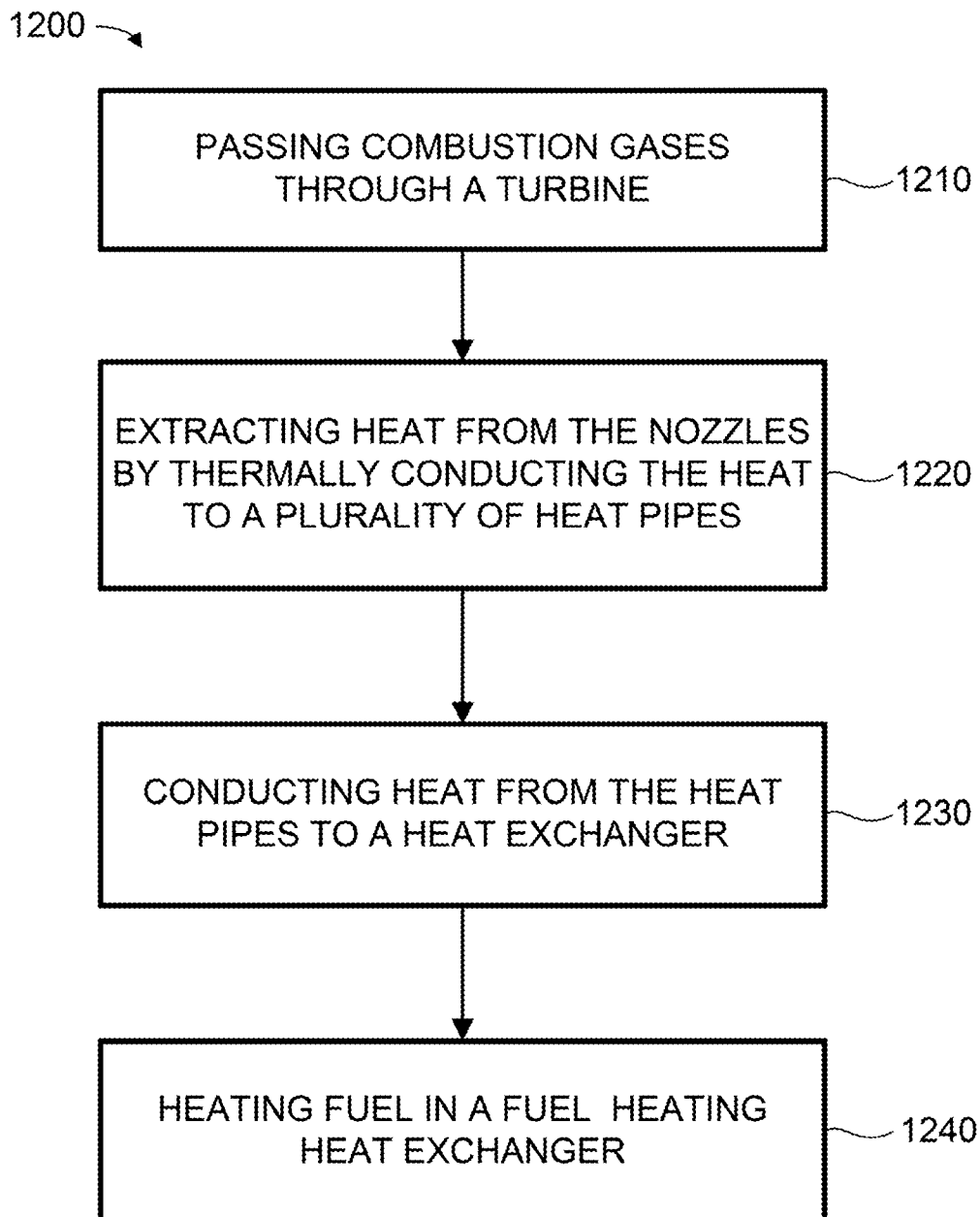


FIG. 12

## INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2015/024127

A. CLASSIFICATION OF SUBJECT MATTER  
INV. F01D25/12  
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
F01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                  | Relevant to claim No. |
|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Y         | US 2011/103939 A1 (ZHANG HUA [US] ET AL)<br>5 May 2011 (2011-05-05)<br>abstract<br>paragraph [0024]<br>figures 2-6                                                                  | 9-20                  |
| Y         | US 8 794 907 B1 (BROSTMAYER JOSEPH D [US]<br>ET AL) 5 August 2014 (2014-08-05)<br>abstract<br>column 1, line 23 - line 39<br>column 4, line 27 - line 63<br>figures<br>-----<br>-/- | 9-20                  |



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

19 January 2016

Date of mailing of the international search report

29/01/2016

Name and mailing address of the ISA/

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Authorized officer

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## INTERNATIONAL SEARCH REPORT

International application No

PCT/US2015/024127

| C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                                                                                                                                                         |                       |
|------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Category*                                            | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                      | Relevant to claim No. |
| Y                                                    | US 2012/017564 A1 (DHINGRA HARISH CHANDRA<br>[US] ET AL) 26 January 2012 (2012-01-26)<br>abstract<br>paragraph [0023] - paragraph [0024]<br>paragraph [0029] - paragraph [0030]<br>paragraph [0046]<br>figures<br>----- | 14,15,<br>19,20       |

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US2015/024127

### Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claims Nos.: 1-8  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:  
see FURTHER INFORMATION sheet PCT/ISA/210
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

### Box No. III Observations where unity of invention is lacking (Continuation of Item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

#### Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

**FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210**

Continuation of Box II.2

Claims Nos.: 1-8

Claims 1 and 9 have been drafted as separate independent claims in the same category (device). According to the PCT Guidelines 9.34 and 9.35, the applicant was asked to file a statement indicating the subject-matter to be searched. In his reply, the applicant indicated the independent device claim 9 (with dependent claims 10-16) and the independent method claim 17 (with the dependent claims 18-20) as the basis for the search.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guidelines C-IV, 7.2), should the problems which led to the Article 17(2) declaration be overcome.

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2015/024127

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date           |
|-------------------------------------------|---------------------|----------------------------|-------------------------------|
| US 2011103939                             | A1                  | 05-05-2011                 | CH 702160 A2 13-05-2011       |
|                                           |                     |                            | CN 102052106 A 11-05-2011     |
|                                           |                     |                            | DE 102010038275 A1 12-05-2011 |
|                                           |                     |                            | JP 2011094615 A 12-05-2011    |
|                                           |                     |                            | US 2011103939 A1 05-05-2011   |
| -----                                     |                     |                            |                               |
| US 8794907                                | B1                  | 05-08-2014                 | NONE                          |
| -----                                     |                     |                            |                               |
| US 2012017564                             | A1                  | 26-01-2012                 | CN 102337972 A 01-02-2012     |
|                                           |                     |                            | US 2012017564 A1 26-01-2012   |
| -----                                     |                     |                            |                               |