



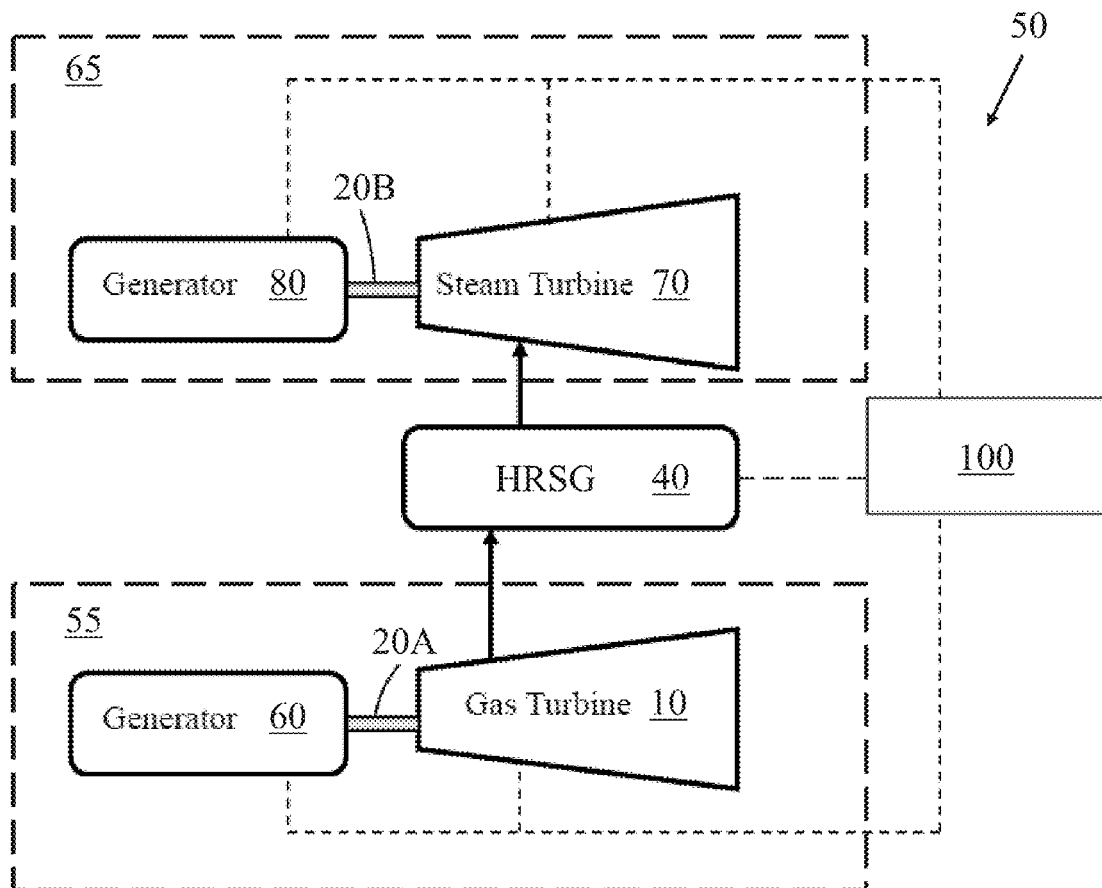
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(19) **United States**(12) **Patent Application Publication****Zhang et al.**(10) **Pub. No.: US 2018/0135467 A1**(43) **Pub. Date: May 17, 2018**(54) **COOLING OF GAS TURBINE AT VARYING LOADS**(52) **U.S. Cl.**CPC **F01K 13/025** (2013.01); **F01K 23/10** (2013.01)(71) Applicant: **General Electric Company,**
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(57)

ABSTRACT(72) Inventors: **Hua Zhang**, Greer, SC (US); **Douglas Beadie**, Greer, SC (US); **Manuel Cardenas**, Greenville, SC (US); **John Edward Sholes, JR.**, Kings Mountain, NC (US)

Embodiments of the present disclosure relate to cooling a gas turbine which operates at varying loads. An apparatus according to embodiments of the present disclosure may include: an outlet heat exchanger positioned within a transition duct of a turbine outlet of a gas turbine, wherein the transition duct is positioned upstream from a heat recovery steam generator (HRSG); an extraction line fluidly connecting the outlet heat exchanger to the HRSG, such that a heat exchange fluid flows from the HRSG to the outlet heat exchanger through the extraction line; and a return line fluidly connecting the outlet heat exchanger to the HRSG, such that the heat exchange fluid returns to the HRSG through the return line after passing through the outlet heat exchanger.

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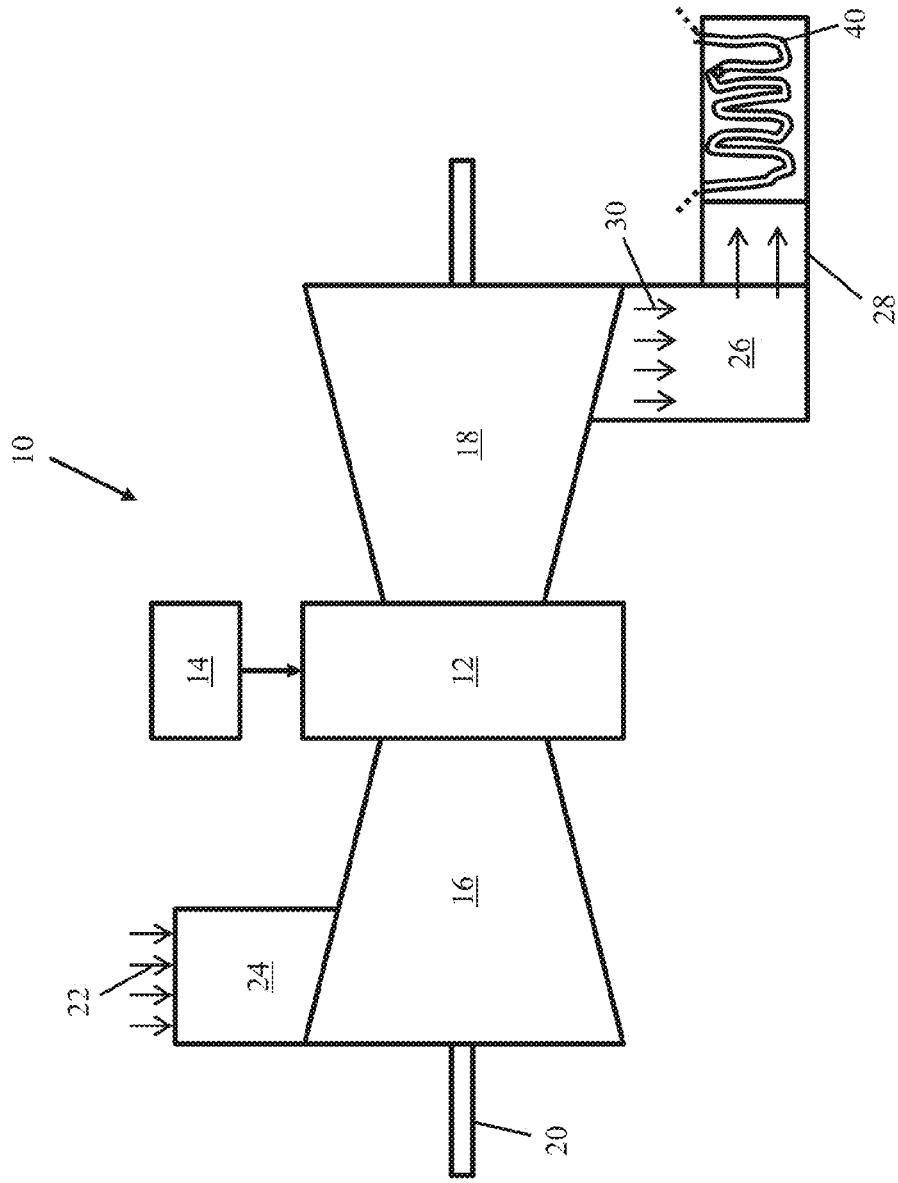


FIG. 1 (Prior Art)

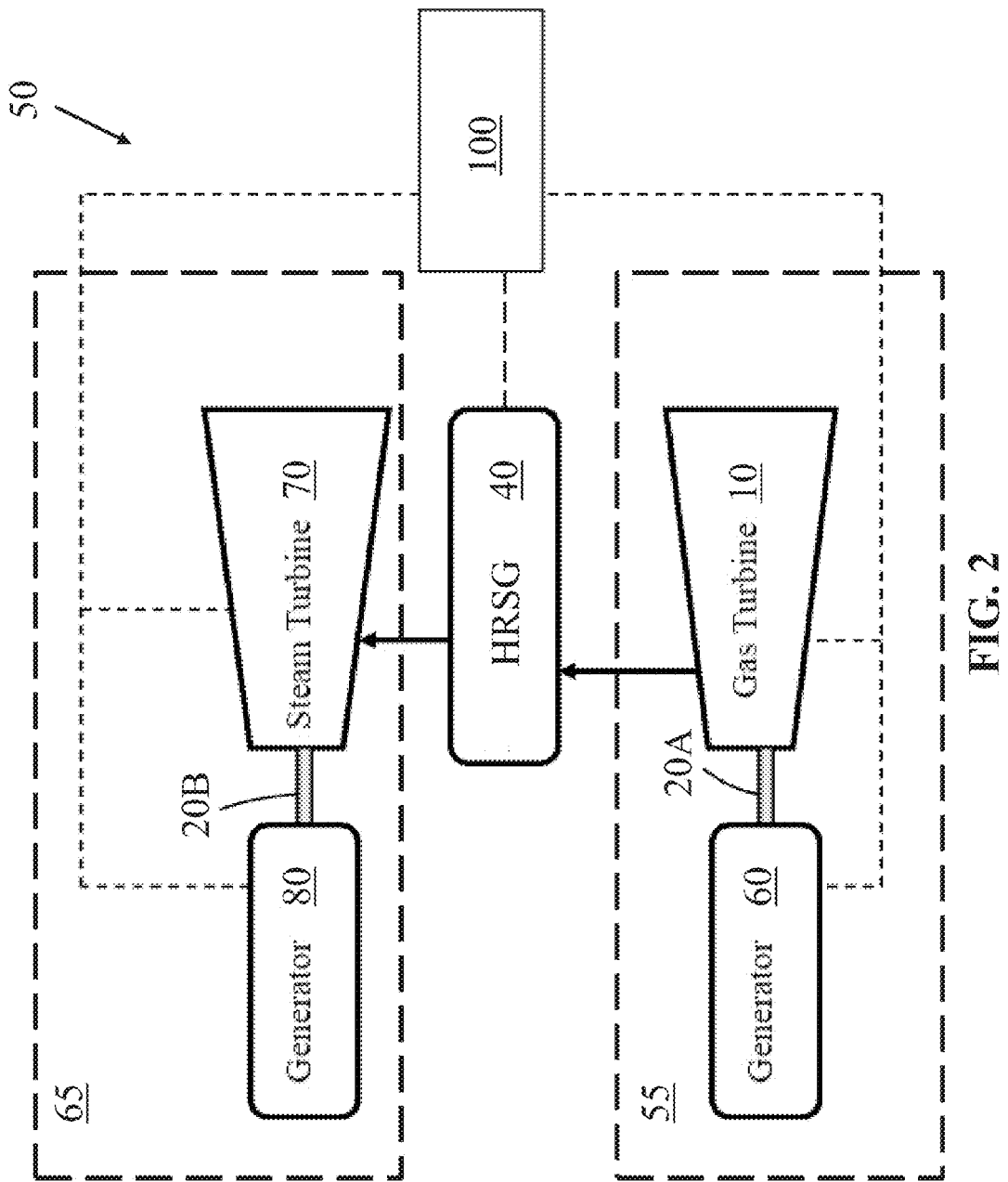


FIG. 2

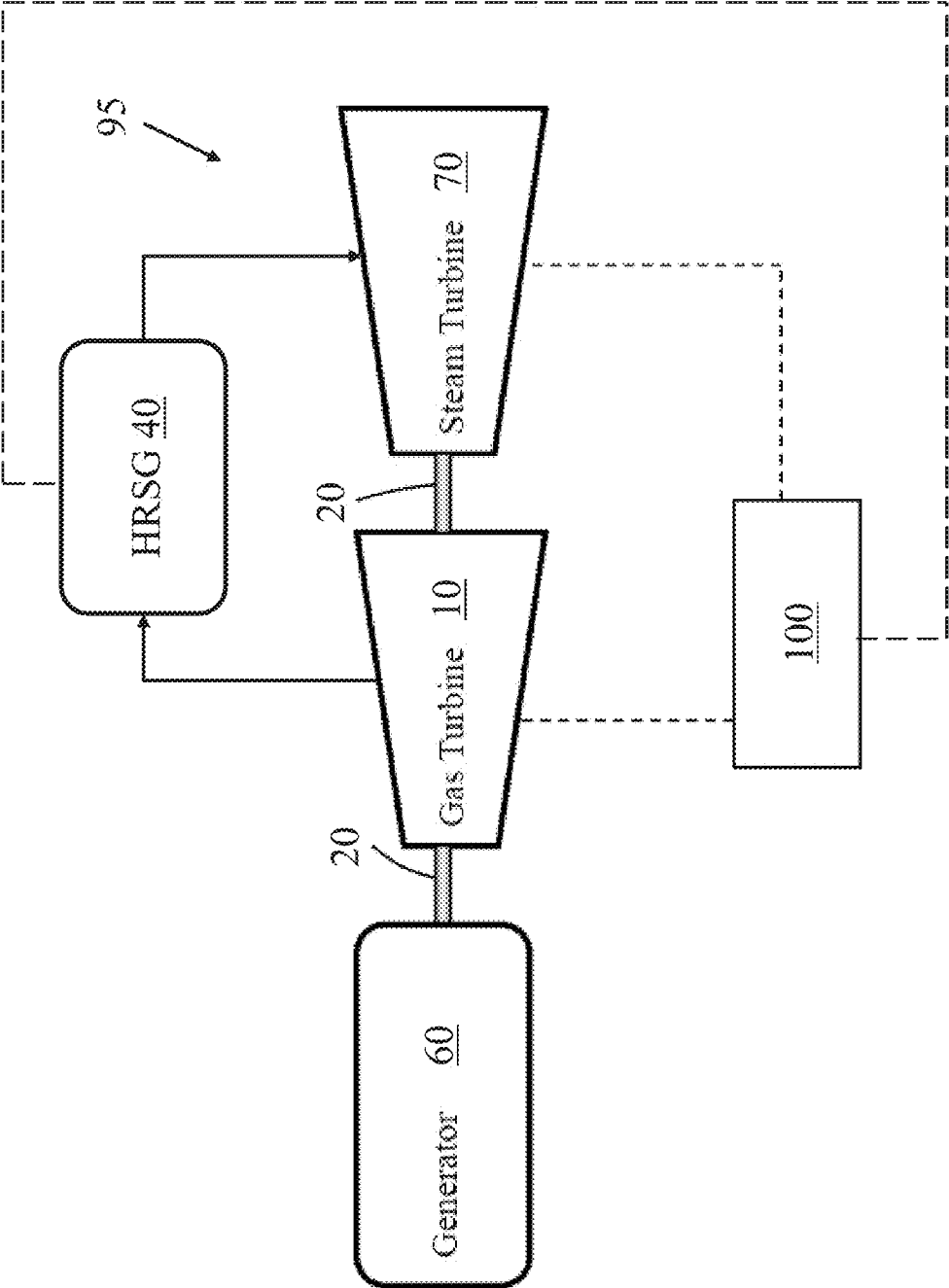


FIG. 3

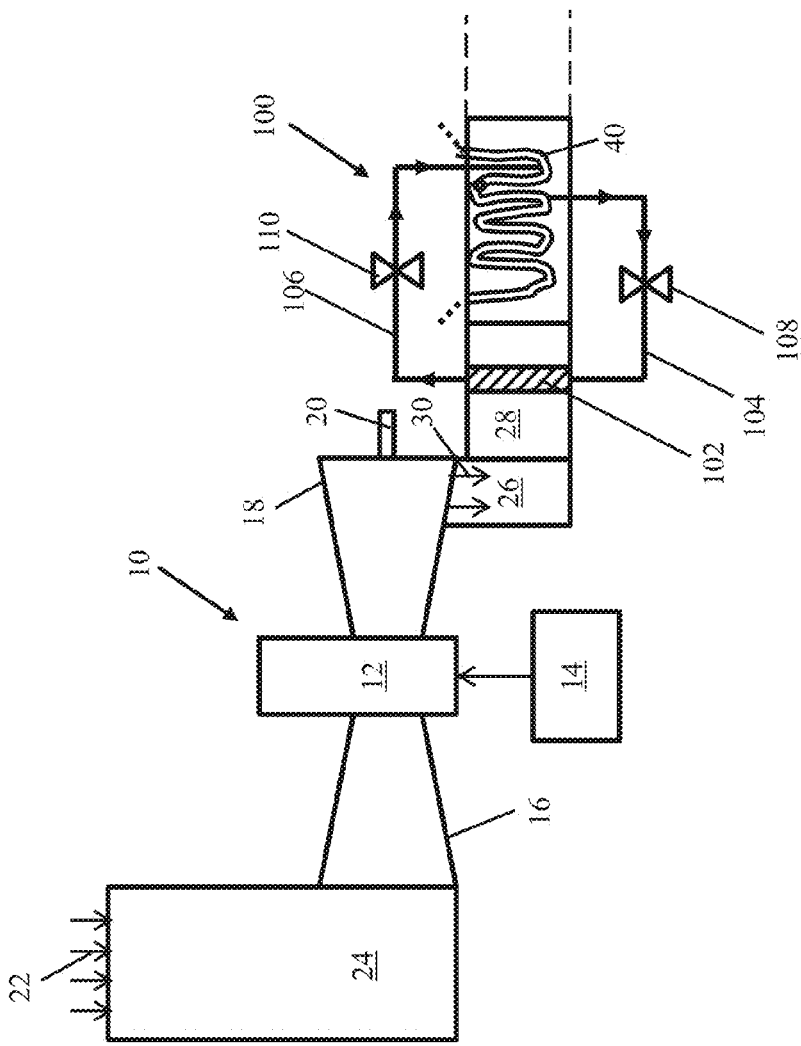


FIG. 4

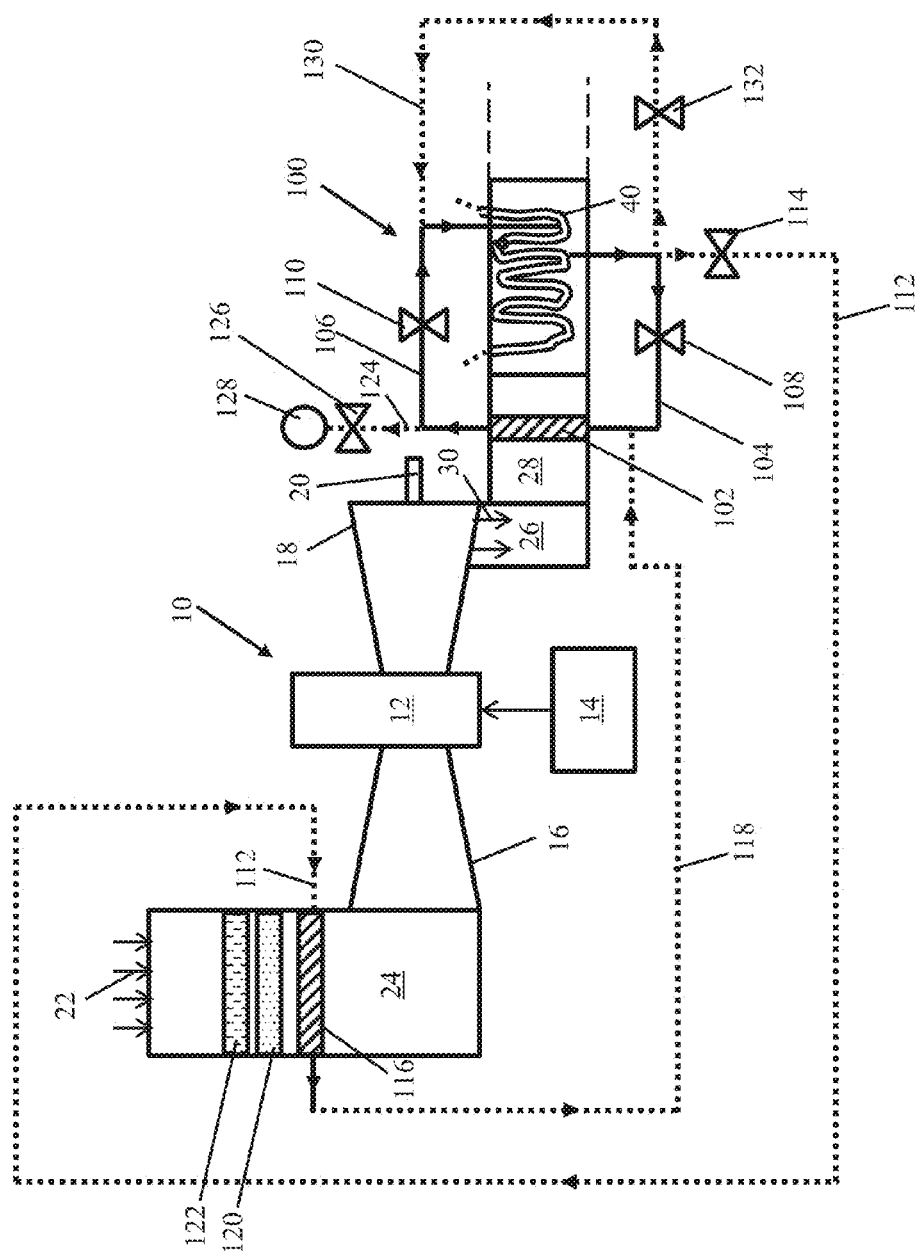
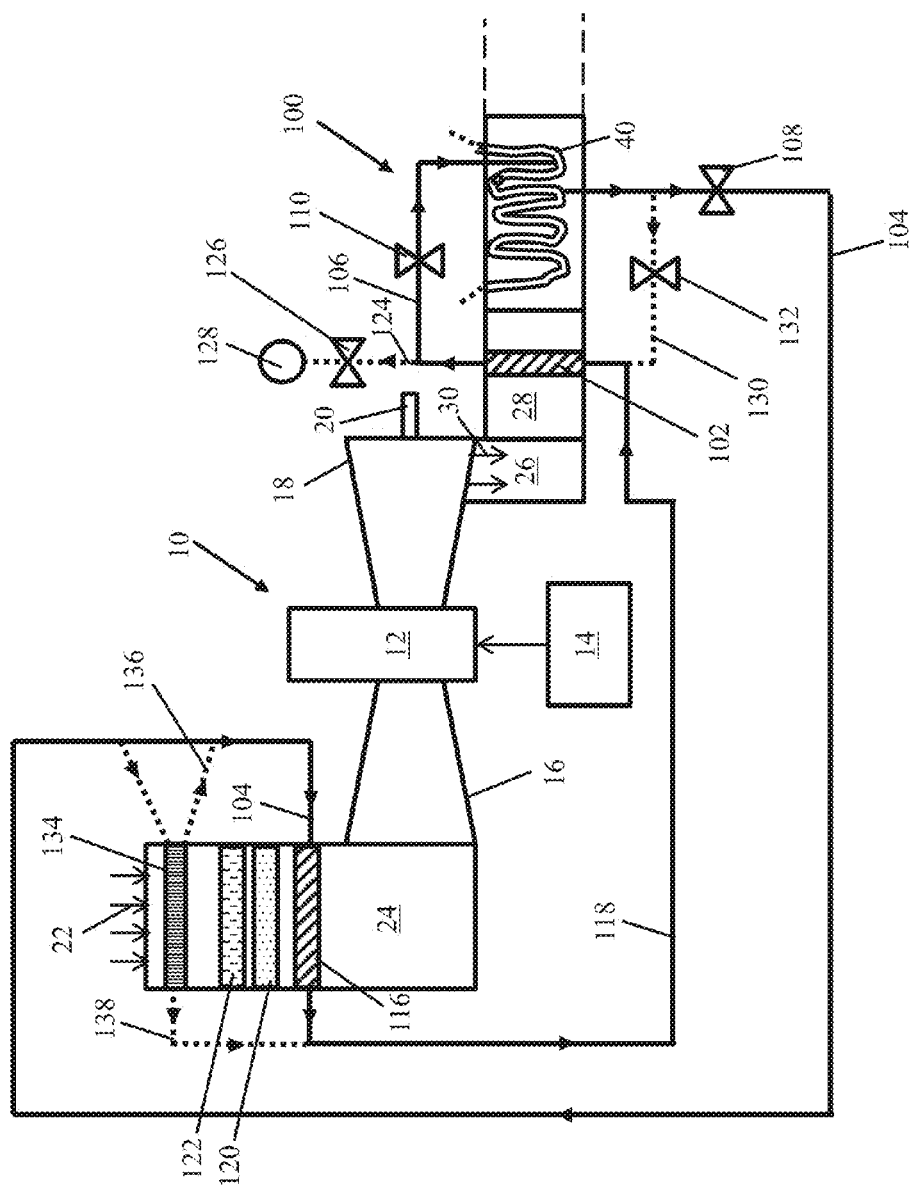


FIG. 5



611

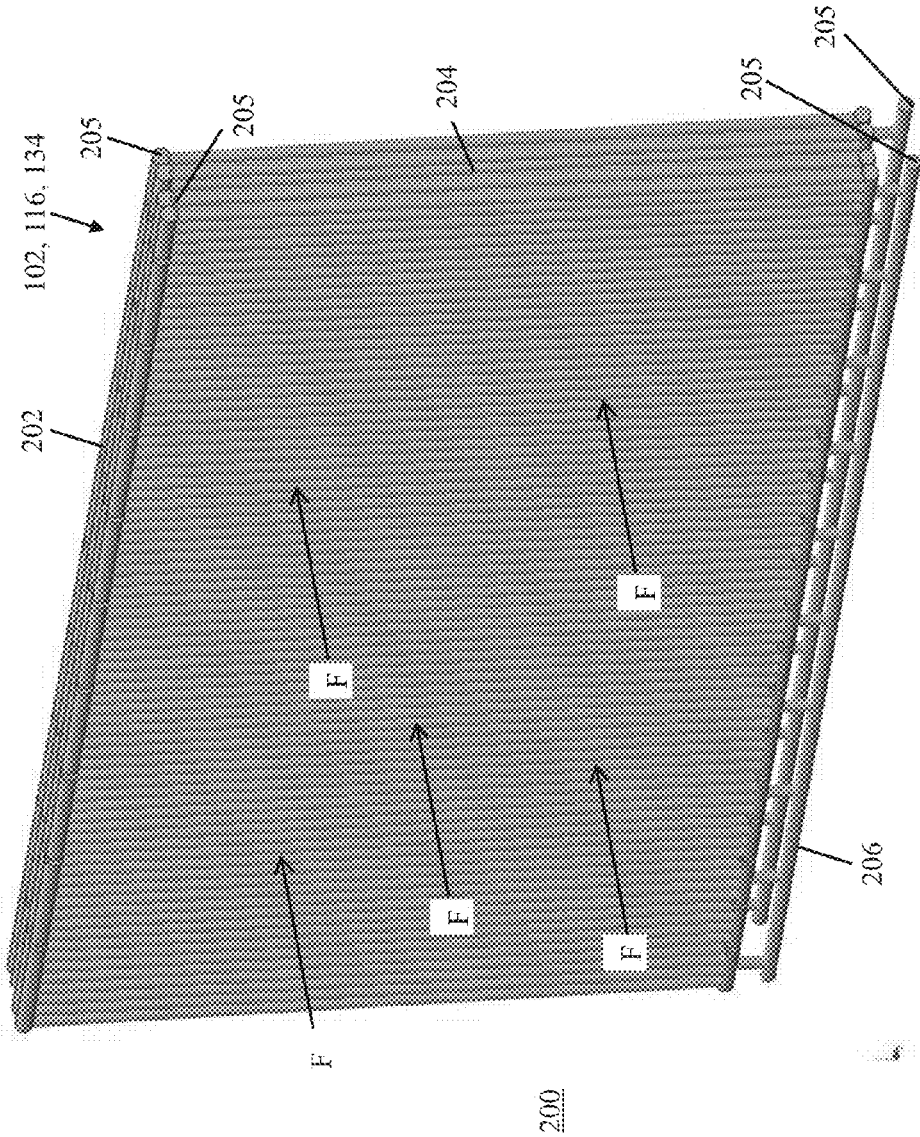


FIG. 7

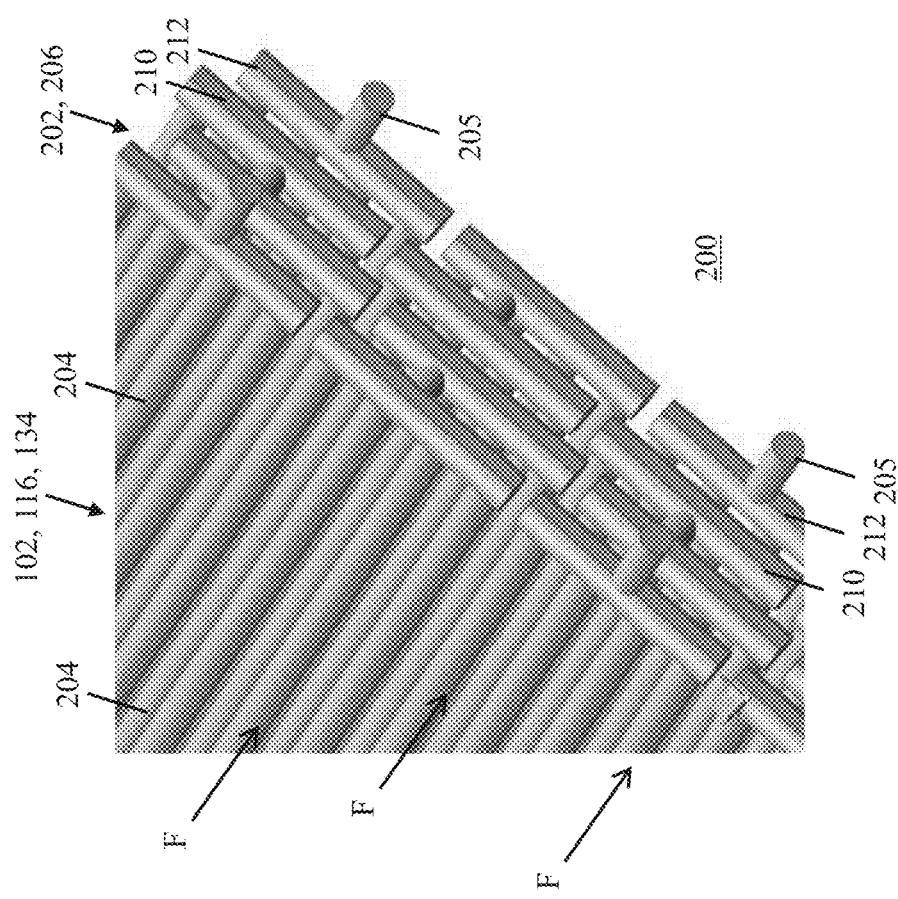


FIG. 8

COOLING OF GAS TURBINE AT VARYING LOADS

BACKGROUND

[0001] The disclosure relates generally to apparatuses and methods for cooling a gas turbine at varying operating loads. More specifically, the disclosure relates to methods and apparatuses of cooling a gas turbine during operation at a startup load, a reduced load, and a base load.

[0002] Conventional turbine systems are frequently used to generate power for, e.g., electric generators. A working fluid such as hot gas or steam can be forced across sets of turbine blades coupled to a rotor of the turbine system. The force of the working fluid on the blades causes those blades (and the coupled body of the rotor) to rotate. In many cases, the rotor body is coupled to the drive shaft of a dynamo-electric machine such as an electric generator. In this sense, initiating rotation of the turbine system rotor can also rotate the drive shaft in the electric generator to generate an electrical current (associated with a power output).

[0003] Variables such as the turbine's efficiency, power output, and risk of failure are at least partially dependent on the internal temperature of particular components and passages, such as inlets, outlets, etc. The temperature of a working fluid flowing through the turbine system will affect outputs, such as the rotation torque and/or power generated. Designing a turbine system to have a particular operating temperature can improve these outputs. The process of controlling operating temperatures to increase the power output of a system can be known as "turbine power augmentation." To manage the temperature of a turbine system, various cooling systems may be deployed.

[0004] When generating power to consistently satisfy minimum consumer demand, a gas turbine operates at its "base load." A gas turbine may be structured to provide a sufficient level of cooling to its heat-sensitive components when operating at base load, and without overuse of cooling fluids and/or other inputs for cooling the gas turbine. The health and performance of a gas turbine can be at least partially dependent on the amount of cooling required, and the means by which coolants are provided to various components of the gas turbine. A gas turbine may also yield a power output that is less than its base load in some situations. For example, during startup operation of a gas turbine, the power output will gradually increase to its base load. At a reduced load, the gas turbine may operate at a consistent but reduced power output relative to its base load, e.g., to accommodate periods of reduced minimum demand. These varying loads of the gas turbine may be associated with significantly different temperature profiles of the gas turbine. As an example, the temperature at an inlet to the compressor component and/or an outlet from the turbine component of the gas turbine may be significantly different during startup and/or reduced loads, e.g., based on varying amounts of combustion. Managing the temperature profile of a gas turbine at these varying loads can affect a gas turbine's operational performance and efficiency.

SUMMARY

[0005] A first aspect of the invention provides an apparatus including: an outlet heat exchanger positioned within a transition duct of a turbine outlet of a gas turbine, wherein the transition duct is positioned upstream from a heat

recovery steam generator (HRSG); an extraction line fluidly connecting the outlet heat exchanger to the HRSG, such that a heat exchange fluid flows from the HRSG to the outlet heat exchanger through the extraction line; and a return line fluidly connecting the outlet heat exchanger to the HRSG, such that the heat exchange fluid returns to the HRSG through the return line after passing through the outlet heat exchanger.

[0006] A second aspect of the invention provides an apparatus including: an inlet heat exchanger positioned within a compressor inlet of a gas turbine; an outlet heat exchanger positioned within a transition duct of a turbine outlet of the gas turbine, wherein the transition duct is positioned upstream from a recovery steam generator (HRSG); an extraction line fluidly coupling the inlet heat exchanger to the heat recovery steam generator (HRSG); an inlet return line fluidly coupling the inlet heat exchanger to the outlet heat exchanger, and a return line fluidly coupling the outlet heat exchanger to the HRSG.

[0007] A third aspect of the invention provides a method for cooling a gas turbine at varying loads, the gas turbine including a compressor inlet and a turbine outlet, wherein the turbine outlet further includes a transition duct positioned upstream from a heat recovery steam generator (HRSG), the method including: operating the gas turbine at one of a startup load and a reduced load, the startup load and the reduced load having a reduced power output relative to a base load of the gas turbine; extracting a heat exchange fluid from the HRSG through an extraction line; transmitting the extracted heat exchange fluid through the extraction line to an outlet heat exchanger positioned within the transition duct of the turbine outlet to yield a heated fluid; and transmitting the heated fluid through a return line to the HRSG.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] These and other features of this disclosure will be more readily understood from the following detailed description of the various aspects of the disclosure taken in conjunction with the accompanying drawings that depict various embodiments of the invention, in which:

[0009] FIG. 1 is a schematic view of a conventional gas turbine assembly.

[0010] FIG. 2 shows a schematic block diagram illustrating portions of a multi-shaft combined cycle power plant system according to embodiments.

[0011] FIG. 3 shows a schematic block diagram illustrating portions of a single-shaft combined cycle power plant system according to embodiments.

[0012] FIG. 4 provides a schematic view of an apparatus according to embodiments.

[0013] FIG. 5 provides a schematic view of an apparatus according to further embodiments.

[0014] FIG. 6 depicts provides a schematic view of another apparatus according to alternative embodiments.

[0015] FIG. 7 provides a perspective view of a heat exchanger included in various embodiments.

[0016] FIG. 8 provides a magnified, partial perspective view of a heat exchanger included in various embodiments.

[0017] It is noted that the drawings of the invention are not necessarily to scale. The drawings are intended to depict only typical aspects of the invention, and therefore should

not be considered as limiting the scope of the invention. In the drawings, like numbering represents like elements between the drawings.

DETAILED DESCRIPTION

[0018] As discussed herein, aspects of the disclosure relate generally to distributing heat in a turbine, e.g., by heating a gas turbine inlet and cooling a gas turbine outlet while the gas turbine operates at varying loads. More particularly, as discussed herein, aspects of the disclosure relate to apparatuses and methods for heating a gas turbine inlet and/or cooling a gas turbine outlet at varying loads, e.g., a startup and/or reduced load with a lower power output than the gas turbine's base load. Embodiments of the present disclosure provide additional cooling or heating to a gas turbine outlet or inlet, e.g., by transmitting fluids from a heat recovery steam generator to heat exchangers positioned in a turbine outlet and/or compressor inlet.

[0019] Referring to FIG. 1, a schematic view of a conventional gas turbine 10 is provided. Embodiments of the present disclosure can include or otherwise be adapted for use with gas turbine 10 and/or can be integrated into components thereof. Gas turbine 10 may be connected to and/or used in conjunction with other types of turbomachines where applicable, as discussed herein. A combustor 12 including a plurality of fuel nozzles 14 is typically located between a compressor 16 and a turbine component ("turbine") 18 of power generation system 10. Compressor 16 and turbine 18 can be mechanically coupled to each other through a rotatable shaft 20. In one embodiment, gas turbine 10 is a MS7001FB engine, sometimes referred to as a 9FB engine, commercially available from General Electric Company, Greenville, S.C. The present disclosure is not limited to any one particular gas turbine system and may be implanted in connection with other engines including, for example, the MS7001FA (7FA) and MS9001FA (9FA) engine models of General Electric Company.

[0020] Air 22 flows sequentially through compressor 16, combustor 12, and turbine 18. The compression provided from compressor 16 can also increase the temperature of air 22. Fuel nozzle(s) 14 can provide fuel to combustor 12, where the fuel combusts in the presence of air 22 to yield a hot gas stream. The hot gas stream from combustor 12 can enter turbine 18 to impart mechanical energy to rotatable shaft 20, e.g., by rotating a group of turbine blades, thereby delivering power back to compressor 16 and/or any loads (not shown) mechanically coupled to rotatable shaft 20. Power generation system 10 may include a compressor inlet 24 positioned upstream from compressor 16, and more specifically, upstream from an inlet guide vane (IGV) section of compressor 16. As discussed elsewhere herein, compressor inlet 24 may include additional components (e.g., silencers, filters, etc.) which affect air 22 entering gas turbine 10, and the emissions, dynamics, etc., of gas turbine 10. Air 22 can be provided to compressor 16 through compressor inlet 24 before being compressed and delivered to combustor 12. Power generation system 10 may also include a turbine outlet 26. Turbine outlet 26 may be structured to include a transition duct 28 positioned downstream from turbine 18. A flue gas 30 (also known as an "exhaust gas") yielded from turbine 18 may pass through turbine outlet 26, including transition duct 28, before reaching a heat recovery steam generator (HRSG) 40 positioned downstream from gas turbine 10. Although not shown

specifically in FIG. 1, gas turbine 10 can include multiple stages with respective combustors 12, compressors 16, and/or turbines 18. Gas turbine 10 may in addition be one of several individual turbomachines controlled via the same operator and/or may be part of a larger power generation system.

[0021] Turning to FIG. 2, a schematic view of portions of an illustrative combined cycle power generating system 50 are shown. In the instant example, combined cycle power generating system 50 is a multiple shaft system with two generators, but one with skill in the art will readily understand that the teachings of the disclosure are applicable to any variety of combined cycle power generating system. Combined cycle power generating system 50 may include a gas turbine system 55, including gas turbine 10 operably connected to a generator 60 through shaft 20A. Combined cycle power generating system 50 can also include a steam turbine system 65 in which a steam turbine 70 is operably coupled to another generator 80 through shaft 20B. Generator 60 and gas turbine system 10 may be mechanically coupled by shaft 20A, which may transfer energy between a drive shaft (not shown) of gas turbine system 10 and generator 60. Also shown in FIG. 2, HRSG 40 is operably connected to gas turbine system 55 and steam turbine system 65. HRSG 40 may include a conventional HRSG configuration, such as those used in conventional combined cycle power systems, and/or may be embodied as another type of heat exchanger or similar component for using exhaust energy to produce steam. For example, HRSG 40 may include a thermally conductive pipe, line, etc., with water therein such that water in HRSG 40 is heated by flue gas 30 (FIG. 1) to produce steam. HRSG 40 may be fluidly connected to both gas turbine system 55 and steam turbine system 65 via conventional conduits (numbering omitted). It is understood that generators 60, 80 and shafts 20A, 20B may be of any size or type known in the art and may differ depending upon their application or the system to which they are connected. Common numbering of the generators and shafts is for clarity and does not necessarily suggest these generators or shafts are identical.

[0022] FIG. 2 also represents the combined cycle in its simplest form in which the energy in the exhaust gases exiting gas turbine 10 are converted into additional useful work. The exhaust gases exchange heat with HRSG 40 in which water is converted to steam in the manner of a boiler. HRSG 40 may also use the energy to create a hot feedwater, e.g., having temperature in the range of 95 to 99° C. Steam turbine system 65 may include one or more steam turbines, e.g., a high pressure (HP) turbine, an intermediate pressure (IP) turbine and a low pressure (LP) turbine, each of which are coupled to shaft 20B. Regardless of how many steam turbines 70 are included, each steam turbine 70 may include a plurality of rotating blades (not shown) mechanically coupled to shaft 20B. In operation, steam from HRSG 40, and perhaps other sources, enters an inlet (not shown) of steam turbine 70, and is channeled to impart a force on blades thereof causing shaft 20B to rotate. As understood, steam from an upstream turbine (not shown) may be employed later in a downstream turbine (not shown). The steam thus produced by HRSG 40 drives at least a part of steam turbine system 65 in which additional work is extracted to drive shaft 20B and an additional load such as generator 80 which, in turn, produces additional electric power.

[0023] In another embodiment, shown in FIG. 3, a single shaft combined cycle power plant 95 may include a single generator 60 coupled to both gas turbine 10 and steam turbine 70 via a common shaft 20. Steam turbine 70 and/or gas turbine 10 may include one or more blades (not shown), described with reference to FIG. 1 and/or other embodiments described herein. However embodied, power plant systems 50 (FIG. 2), 95 incorporating gas turbine 10, HRSG 40, and steam turbine 70 can include or interact with an apparatus 100 according to embodiments of the present disclosure, as described herein.

[0024] Turning to FIG. 4, an apparatus 100 forming part of and/or used with gas turbine 10 is shown. The temperature of various components within gas turbine 10 may be significantly different when gas turbine 10 operates with a reduced power output relative to base load. In particular, gas turbine 10 may temporarily operate at a startup load, i.e., a transient operation during which gas turbine 10 transitions between being shut down and operating at base load. Although this type of operation is referred to herein as a “startup load” for the sake of consistency, such operation of a gas turbine may be known in the art simply as “startup.” During operation at startup load, the temperature of flue gas 30 in turbine outlet 26 may greatly increase relative to air 22 in compressor inlet 24. Gas turbine 10 may also operate at a reduced load, i.e., a steady-state operation in which gas turbine 10 produces a lower power output than its base load. During operation at a reduced load, air 22 from ambient in compressor inlet 24 may have a temperature that is too low for the optimal operation of a gas turbine relative to a desired inlet air temperature. During reduced load operation, the inlet air temperature typically must be elevated above ambient temperature to improve the gas turbine efficiency, e.g. inlet air heating using hotter than ambient air temperature water. Flue gas 30 in turbine outlet 26 may have a greatly increased temperature relative to base load to improve gas turbine operation, and because of the heated inlet air. Such differences in temperature, also known as a “temperature differential,” between compressor inlet 24 and turbine outlet 26 may reduce the efficiency of gas turbine 10 during operation at these loads. Embodiments of the present disclosure can reduce such differences in temperature between compressor inlet 24 air temperature and desired optimal inlet air temperature. Embodiments of the present disclosure can also permit increased operating temperatures in turbine outlet 26 during non-base load operation of gas turbine 10 to protect HRSG 40 from the harm of high gas turbine exhaust temperature.

[0025] Apparatus 100 can include, e.g., an outlet heat exchanger 102 positioned within transition duct 28 of turbine outlet 26. Transition duct 28 may be distinguished from other portions of turbine outlet 26 by including, e.g., one or more turns along the flowpath for flue gas 30 therein, and/or a decreasing cross-sectional area which typically may cause flue gas 30 passing therethrough to increase in temperature. As noted elsewhere herein, transition duct 28 may be positioned upstream from HRSG 40. Embodiments of apparatus 100 can allow flue gas 30 to be cooled at least partially by outlet heat exchanger 102 before reaching HRSG 40. As discussed herein, outlet heat exchanger 102 can thus reduce the temperature of flue gas 30 during operation of gas turbine 10 below its base load.

[0026] As shown, outlet heat exchanger 102 can be positioned upstream from HRSG 40, and within transition duct

28. In an embodiment, a material composition of outlet heat exchanger 102 may include, e.g., one or more steels, nickel-based alloys, and/or other heat exchange materials configured to structurally withstand the high temperature of flue gas 30 in transition duct 28. In an example embodiment, outlet heat exchanger 102 may include a thermally conductive material capable of withstanding temperatures above, e.g., approximately seven hundred degrees Celsius ($^{\circ}$ C.). Outlet heat exchanger may be configured to reduce the temperature of flue gas 30 within transition duct 28, e.g., by approximately seventy Celsius degrees. As used herein, the term “approximately” in relation to a specified numerical value (including percentages of base numerical values) can include all values within ten percentage points of (i.e., above or below) the specified numerical value or percentage, and/or all other values which cause no operational difference or substantial operational difference between the modified value and the enumerated value. The term approximately can also include other specific values or ranges where specified herein.

[0027] An extraction line 104 may be fluidly coupled to HRSG 40 at one end and outlet heat exchanger 102 at its other, opposing end. Extraction line 104 can extract a heat exchange fluid from HRSG 40 for transmission to outlet heat exchanger 102. The extracted heat exchange fluid extracted from HRSG 40 and transmitted through apparatus 100 may generally include water, which may be in liquid phase or may be in the form of steam when extracted from HRSG 40 for use in apparatus 100. In an example embodiment, HRSG 40 may generate steam for a low pressure or intermediate pressure section of a steam turbine, e.g., steam turbine 70 (FIGS. 2-3) of steam turbine system 65 (FIG. 2). The heat exchange fluids extracted from HRSG 40 may pass through extraction line 104 to reach outlet heat exchanger 102. The extracted heat exchange fluids entering outlet heat exchanger 102 may have a lower temperature than flue gas 30. In this case, the fluids passing through outlet heat exchanger 102 can absorb heat from flue gas 30, causing a temperature reduction of flue gas 30 in transition duct 28.

[0028] Apparatus 100 may also include a return line 106 fluidly connecting outlet heat exchanger 102 to HRSG 40. The heat exchange fluid(s) extracted from HRSG 40 may be heated within outlet heat exchanger 102 in addition or alternatively to being heated by exhaust gases downstream from transition duct 28. Outlet heat exchanger 102 can reduce the temperature of flue gas 30 in turbine outlet 26 before those fluids reach HRSG 40, without significantly affecting the operation of HRSG 40. Extraction line 104 and return line 106 can also include valves for adjusting the amount of heat exchange fluid in apparatus 100. Extraction line 104 can include an extraction valve 108 for adjusting an amount of heat exchange fluid extracted from HRSG 40. Return line 106 may additionally or alternatively include a return valve 110 for controlling an amount of heat exchange fluid in return line 106. Valve(s) 108, 110 can be in the form of any currently known or later developed valve component, including without limitation, a hydraulic valve, a ball valve, a disc valve, a globe valve, etc. Valve(s) 108, 110 can be manually actuated or electrically actuated. Valve(s) 108, 110 can control an amount of heat exchange fluid extracted from and/or returned to HRSG 40. As examples, each valve 108, 110 can be manually operated by a user or another machine or piece of equipment operatively connected to valve(s) 108, 110.

[0029] Referring to FIG. 5, apparatus 100 is shown according to further embodiments and/or with optional features included therein. The various additional or optional features of apparatus 100 are shown with phantom lines and discussed in detail herein. In particular, apparatus 100 may include features for exchanging heat between fluids extracted from HRSG 40 and compressor inlet 24, in addition to providing thermal communication with exhaust passing through transition duct 28. An inlet line 112, which may include an inlet valve 114 therein, can fluidly couple extraction line 104 to an inlet heat exchanger 116. Inlet heat exchanger 116 may be positioned within compressor inlet 24 such that air 22 is in thermal communication with heat exchanger fluid directed to inlet heat exchanger 116 from extraction line 104. Inlet heat exchanger 116 may be composed of any currently-known or later developed thermal-transmitting material capable of structurally withstanding the temperature of air 22 passing through compressor inlet 24. In particular, inlet heat exchanger 116 may be composed of one or more of the example materials discussed elsewhere herein relative to outlet heat exchanger 102 (e.g., steels and/or nickel-based alloys). The temperature of heat exchange fluids passing through inlet heat exchanger 116 may be greater than air 22 in compressor inlet 24. In an embodiment, apparatus 100 with inlet heat exchanger 116 therein may increase the temperature of air 22 in compressor inlet 24, e.g., by approximately thirty Celsius degrees, before air 22 reaches compressor inlet 24.

[0030] Fluids passing through inlet heat exchanger 116 may flow to an inlet return line 118 fluidly coupled to extraction line 104 downstream from inlet line 112. Heat exchange fluids exiting inlet heat exchanger 116 can flow to outlet heat exchanger 102 through inlet return line 118. At least a portion of heat exchange fluids extracted from HRSG 40 may be transmitted to inlet heat exchanger 116 before entering outlet heat exchanger 102, e.g., to absorb heat from air 22 before exchanging heat with flue gases 30 in transition duct 28. Inlet heat exchanger 116 may be positioned in any desired location, region, etc., of inlet 24, and in an example may be positioned downstream from a silencer 120 and a filter 122 of compressor inlet 24. Silencer 120 may include any currently known or later-developed component for reducing the amount of sound produced by gas turbine 10 during operation. Filter 122 may include any currently known or later-developed structure for removing particles, contaminants, etc., from air 22. Inlet heat exchanger 116 may also be positioned within compressor inlet 24 upstream from one or more inlet guide vanes (not shown) of compressor 16. Inlet heat exchanger 116, due to being positioned downstream from silencer 120 and filter 122, and upstream of any inlet guide vanes of compressor 16, may transmit heat to the resulting flow of filtered air 22 to compressor inlet 24 without significantly contributing to the acoustic output of gas turbine 10.

[0031] Outlet and/or inlet heat exchangers 102, 116 together may increase the temperature of air 22 in compressor inlet 24, while reducing the temperature of flue gas 30 of turbine outlet 26, as gas turbine 10 operates at a reduced load. However, the need for cooling and heating of compressor inlet 24 and turbine outlet 26 by apparatus 100 may be greatly reduced when gas turbine 10 operates at base load. When a user closes one or more valves 108, 110, 114 to reduce or prevent the flow of heat exchange fluid through heat exchangers 102, 116, apparatus 100 may include addi-

tional features for removing heat exchange fluids from apparatus 100. For example, apparatus 100 can include a drain line 124 and drain valve 126 for controlling a flow of heat exchange fluid from outlet heat exchanger 102 to a drain 128. Drain 128 may be embodied as a line to one or more components, reservoirs, ambient regions, etc., positioned outside gas turbine 10. In some cases, drain 128 may include a tank, reservoir, etc., for holding drained fluids therein. When gas turbine 10 operates at its base load, a user may open drain valve 126 and close one or more other valves 108, 110, 114, such that any remaining fluids in outlet heat exchanger 102 are transmitted to drain 128 and removed from gas turbine 10, e.g., without returning to HRSG 40. Such draining of fluid in outlet heat exchanger 102 may be advantageous when no heat transfer is needed to protect the structural composition of heat exchanger 102.

[0032] Apparatus 100 can be adapted to vary the amounts of heat exchange fluid transmitted to outlet heat exchanger 102 during a startup and/or reduced load. For example, gas turbine 10 begins to operate at base or reduced load, a user may gradually decrease the amount of heat exchange fluid transmitted to outlet heat exchanger 102 by way of a bypass line 130 fluidly coupled between extraction line 104 and return line 106. A bypass valve 132 in bypass line 130 may be opened or closed to adjust an amount of heat exchange fluid which bypasses outlet heat exchanger 102 and directed back to HRSG 40. The ratio of heat exchange fluid in bypass line 130 relative to outlet heat exchanger 102 can vary based on the degree to which bypass valve 132 is opened or closed. Bypass line 130 may be used in addition to and/or as a substitution for other components described herein for varying the amount of heat exchange fluid transmitted from HRSG 40 to outlet heat exchanger 102.

[0033] Turning to FIG. 6, embodiments of apparatus 100 may include additional features and/or alternative arrangements of features. For example, apparatus 100 may be configured to extract heat exchange fluid from HRSG 40 for direct transmission to inlet heat exchanger 116. The extracted heat exchange fluid may then be transmitted to outlet heat exchanger 102 and to HRSG 40 thereafter. Apparatus 100 may include extraction line 104 with extraction valve 108 fluidly coupled between HRSG 40 and inlet heat exchanger 116, as shown. Inlet return line 118 may fluidly couple inlet heat exchanger 116 to outlet heat exchanger 102 as described elsewhere herein. Return line 106 with return valve 110 may fluidly couple outlet heat exchanger 102 to HRSG 40. As also described by example herein, inlet heat exchanger 116 may provide thermal communication with air 22 passing through compressor inlet 24. Outlet heat exchanger 102 may provide thermal communication between heat exchange fluids exiting inlet heat exchanger 116, and flue gases 30 passing through outlet transition duct 28. Outlet heat exchanger 102 can be positioned upstream from HRSG 40, as noted elsewhere herein relative to other embodiments of apparatus 100.

[0034] In addition to inlet and outlet heat exchangers 102, 116, apparatus 100 can include additional components for exchanging heat between fluids extracted from HRSG 40 and operative fluids in gas turbine 10. A pre-filter heat exchanger 134 may be fluidly coupled to extraction line 104 at a location upstream from inlet heat exchanger 116, e.g., through a pre-filter line 136. Pre-filter heat exchanger 134 may be positioned in compressor inlet 24 upstream from silencer 120 and filter 122. Pre-filter heat exchanger 134

may therefore be in thermal communication with air 22 positioned upstream from inlet heat exchanger 116. Silencer 120 and filter 122 can be positioned directly between inlet heat exchanger 116 and pre-filter heat exchanger 134, e.g., without further heat exchange components of apparatus 100 being positioned therebetween.

[0035] Heat exchange fluids extracted from HRSG 40 may have a higher temperature than air 22. During operation, heat exchange fluids can be transmitted to pre-filter heat exchanger 134 through pre-filter line 136 after being extracted from HRSG 40. In this case, the extracted fluids can be transmitted to inlet heat exchanger 116 after passing through pre-filter heat exchanger 134. Together, inlet heat exchanger 116 and pre-filter heat exchanger 134 can allow apparatus 100 to increase the temperature of air 22 in compressor inlet 24 at multiple locations. The heat exchange fluids can then be transmitted to outlet heat exchanger 102 after exiting inlet heat exchanger 116. The thermal communication provided from inlet heat exchanger 116 and pre-filter heat exchanger 134 can reduce a difference in temperatures between air 22 and flue gas 30 in turbine outlet 26, e.g., at transition duct 28.

[0036] As discussed elsewhere herein, e.g., relative to FIGS. 7-8, pre-filter heat exchanger 134 and/or other heat exchangers 102, 116 may include a plurality of heating tubes each extending between the respective lines to which they are connected. Pre-filter heat exchanger 134 may include a plurality of lines extending between extraction line 104 and pre-filter line 136. Pre-filter heat exchanger 134 may optionally be adapted to transmit gaseous heat exchange fluids (e.g., steam) therein, with a plurality of condensate lines being included to receive condensed heat exchange fluids produced, e.g., from the transfer of heat to air 22 in compressor inlet 24. In this case, pre-filter heat exchanger 134 may also be coupled to a condensate line 138 for transmitting liquefied heat exchange fluids directly to inlet return line 118 without passing through inlet heat exchanger 116. Condensate line 138 can allow apparatus 100 to transmit only gaseous heat exchange fluids (e.g., steam) to inlet heat exchanger 116 to further increase the temperature of air 22 in compressor inlet 24.

[0037] Apparatus 100 may also include one or more features described elsewhere herein relative to alternative configurations. Apparatus 100 may include bypass line 130 and bypass valve 132 therein for controlling an amount of extracted fluids transmitted directly to outlet heat exchanger 102. When bypass valve 132 is opened, heat exchange fluids can pass through bypass line 130 without passing through inlet heat exchanger 116 and/or pre-filter heat exchanger 134. In this case, bypass line 130 may allow a user to reduce or prevent heat transfer from extracted heat exchange fluids to air 22 of compressor inlet 24. Bypass valve 132 may be partially or fully closed, e.g., when gas turbine 10 operates in at a startup load and no heat exchange with compressor inlet 24 is desired. Bypass valve 132 may be opened in situations where gas turbine 10 operates at a reduced, non-startup load in which a user may desire to increase the temperature of air 22 in compressor inlet 24 while decreasing the temperature of flue gases 30 in turbine outlet 26, e.g., at transition duct 28.

[0038] Apparatus 100 may also be configured to prevent further extraction of heat exchange fluids from HRSG 40 and/or operation of at heat exchangers 102, 116, 134 when gas turbine 10 operates at base load. As described elsewhere

herein, apparatus 100 can include drain line 124 and drain valve 126 for controlling a flow of heat exchange fluid from outlet heat exchanger 102 to drain 128. When gas turbine 10 operates at its base load, a user may open drain valve 126 and close one or more other valves 108, 110, 114, such that any remaining fluids in outlet heat exchanger 102 are transmitted to drain 128 and removed from apparatus 100, e.g., without returning to HRSG 40. In this case, a user can prevent further extraction of heat exchange fluids from HRSG 40 while removing any previously extracted fluids from apparatus 100, and to prevent outlet heat exchanger 102 from being damaged by increased steam pressure.

[0039] Referring to FIG. 7, embodiments of the present disclosure further include structural features of outlet heat exchanger 102, inlet heat exchanger 116, and/or pre-filter heat exchanger 134 positioned within a flowpath 200 for an operative fluid, e.g., air 22 (FIGS. 1, 4-6) or flue gas 30 (FIGS. 1, 4-6). Flowpath 200 may correspond to a portion of compressor inlet 24 (FIGS. 4-6) or turbine outlet 26 (FIGS. 4-6) where heat exchanger(s) 102, 116, 134 are positioned as described elsewhere herein. Each heat exchanger 102, 116, 134 may include a first set (i.e., one or more) tubes 202 positioned at one end and fluidly coupled to a source of heat exchange fluid, e.g., extraction line 104 (FIGS. 4-6), through fluid couplings 205 (e.g., inlets and/or outlets). A plurality of transverse tubes 204 may extend through flowpath 200 for (fluid flow designated by reference lines F), and may also be fluidly coupled to a second set (i.e., one or more) tubes 206. Second set of tubes 206 may similarly include fluid couplings 205 (e.g., inlets and/or outlets) for providing a fluid connection to another line for transmitting heat exchange fluid, e.g., return line 106 (FIGS. 4-6). Plurality of transverse tubes 204 may be positioned within flowpath 200 for absorbing heat from or transferring heat to fluids in thermal communication with heat exchanger 102, 116, 134.

[0040] Referring to FIG. 8, additional structural features of heat exchanger(s) 102, 116, 134 are shown. As discussed elsewhere herein, first and second sets of tubes 202, 206 may be fluidly coupled to plurality of transverse tubes 204 in a conventional arrangement, e.g., each transverse tube 204 fluidly connecting to tubes 202, 206 at opposing ends. In addition, further arrangements are contemplated. Heat exchanger(s) 102, 116, 134 may include plurality of transverse tubes 204, each of which may be fluidly coupled to first or second set of tubes 202, 206. First or second set of tubes may include, e.g., transition tubes 210 coupled to two or more tubes in plurality of transverse tubes 204. Each transition tube 210 can be shaped such that fluid exiting one tube passes into another tube in plurality of transverse tubes 204. Transition tubes 210 can extend the total flowpath of heat exchange fluids through transverse tubes 204, before reaching first or second set of tubes 202, 206.

[0041] Terminal tubes 212 may also be connected to one or more tubes in plurality of transverse tubes 204, with each terminal tube 212 including a fluid coupling 205 for acting as a fluid inlet to or outlet from heat exchanger(s) 102, 116, 134. In some cases, terminal tubes 212 may connect to multiple tubes in plurality of transverse tubes 204, with fluid coupling 205 acting as an outlet for collecting and diverting only a portion of heat exchange fluids therein. For instance, a condensed liquid in heat exchange fluid may exit heat exchanger(s) 102, 116, 134 through fluid coupling 205 (e.g., to condensate line 138 (FIG. 6)) in one or more terminal tubes 212. A non-condensed remainder of the heat exchange

fluids can continue to flow through downstream tubes in plurality of transverse tubes 204.

[0042] Returning to FIGS. 5-6, embodiments of the present disclosure can provide methods for heating inlet 24 of gas turbine 10 and cooling outlet 26 of gas turbine 10 at varying loads, e.g., by using heat exchange fluids extracted from HRSG 40 to apparatus 100. In an embodiment, a user may operate gas turbine 10 at a startup load or a reduced load, in which gas turbine 10 produces a reduced power output relative to its base load. As discussed elsewhere herein, the startup load may include a time period in which gas turbine 10 transitions from being shut down until reaching its base load or another output. A reduced load may refer to any operation of gas turbine 10 in which the amount of power produced is less than a predetermined amount for its base load. During operation of gas turbine 10 at a startup or reduced load, methods according to the present disclosure can include extracting a heat exchange fluid (e.g., water or steam) from HRSG 40, e.g., through extraction line 104. The extracted heat exchange fluid can then be transmitted to outlet heat exchanger 102 positioned within transition duct 28, where the composition of outlet heat exchanger 102 can allow transfer of heat from flue gas 30 in transition duct 28 to heat exchange fluids in outlet heat exchanger 102. Transmitting heat exchange fluids through outlet heat exchanger 102 to absorb heat from flue gas 30 can yield a heated fluid, which then may be transmitted (e.g., through return line 106) to HRSG 40.

[0043] The present disclosure can include further processes dependent upon the operating mode of gas turbine 10 and/or the relative temperatures within compressor inlet 24 and/or turbine outlet 26. In the event that gas turbine 10 begins to operate at its base load, further heat exchange within transition duct 28 may not significantly contribute to the total efficiency and/or thermal balance of gas turbine 10. To address this situation, a user of apparatus 100 may close extraction valve 108 and/or similar components to cease extraction of heat exchange fluids from HRSG 40. In addition, a user may open drain valve 126 to cause any heat exchange fluids remaining in outlet heat exchanger 102 to be drained through drain line 124 and drain 128.

[0044] Additional processes may pertain to when gas turbine 10 operates at a reduced load. At reduced loads, an operator of gas turbine 10 may desire to further increase the temperature of air 22 in compressor inlet 24 in addition to cooling flue gases 30 passing through turbine outlet 26, e.g., at transition duct 28. For example, at least a portion of heat exchange fluid extracted from HRSG 40 may be transmitted to inlet heat exchanger 116 and/or pre-filter heat exchanger 134 to increase the temperature of air 22 within compressor inlet 24. Heat exchange fluids extracted from HRSG 40 may be transmitted to inlet heat exchanger 116 and/or pre-filter heat exchanger 134 before being transferred to outlet heat exchanger 102 as discussed elsewhere herein. Inlet heat exchanger 116 may be positioned within compressor inlet 24 downstream from silencer 120 and/or filter 122, while pre-filter heat exchanger 134 may be positioned within compressor inlet 24 upstream from silencer 120 and/or filter 122. Where pre-filter heat exchanger 134 is fluidly coupled to extraction line 104 through condensate line 138, methods according to the present disclosure may include transmitting a condensed portion of the extracted heat exchange fluid (e.g., water) directly to outlet heat exchanger 102 through condensate line 138.

[0045] Embodiments of the present disclosure may offer several commercial and/or technical advantages. Some advantages offered by implementing embodiments of the present disclosure are discussed herein. For example, apparatuses according to the present disclosure may be effective for reducing any differences in temperature between a compressor inlet and a turbine outlet of a gas turbine during operation of the gas turbine at a startup load or a reduced load. Embodiments of the present disclosure can furthermore be adjusted and/or disabled in response to the gas turbine transitioning to its base load. Furthermore, embodiments of the present disclosure can allow an operator to further increase the temperature of fluids entering a compressor inlet, and/or reduce the temperature of flue gases in a transition duct of a turbine outlet to accommodate more stringent temperature specifications for a reduced load. The various embodiments described herein can use heat exchange fluids extracted from an HRSG for further improving the operation of a gas turbine, before those fluids are returned to the HRSG for use in a steam turbine and/or other component of a combined-cycle power plant system.

[0046] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the disclosure. As used herein, the singular forms “a,” “an,” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0047] This written description uses examples to disclose the invention, including the best mode, and 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 language of the claims.

What is claimed is:

1. An apparatus comprising:

an outlet heat exchanger positioned within a transition duct of a turbine outlet of a gas turbine, wherein the transition duct is positioned upstream from a heat recovery steam generator (HRSG);

an extraction line fluidly connecting the outlet heat exchanger to the HRSG, such that a heat exchange fluid flows from the HRSG to the outlet heat exchanger through the extraction line; and

a return line fluidly connecting the outlet heat exchanger to the HRSG, such that the heat exchange fluid returns to the HRSG through the return line after passing through the outlet heat exchanger.

2. The apparatus of claim 1, further comprising an inlet heat exchanger positioned within an inlet to the compressor of the gas turbine and fluidly coupled to the extraction line through an inlet line, such that the heat exchange fluid passes

through the inlet line and the inlet heat exchanger before entering the outlet heat exchanger.

3. The apparatus of claim 1, wherein the transition duct receives a flue gas from a diffusor component of the turbine outlet, such that the outlet heat exchanger is in thermal communication with the flue gas.

4. The apparatus of claim 1, further comprising a drain line fluidly coupled between the outlet heat exchanger and a drain, wherein the drain line includes a drain valve for controlling a flow of the heat exchange fluid from the outlet heat exchanger into the drain.

5. The apparatus of claim 1, further comprising a bypass line fluidly coupling the extraction line to the return line, wherein the bypass line includes a bypass valve for controlling a flow of the heat exchange fluid from the extraction line into the return line to bypass the outlet heat exchanger.

6. The apparatus of claim 1, wherein the outlet heat exchanger includes a plurality of tubes each extending between the extraction line and the return line.

7. The apparatus of claim 1, wherein a material composition of the outlet heat exchanger includes one of a steel or a nickel-based alloy.

8. An apparatus comprising:

an inlet heat exchanger positioned within a compressor inlet of a gas turbine;

an outlet heat exchanger positioned within a transition duct of a turbine outlet of the gas turbine, wherein the transition duct is positioned upstream from a recovery steam generator (HRSG);

an extraction line fluidly coupling the inlet heat exchanger to the heat recovery steam generator (HRSG);

an inlet return line fluidly coupling the inlet heat exchanger to the outlet heat exchanger; and

a return line fluidly coupling the outlet heat exchanger to the HRSG.

9. The apparatus of claim 8, further comprising a pre-filter heat exchanger fluidly coupled between the extraction line and the inlet heat exchanger, the pre-filter heat exchanger being positioned within the compressor inlet upstream from each of a silencer and a filter of the gas turbine, wherein the inlet heat exchanger is positioned downstream from the silencer and the filter of the gas turbine.

10. The apparatus of claim 9, further comprising a condensate line fluidly coupling the pre-filter heat exchanger to the return line, wherein the condensate line transmits a condensed heat exchange fluid in the pre-filter heat exchanger directly to the return line.

11. The apparatus of claim 10, wherein the pre-filter heat exchanger includes a plurality of heating pipes each extending between the extraction line and the condensate line.

12. The apparatus of claim 8, further comprising a drain line fluidly coupled between the outlet heat exchanger and a drain, wherein the drain line includes a drain valve for

controlling a flow of the heat exchange fluid from the outlet heat exchanger into the drain.

13. The apparatus of claim 8, further comprising a bypass line fluidly coupling the extraction line to the inlet return line, wherein the bypass line includes a bypass valve for controlling a flow of the heat exchange fluid from the extraction line into the inlet return line to bypass the inlet heat exchanger.

14. The apparatus of claim 8, wherein a material composition of the inlet and outlet heat exchangers includes one of a steel or a nickel-based alloy.

15. A method for cooling a gas turbine at varying loads, the gas turbine including a compressor inlet and a turbine outlet, wherein the turbine outlet further includes a transition duct positioned upstream from a heat recovery steam generator (HRSG), the method comprising:

operating the gas turbine at one of a startup load and a reduced load, the startup load and the reduced load having a reduced power output relative to a base load of the gas turbine;

extracting a heat exchange fluid from the HRSG through an extraction line;

transmitting the extracted heat exchange fluid through the extraction line to an outlet heat exchanger positioned within the transition duct of the turbine outlet to yield a heated fluid; and

transmitting the heated fluid through a return line to the HRSG.

16. The method of claim 15, further comprising draining the heat exchange fluid from the outlet heat exchanger during operation of the gas turbine at the base load.

17. The method of claim 15, further comprising, in response to operating the gas turbine at the reduced load, transmitting the extracted heat exchange fluid to at least one inlet heat exchanger positioned within the compressor inlet of the gas turbine through an inlet line, before transmitting the extracted heat exchange fluid to the outlet heat exchanger through the extraction line.

18. The method of claim 17, wherein the at least one inlet heat exchanger includes a pre-filter heat exchanger in thermal communication with the compressor inlet, and positioned within the inlet to the compressor upstream from a filter and a silencer of the gas turbine.

19. The method of claim 17, further comprising transmitting a condensed portion of the extracted heat exchange fluid from the pre-filter heat exchanger directly to the outlet heat exchanger through a condensate line.

20. The method of claim 15, wherein the transition duct receives a flue gas from a diffusor component of the turbine outlet, such that the outlet heat exchanger is in thermal communication with the flue gas.

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