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(54) TURBOMACHINE ASSEMBLY FOR RECOVERING WASTE HEAT AND METHOD OF USING SAME

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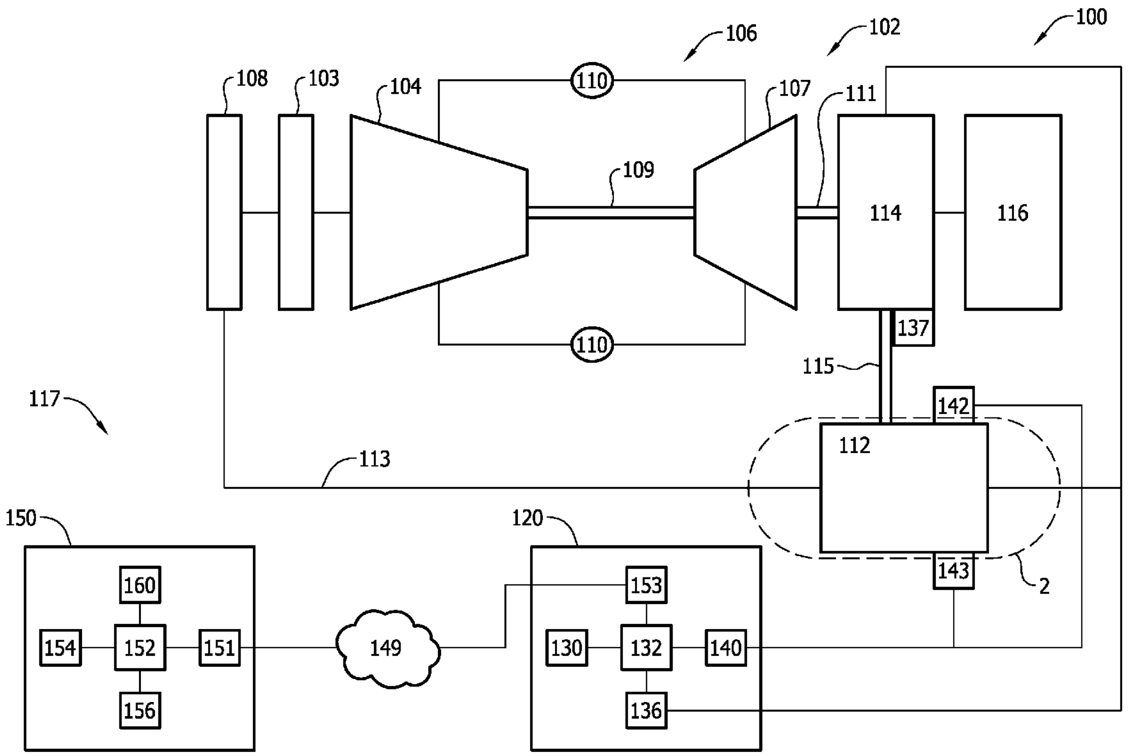
(57) **ABSTRACT**

A turbomachine assembly for recovering waste heat generally has a compressor section that is configured to generate a compressed fluid flow and to channel the compressed fluid flow within the turbomachine assembly. A turbine section is coupled to the compressor section via a rotating member such that portions of the rotating member are located within the compressor section and the turbine section, respectively. The turbine section is in flow communication with the compressor section such that the compressed fluid flow is received by the turbine section. At least one heat exchanger is positioned at least partly within the turbine section where the heat exchanger receives waste heat energy. The heat exchanger transfers energy from the waste heat into the compressed fluid flow to increase at least one parameter of the compressed fluid flow contributing to the generation of a power output.



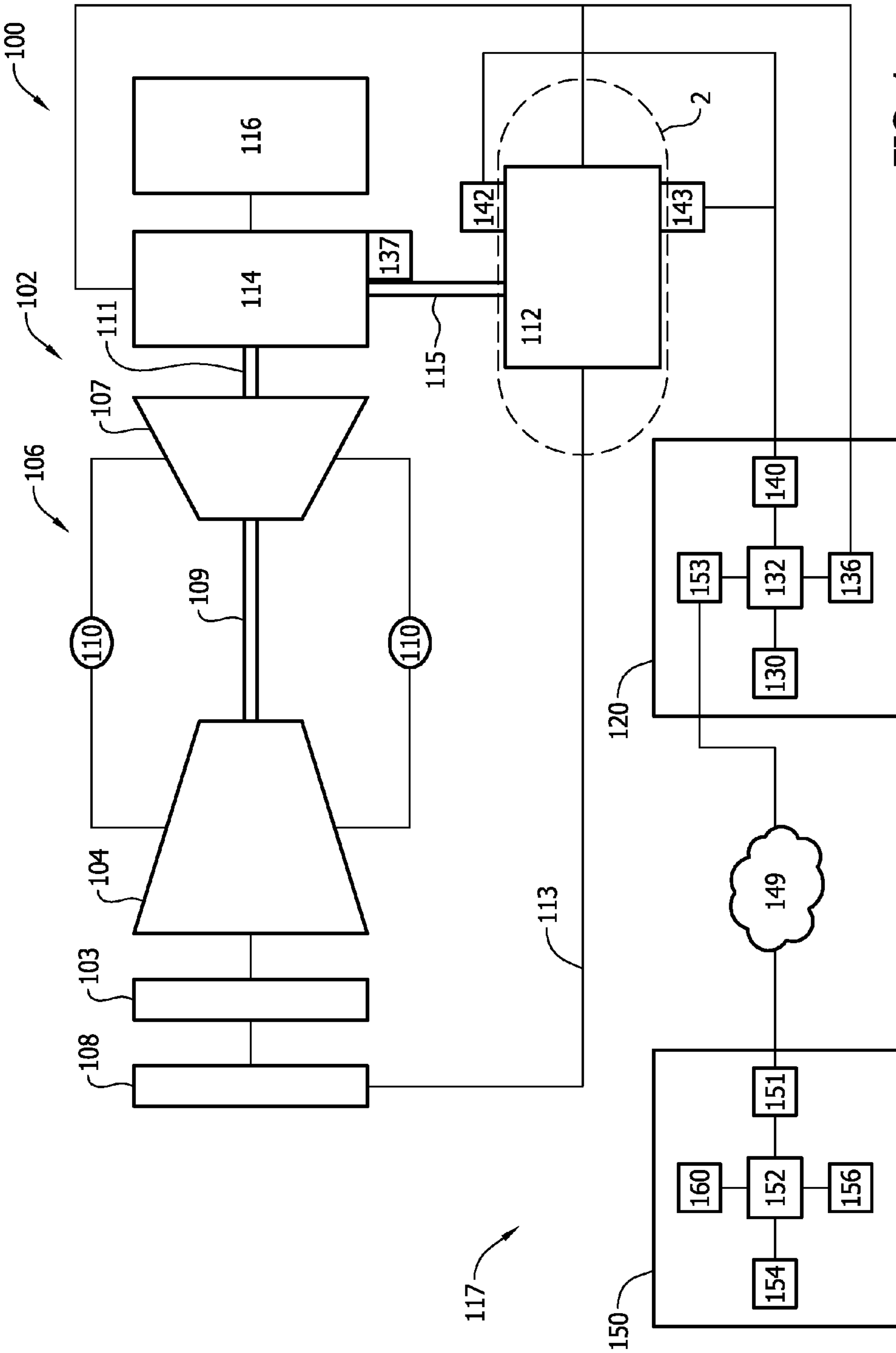

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FIG. 1

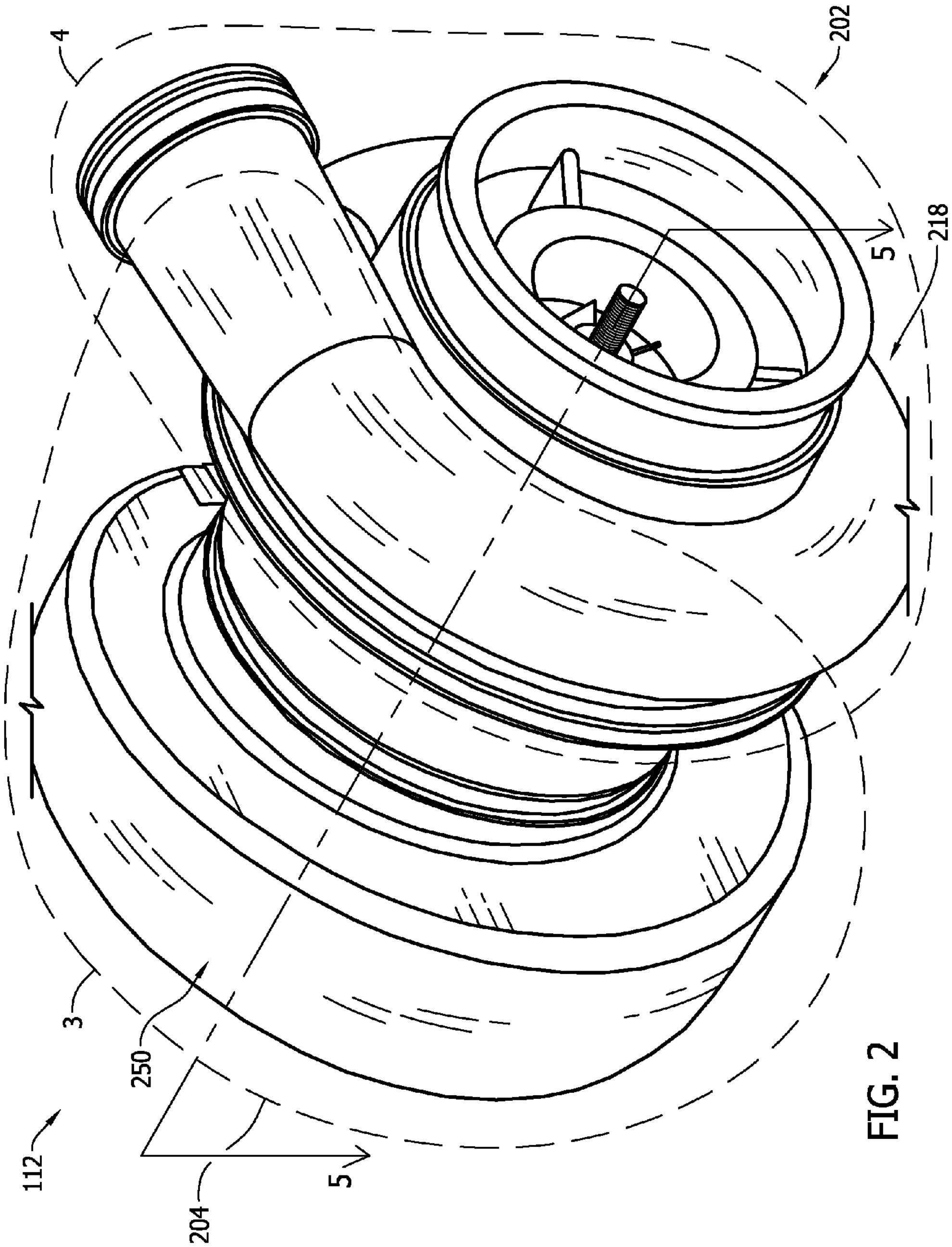

FIG. 2

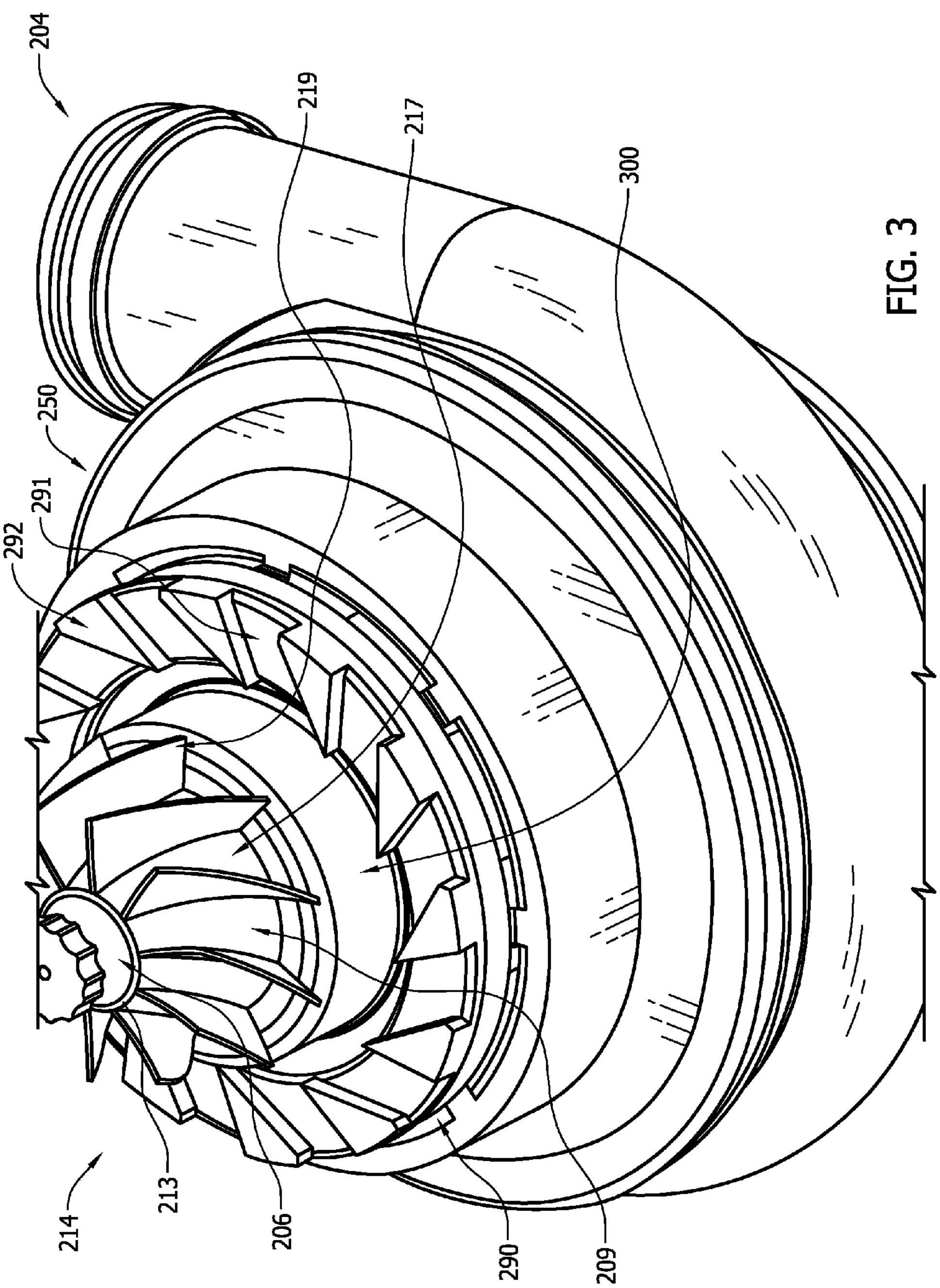

FIG. 3

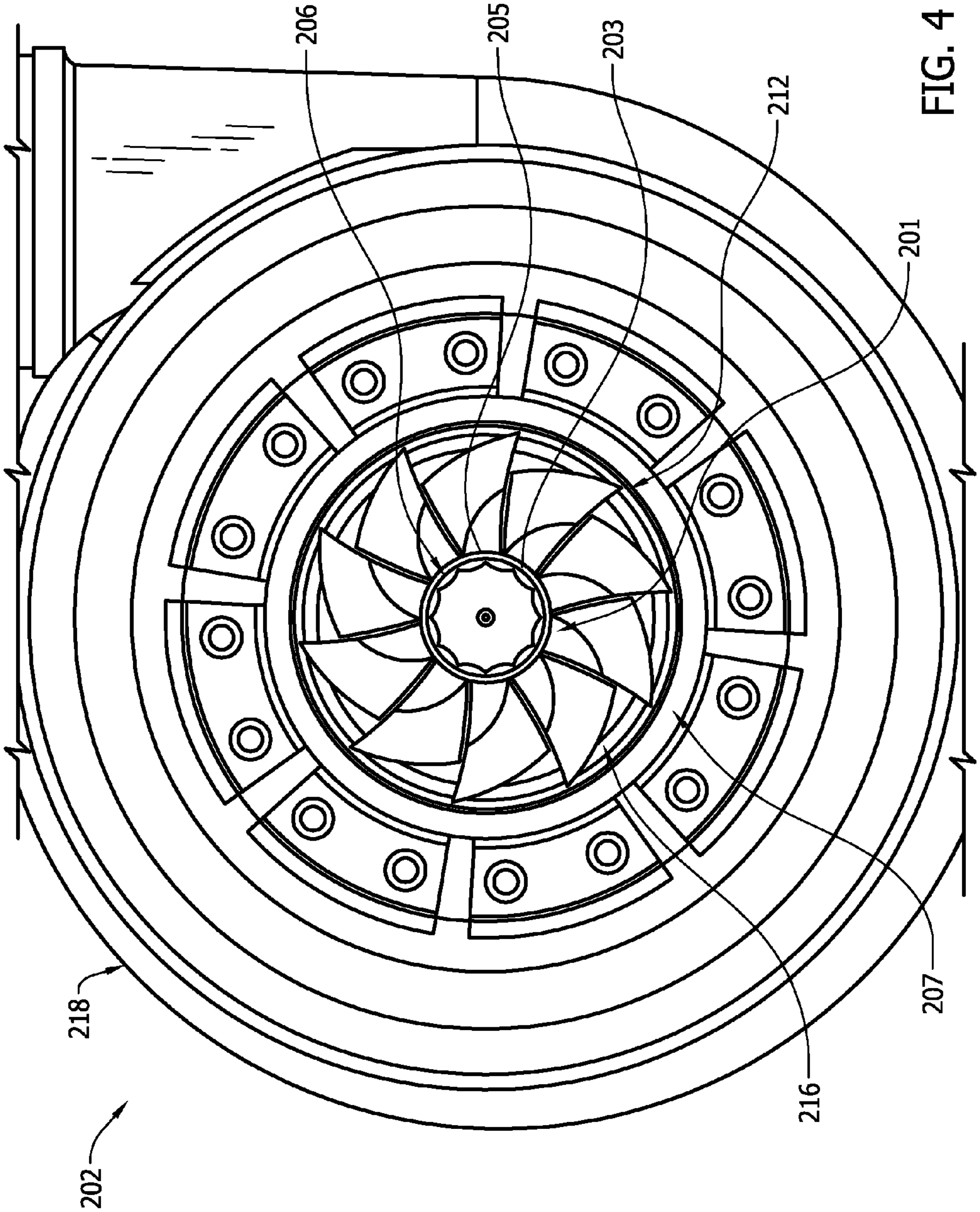

FIG. 4

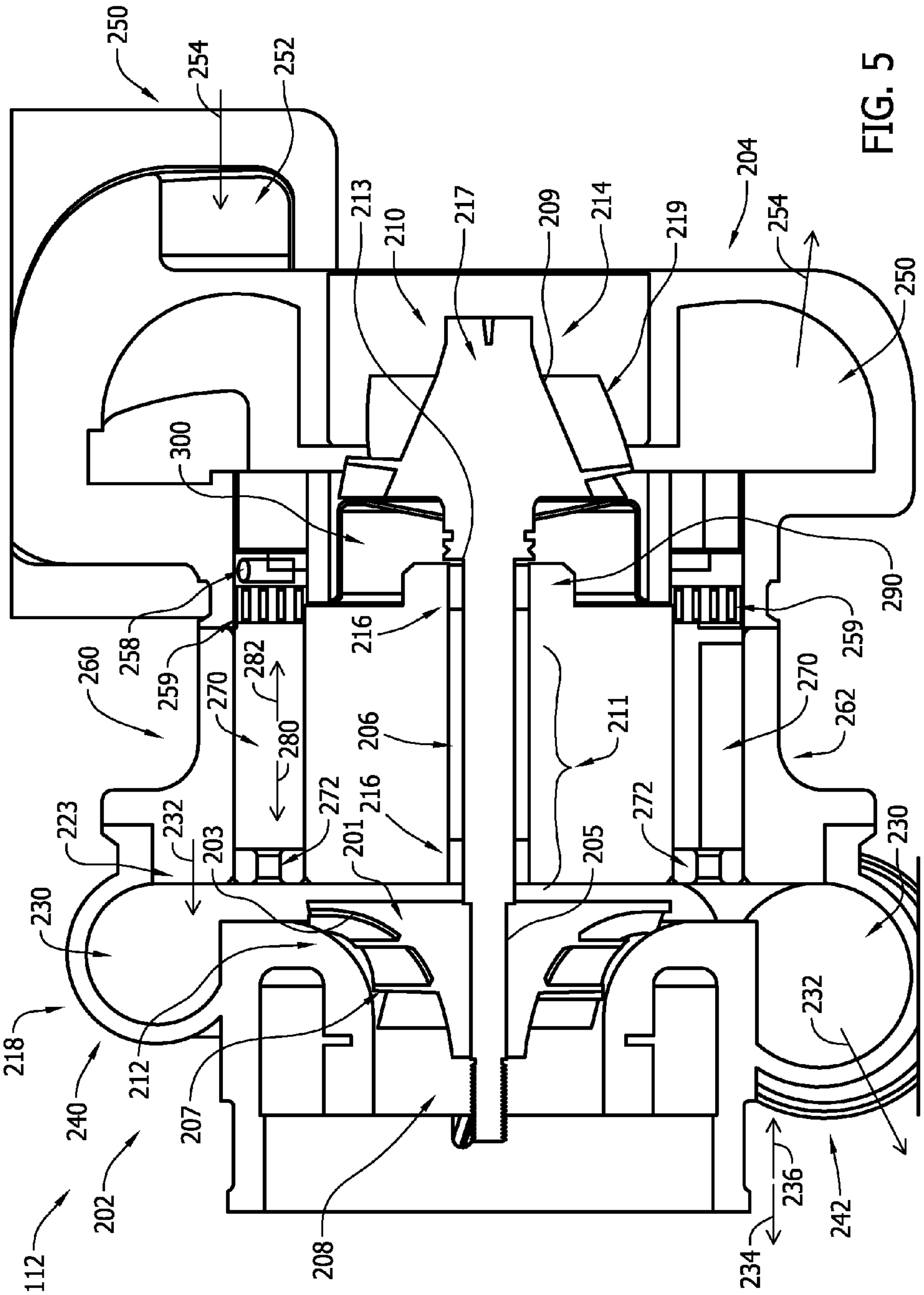

FIG. 5

TURBOMACHINE ASSEMBLY FOR RECOVERING WASTE HEAT AND METHOD OF USING SAME

BACKGROUND

[0001] The field of the invention relates generally to power systems and, more particularly, to a turbomachine assembly that may be used for recovering waste heat energy from a power system for power generation.

[0002] At least some known power systems use at least one machine that is coupled to a load for the generation of a power output. The machine may be a turbomachine, such as a turbine engine, that generates mechanical torque. The load may be an electrical system, such as an electrical generator or inverter, which converts the mechanical energy to electrical energy for the power output. The load may also be coupled to an energy storage device such that some of the power output may be stored for later use. For example, at least some known power systems provide bi-directional or multi-directional electrical energy or power flow, wherein the power output from the load may be transferred to the turbine engine to power the turbine engine or the power output may be delivered to, for example, the energy storage device for storage.

[0003] At least some known power systems generate relatively large amounts of waste heat energy. For example, the turbomachines that may be used with power systems include gas turbine engines that generate waste heat energy in the form of exhaust gases. Due to environmental concerns and/or laws that companies need to adhere to, power systems may be configured to recover and reuse the waste heat energy. For example, at least some known power systems use waste heat recovery systems or assemblies that include using the turbomachines to recover and reuse the waste heat.

[0004] However, using the turbomachines themselves to recover the waste heat can be complex. For example, externally located heat exchangers may need to be installed, along with the necessary externally located piping and control valves. Such installation may take a considerable amount of time and labor. Moreover, in some circumstances, the turbomachine may need to be dismantled and reassembled for the installation of the heat exchangers and piping.

BRIEF DESCRIPTION

[0005] In an exemplary embodiment, a turbomachine assembly for recovering waste heat is provided. The turbomachine assembly generally comprises a compressor section that is configured to generate a compressed fluid flow and to channel the compressed fluid flow within the turbomachine assembly. A turbine section is coupled to the compressor section via a rotating member such that a first portion of the rotating member is positioned within the compressor section and a second portion of the rotating member is positioned within the turbine section. The turbine section is in flow communication with the compressor section such that the compressed fluid flow is received by the turbine section. At least one heat exchanger is positioned at least partly within the turbine section. The heat exchanger is configured to receive waste heat and to transmit energy from the waste heat into the compressed fluid flow to increase at least one parameter, such as pressure, temperature, or flow rate, of the compressed fluid flow contributing to the generation of a power output.

[0006] In another embodiment, a power system is provided. The power system generally comprises a load apparatus that includes a load configured to convert mechanical rotational energy to electrical energy for a power output. The power system also includes a turbomachine assembly that is coupled to the load apparatus. The turbomachine assembly includes a compressor section that is configured to generate a compressed fluid flow and to channel the compressed fluid flow within the turbomachine assembly. A turbine section is coupled to the compressor section via a rotating member such that a first end portion of the rotating member is positioned within the compressor section and a second end portion of the rotating member is positioned within the turbine section. The turbine section is in flow communication with the compressor section such that the compressed fluid flow is received by the turbine section. At least one heat exchanger is positioned at least partly within the turbine section. The heat exchanger is configured to receive waste heat and to transmit energy from the waste heat into the compressed fluid flow so as to increase at least one parameter, such as pressure, temperature, or flow rate, of the compressed fluid flow and thereby facilitate the generation of the power output.

[0007] In yet another embodiment, a method of using a turbomachine assembly for recovering waste heat is provided. The method generally comprises providing a compressor section that is configured to generate a compressed fluid flow. A turbine section is coupled to the compressor section via a rotating member such that a first end portion of the rotating member is positioned within the compressor section and a second end portion of the rotating member is positioned within the turbine section. The turbine section is in flow communication with the compressor section. At least one heat exchanger is positioned at least partly within the turbine section. The compressed fluid flow is channeled from the compressor section to the turbine section. The heat exchanger is used to receive waste heat. Energy from the waste heat is transmitted, via the heat exchanger, into the compressed fluid flow to increase at least one parameter, such as pressure, temperature, or flow rate, of the compressed fluid flow contributing to the generation of a power output.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. **1** is a block diagram of an exemplary power system;

[0009] FIG. **2** is a perspective view of a portion of an exemplary turbomachine assembly that may be used with the power system shown in FIG. **1** and taken from area **2**;

[0010] FIG. **3** is a perspective view of a portion of the turbomachine assembly shown in FIG. **2** and taken from area **3**;

[0011] FIG. **4** is a side view of a portion of the turbomachine assembly shown in FIG. **2** and taken from area **4**; and

[0012] FIG. **5** is a cross-sectional view of a portion of the turbomachine assembly shown in FIG. **2** and taken along line **5-5**.

DETAILED DESCRIPTION

[0013] The exemplary systems and methods described herein provide a turbomachine assembly for use in a power system that may be coupled to other components/machines within the power system and the turbomachine assembly is configured to recover waste heat from within the power system, such as from the attached machine, wherein the recovered waste heat can be used for power generation. The turbomachine assembly includes a compressor section that is configured to generate a compressed fluid flow and a turbine section that is in flow communication with the compressor section and configured to receive the compressed fluid flow. At least one heat exchanger is positioned at least partly within the turbine section, wherein the heat exchanger is configured to receive waste heat and to transmit energy from the waste heat into the compressed fluid flow to increase at least one parameter of the compressed fluid flow such that the waste heat contributes to the power output. Accordingly, the turbomachine assembly is configured such that waste heat can be relatively easily recovered by the turbomachine assembly and used in the process of power generation. By using a turbomachine assembly that is configured to recover and use waste heat, a user would not need to install externally located heat exchangers, along with the necessary externally located piping and control valves in order for the power system to be able to recover and reuse waste heat therein. Moreover, any existing machines within the system may not need to be taken apart or reassembled.

[0014] FIG. **1** illustrates an exemplary power system **100**. Although the exemplary embodiment illustrates a power system, the present disclosure is not limited to power systems, and one of ordinary skill in the art will appreciate that the current disclosure may be used in connection with any type of system. In the exemplary embodiment, power system **100** includes a machine **102**. More specifically, in the exemplary embodiment, machine **102** is a gas turbine engine. While the exemplary embodiment includes a gas turbine engine, the present disclosure is not limited to any one particular type of machine, and one of ordinary skill in the art will appreciate that the current disclosure may be used in connection with other types of machines. For example, machine **102** may be a compressor, a pump, a turbocharger, and/or various types of turbines.

[0015] Moreover, in the exemplary embodiment, machine **102** includes an intake section **103**, a compressor section **104** coupled downstream from intake section **105**, a combustor section **106** coupled downstream from compressor section **104**, a turbine section **107** coupled downstream from combustor section **106**, and an exhaust section **108**. It should be noted that, as used herein, the term "couple" is not limited to a direct or immediately sequential mechanical, thermal, flow communication, and/or an electrical connection between components, but may also include an indirect mechanical, thermal, flow communication and/or electrical connection between multiple components or through components that are placed between the coupled elements.

[0016] Turbine section **107**, in the exemplary embodiment, is coupled to compressor section **104** via a drive shaft **109**. In the exemplary embodiment, combustor section **106** includes a plurality of combustors **110**. Combustor section **106** is coupled to compressor section **104** such that each combustor **110** is positioned in flow communication with compressor section **104**. Machine **102**, in the exemplary embodiment, is coupled to a turbomachine assembly **112** and to a load apparatus **114**. More specifically, in the exemplary embodiment, turbine section **107** of machine **102** is coupled to load apparatus **114** via a rotor shaft **111** and exhaust section **108** of machine **102** is coupled to a turbomachine assembly **112** via a fluid conduit **113**.

[0017] In the exemplary embodiment, turbomachine assembly **112** includes a compressor section (not shown in FIG. **1**), a turbine section (not shown in FIG. **1**) coupled downstream from the compressor section via a turbomachine assembly rotor shaft (not shown in FIG. **1**), and a center section positioned between the compressor and turbine sections (not shown in FIG. **1**). In one embodiment, turbomachine assembly **112** may include an energy source (not shown) and an energy injection system, such as a combustible fuel source and a fuel injection assembly, to facilitate powering turbomachine assembly **112**. For example, a burner (not shown in FIG. **1**) may be positioned proximate to the turbine section and/or a combustor (not shown) may be positioned in the center section. The fuel source may then channel fuel, via the fuel injection assembly, to the burner and/or to the combustor such that the energy can be used to facilitate generating combustion gases that can be used by the turbine section of turbomachine assembly **112**.

[0018] Turbomachine assembly **112** is coupled to load apparatus **114** via a shaft **115**. Load apparatus **114**, in the exemplary embodiment, includes a load (not shown) such as an electrical system, in particular a high speed electrical generator or inverter. More specifically, in the exemplary embodiment, load apparatus **114** can comprise the load apparatus described in co-pending U.S. patent application Ser. No. 13/682,313 entitled LOAD APPARATUS AND METHOD OF USING SAME (attorney docket no. 31938-6) filed Jan. 29, 2013, which is incorporated herein by reference in its entirety. Load apparatus **114** can be coupled to an energy storage device **116**, such as a battery.

[0019] Power system **100** also includes a control system **117** that is coupled to each of load apparatus **114** and turbomachine assembly **112**. Control system **117**, in the exemplary embodiment, is configured to control the power output produced by load apparatus **114** and to control fluid flow within turbomachine assembly **112**. In the exemplary embodiment, control system **117** includes a controller **120** that is operatively coupled to vary the operation of load apparatus **114** and turbomachine assembly **112**, as a function of values determined from sensors (not shown) responsive to parameters such as flow rates, rotational speed, local pressures, torque, temperatures and the like, as well as rates of change of such parameters, according to a programmed control scheme or algorithm. More specifically, controller **120** may be coupled to, for example, at least one valve (not shown) in load apparatus **114** and at least one valve (not shown in FIG. **1**) in turbomachine assembly **112**. Controller **120** is enabled to facilitate operative features of the valves, via features that include, without limitation, receiving permissive inputs, transmitting permissive outputs, and transmitting opening and closing commands.

[0020] In the exemplary embodiment, controller **120** may be a real-time controller and may include any suitable processor-based or microprocessor-based system, such as a computer system, that includes microcontrollers, reduced instruction set circuits (RISC), application-specific integrated circuits (ASICs), logic circuits, and/or any other circuit or processor that is capable of executing the functions described herein. In one embodiment, controller **120** may be a microprocessor that includes read-only memory (ROM) and/or random access memory (RAM), such as, for example, a 32 bit microcomputer with 2 Mbit ROM and 64 Kbit RAM. As used herein, the term "real-time" refers to outcomes occurring in a substantially short period of time after a change in the inputs affect the outcome, with the time period being a design parameter that may be selected based on the importance of the outcome and/or the capability of the system processing the inputs to generate the outcome.

[0021] Controller **120**, in the exemplary embodiment, includes a memory device **130** that stores executable instructions and/or one or more operating parameters representing and/or indicating an operating condition of load apparatus **114** and of turbomachine assembly **112**. Controller **120** also includes a processor **132** that is coupled to the memory device **130** via a system bus **134**. In one embodiment, processor **132** may include a processing unit, such as, without limitation, an integrated circuit (IC), an application specific integrated circuit (ASIC), a microcomputer, a programmable logic controller (PLC), and/or any other programmable circuit. Alternatively, processor **132** may include multiple processing units (e.g., in a multi-core configuration). The above examples are exemplary only, and thus are not intended to limit in any way the definition and/or meaning of the term "processor."

[0022] Moreover, in the exemplary embodiment, controller **120** includes a control interface **136** that is coupled to turbomachine assembly **112** and to load apparatus **114**. More specifically, control interface **136** is coupled to the valves within turbomachine assembly **112** and within load apparatus **114**, and control interface **136** is configured to control an operation of the valves. For example, processor **132** may be programmed to generate one or more control parameters that are transmitted to control interface **136**. Control interface **136** may then transmit a control parameter to modulate, open, or close the valves.

[0023] Various connections are available between control interface **136** and turbomachine assembly **112** and load apparatus **114**. Such connections may include, without limitation, an electrical conductor, a low-level serial data connection, such as Recommended Standard (RS) **232** or RS-485, a high-level serial data connection, such as USB, a field bus, a PROFIBUS®, or Institute of Electrical and Electronics Engineers (IEEE) 1394 (a/k/a FIREWIRE), a parallel data connection, such as IEEE 1284 or IEEE 488, a short-range wireless communication channel such as BLUETOOTH, and/or a private (e.g., inaccessible outside power system **100**) network connection, whether wired or wireless. PROFIBUS is a registered trademark of Profibus Trade Organization of Scottsdale, Ariz. IEEE is a registered trademark of the Institute of Electrical and Electronics Engineers, Inc., of New York, N.Y. BLUETOOTH is a registered trademark of Bluetooth SIG, Inc. of Kirkland, Wash.

[0024] In the exemplary embodiment, control system **117** also includes at least one sensor **137** that is coupled to load apparatus **104** and to controller **120**. More specifically, in the exemplary embodiment, controller **120** includes a sensor interface **140** that is coupled to sensor **137**. In the exemplary embodiment, sensor **137** is positioned in close proximity to, and coupled to at least a portion of load apparatus **114**. Alternatively, sensor **137** may be coupled to various other components within power system **100**. In the exemplary embodiment, sensor **137** is configured to detect the level of the power output being produced by load apparatus **114**. Alternatively, sensor **137** may detect various other operating parameters that enable load apparatus **114** and/or power system **100** to function as described herein.

[0025] Control system **117** also includes at least two sensors **142** and **143** that are each coupled to turbomachine assembly **112** and to controller **120**. In the exemplary embodiment, sensors **142** and **143** are each positioned in close proximity to, and coupled to at least a portion of turbomachine assembly **112** and to sensor interface **140**. More specifically, sensor **142** is coupled to the compressor section and sensor **143** is coupled to the turbine section of turbomachine assembly **112**. In the exemplary embodiment, sensors **142** and **143** are each configured to detect various operating parameters, such as temperature and/or flow rate, within the compressor section and the turbine section, respectively.

[0026] Sensors **137**, **142**, and **143** each transmit a signal corresponding to their respective detected parameters to controller **120**. Sensors **137**, **142**, and **143** may each transmit a signal continuously, periodically, or only once, for example. Other signal timings may also be contemplated. Furthermore, sensors **137**, **142**, and **143** may each transmit a signal either in an analog form or in a digital form. Various connections are available between sensor interface **140** and sensors **137**, **142**, and **143**. Such connections may include, without limitation, an electrical conductor, a low-level serial data connection, such as RS 232 or RS-485, a high-level serial data connection, such as USB or IEEE® 1394, a parallel data connection, such as IEEE® 1284 or IEEE® 488, a short-range wireless communication channel such as BLUETOOTH®, and/or a private (e.g., inaccessible outside power system **100**) network connection, whether wired or wireless.

[0027] Control system **117** may also include a user computing device **150** that is coupled to controller **120** via a network **149**. More specifically, computing device **150** includes a communication interface **151** that is coupled to a communication interface **153** contained within controller **120**. User computing device **150** includes a processor **152** for executing instructions. In some embodiments, executable instructions are stored in a memory device **154**. Processor **152** may include one or more processing units (e.g., in a multi-core configuration). Memory device **154** is any device allowing information, such as executable instructions and/or other data, to be stored and retrieved.

[0028] User computing device **150** also includes at least one media output component **156** for use in presenting information to a user. Media output component **156** is any component capable of conveying information to the user. Media output component **156** may include, without limitation, a display device (not shown) (e.g., a liquid crystal display (LCD), an organic light emitting diode (OLED) display, or an audio output device (e.g., a speaker or headphones)).

[0029] Moreover, in the exemplary embodiment, user computing device **150** includes an input interface **160** for receiving input from a user. Input interface **160** may include, for example, a keyboard, a pointing device, a mouse, a stylus, a touch sensitive panel (e.g., a touch pad or a touch screen), a gyroscope, an accelerometer, a position detector, and/or an audio input device. A single component, such as a touch screen, may function as both an output device of media output component **156** and input interface **160**.

[0030] During operation, intake section **103** channels air towards compressor section **104** wherein the air is compressed to a higher pressure and temperature prior to being discharged towards combustor section **106**. The compressed air is mixed with fuel and other fluids and ignited to generate combustion gases that are channeled towards turbine section **107**. More specifically, fuel is injected into combustors **110**, and into the air flow, such as natural gas and/or fuel oil, air, diluents, and/or Nitrogen gas (N_2). The blended mixtures are ignited to generate high temperature combustion gases that are channeled towards turbine section **107**. Turbine section **107** converts the thermal energy from the gas stream to mechanical rotational energy, as the combustion gases impart rotational energy to turbine section **107** and to the rotor disk assembly.

[0031] The mechanical rotational energy is converted to electrical energy via load apparatus **114** for a power output. Load apparatus **114** facilitates multi-directional power flow within power system **100** such that the power output from load apparatus **114** may be transferred to either machine **102** or to turbomachine assembly **112** to power each, or the power output may be delivered to, for example, energy storage device **116**. For example, a user may initially input a predefined threshold value for a power output from load apparatus **114** via input interface **160**. The predefined threshold value may be programmed with user computing device **150** and/or controller **120**. As such, when the mechanical rotational energy is converted to electrical energy via load apparatus **114** for a power output, the output is detected by sensor **137**. Sensor **137** then transmits a signal representative of the power output to controller **120**.

[0032] Depending on whether the power output is less than, greater than, or equal to the predefined threshold, controller **120** will transmit a control parameter to the valve within load apparatus **114**. For example, in the exemplary embodiment, if the power output exceeds the predefined threshold, controller **120** will transmit a control parameter to the valve such that electrical energy (i.e. power output) is channeled in a first direction **184** towards energy storage device **110** such that the power output may be stored for later use by power system **100**. If the power output is below the predefined threshold, controller **120** may transmit a control parameter to the valve such that electrical energy is channeled in a second direction **186** towards machine **102** such that the power output may be used by machine **102** to generate more power or in a third direction **188** towards turbomachine assembly **112** such that the power output may be used by turbomachine assembly **112** to generate additional power.

[0033] Moreover, as explained in more detail below with respect to FIGS. **2-5**, power system **100** uses turbomachine assembly **112** to recover waste heat generated within system **100** such that the waste heat contributes to power generation by the power system. For example, during operation of machine **102**, waste heat, such as the exhaust gases, are generated by machine **102** and/or by the turbine section of turbomachine assembly **112**. For example, the exhaust gases from machine **102** can be channeled from exhaust section **108** to turbomachine assembly **112** via conduit **113**. As explained in more detail below with respect to FIGS. **2-5**, the exhaust gases recovered by turbomachine assembly **112** may be used to facilitate additional power output. Control systems **117** controls the fluids being channeled within turbomachine assembly **112**. The fluids being channeled within turbomachine assembly **112** enable the rotor shaft that extends from the compressor section to the turbine section to rotate, thereby facilitating the generation of mechanical rotational energy. The mechanical rotational energy is converted to electrical energy via load apparatus **114** for an additional power output. Accordingly, turbomachine assembly **112** is configured such that waste heat can be relatively easily recovered by turbomachine assembly **112** and used for power generation. By using turbomachine assembly **112**, a user may simply couple turbomachine assembly **112** to machine **102**. The user may not need to install externally located heat exchangers (not shown), along with the necessary externally located piping (not shown) and control valves (not shown), within power system **100** and/or take apart and reassemble machine **102** in order for power system **100** to be able to recover and reuse waste heat therein.

[0034] FIG. **2** is a perspective view of a portion of turbomachine assembly **112** taken from area **2** (shown in FIG. **1**). FIG. **3** is a perspective view of a portion of turbomachine assembly **112** taken from area **3** (shown in FIG. **2**). FIG. **4** is a side view of a portion of turbomachine assembly **112** taken from area **4** (shown in FIG. **2**). FIG. **5** is a cross-sectional view of a portion of turbomachine assembly **112** taken along line **5-5** (shown in FIG. **2**).

[0035] Referring to FIGS. **2** and **5**, turbomachine assembly **112** includes a compressor section **202** and a turbine section **204** coupled to compressor section **202** via a rotor shaft **206** such that turbine section **204** is positioned downstream from compressor section **202** and such that turbine section **204** is in flow communication with compressor section **202**. In the exemplary embodiment, rotor shaft **206** includes a first end portion **208**, a second end portion **210**, and a middle portion **211** therebetween. Rotor shaft **206** extends from compressor section **202** to turbine section **204** such that first end portion **208** of rotor shaft **206** is positioned within compressor section **202** and second end portion **210** of rotor shaft **206** is positioned within turbine section **204**. A compressor rotor **212** substantially circumscribes at least a portion of first end portion **208** and a turbine rotor **214** substantially circumscribes at least a portion of second end portion **210**.

[0036] In the exemplary embodiment, referring to FIGS. **4** and **5**, compressor rotor **212** includes an annular base portion **201** having an exterior surface **203** and an opposing interior surface **205**, wherein interior surface **205** substantially circumscribes at least a portion of first end portion **208** of rotor shaft **206** and a plurality of rotor blades **207** extend radially outwardly from base portion exterior surface **203** such that each blade **207** is substantially perpendicular with respect to exterior surface **203**. Similarly, referring to FIGS. **3** and **5**, turbine rotor **214** includes an annular base portion **217** having an exterior surface **209** and an opposing interior surface **213**, wherein interior surface **213** substantially circumscribes at least a portion of second end portion **210** of rotor shaft **206** and a plurality of rotor blades **219** extend radially outwardly from exterior surface **209** such that each blade **219** is substantially perpendicular with respect to exterior surface **209**. Turbomachine assembly **112** also includes at least two shaft bearings **216** such that one bearing **216** is adjacent to at least a portion of first end portion **208** of rotor shaft **206** and one bearing **216** is adjacent to at least a portion of second end portion **210** of rotor shaft **206**.

[0037] In the exemplary embodiment, first end portion **208**, middle portion **211**, and second end portion **210** of rotor shaft **206** are formed integrally together such that rotor shaft **206** is a single unitary component. Alternatively, one or more of the components of rotor shaft **206** may be formed separate and removably or permanently coupled together. Each of the first end portion **208**, middle portion **211**, and second end portion **210** of rotor shaft **206** may be formed via a variety of manufacturing processes known in the art, such as, but not limited to, molding processes, drawing processes, or machining processes. One or more types of materials may be used to fabricate rotor shaft **206** with the materials selected based on suitability for one or more manufacturing techniques, dimensional stability, cost, moldability, workability, rigidity, and/or other characteristic of the material(s). For example, rotor shaft **206** may be at least partially formed from lightweight and rigid materials, such as an alumina material, a ceramic material, and/or a metal matrix composite material. The metal matrix composite material may include a first metal material and at least one other material, such as a second metal material and/or a ceramic compound. Alternatively, rotor shaft **206** may be formed of any suitable material that enables the turbomachine assembly **112** and/or power system **100** (shown in FIG. **1**) to function as described herein.

[0038] In the exemplary embodiment, compressor section **202** is coupled to load apparatus **114** (shown in FIG. **1**) such that compressor section **202** is directly adjacent to load apparatus **114**. More specifically, first end portion **208** of rotor shaft **206** is coupled to drive shaft **106** (shown in FIG. **1**). Referring to FIGS. **2**, **4**, and **5**, compressor section **202** includes a cover portion **218** that is configured to substantially enclose at least a portion of first end portion **208** of rotor shaft **206** and at least a portion of compressor rotor **212** therein. Cover portion **218** may be formed via a variety of manufacturing processes known in the art, such as, but not limited to, molding processes, drawing processes, or machining processes. One or more types of materials may be used to fabricate cover portion **218** with the materials selected based on suitability for one or more manufacturing techniques, dimensional stability, cost, moldability, workability, rigidity, and/or other characteristic of the material(s). For example, cover portion **218** may be at least partially formed from a metal material.

[0039] Referring to FIG. **5**, compressor section **202** includes a bypass valve **223** coupled to cover portion **218**. More specifically, in the exemplary embodiment, cover portion **218** includes a channel **230** that defines a flow path **232** therein, and bypass valve **223** is positioned within flow path **232**. Channel **230** is in flow communication with a compressor inlet opening **240** and a compressor bypass circuit inlet opening **242**. In the exemplary embodiment, bypass valve **223** is configured to be modulated such that flow path **232** may be opened, closed, or partially opened such that fluid flow may be controlled within flow path **232**. More specifically, bypass valve **223** is configured to be modulated such that fluid flow may be directed in a first direction **234** through bypass circuit inlet opening **242** and towards load apparatus **114** or in a second direction **236** through compressor inlet opening **240** and towards other components within turbomachine assembly **112**.

[0040] Referring to FIGS. **2**, **3**, and **5**, turbine section **204** includes a turbine cover portion **250** that is configured to substantially enclose at least portion of second end portion **210** of rotor shaft **206** and at least a portion of turbine rotor **214** therein. Turbine cover portion **250** may be formed via a variety of manufacturing processes known in the art, such as, but not limited to, molding processes, drawing processes, or machining processes. One or more types of materials may be used to fabricate turbine cover portion **250** with the materials selected based on suitability for one or more manufacturing techniques, dimensional stability, cost, moldability, workability, rigidity, and/or other characteristic of the material(s). For example, turbine cover portion **250** may be at least partially formed from a metal material.

[0041] In the exemplary embodiment, referring to FIG. **5**, turbine cover portion **250** includes a channel **252** that defines a flow path **254** therein such that fluids, such as exhausts being emitted from turbomachine assembly **112** may be channeled through flow path **254**. Moreover, cover portion **250** also includes an opening (not shown) such that channel **252** may be in flow communication with conduit **113** (shown in FIG. **1**) to facilitate the channeling of exhausts from machine **102** to be channeled to turbine section **204** of turbomachine assembly **112**. A burner **258** may be included within turbine section **204**. Nozzle ring **256**, in the exemplary embodiment, may be a stationary nozzle ring that is configured to facilitate the optimization of work energy utilization for turbine rotor **214**.

[0042] Moreover, in the exemplary embodiment, at least one heat exchanger **259** is positioned within turbine section **204**, wherein heat exchanger **259** is configured to receive waste heat, such as exhaust gases, from machine **102** and/or from turbomachine assembly **112**. For example, heat exchanger **259** may be positioned adjacent to the cover portion opening such that exhaust gases being channeled to turbine section **204** from exhaust section **108** of machine **102** may be recovered by heat exchanger **259**. Exhaust gases being generated by turbine section **204** may also be recovered by heat exchanger **259**. In the exemplary embodiment, heat exchanger **259** may be any suitable type of heat exchanger known in the art, such as a compact heat exchanger that is configured to be received and positioned within turbine section **204**.

[0043] Referring to FIGS. **3** and **5**, turbine section **204**, in the exemplary embodiment, also includes an annular nozzle ring **290** that is positioned adjacent to bearing **216**. Nozzle ring **290**, in the exemplary embodiment, may be a stationary nozzle ring that is configured to facilitate the optimization of work energy utilization for turbine rotor **214**. Nozzle ring **290** includes a surface **291** and a plurality of nozzle vanes **292** that extend outwardly from surface **291**. In the exemplary embodiment, nozzle ring **290**, along with surface **291** and vanes **292**, are integrally formed together. Alternatively, nozzle ring **290**, along with surface **291** and vanes **292**, may be formed as separate parts that are removably or permanently coupled together.

[0044] Nozzle ring **290**, along with surface **292** and vanes **292**, may be formed via a variety of manufacturing processes known in the art, such as, but not limited to, molding processes, drawing processes, or machining processes. One or more types of materials may be used to fabricate nozzle ring **290**, along with surface **292** and vanes **292**, with the materials selected based on suitability for one or more manufacturing techniques, dimensional stability, cost, moldability, workability, rigidity, and/or other characteristic of the material(s). For example, nozzle ring **290**, along with surface **292** and vanes **292**, may be at least partially formed from a metal material. Nozzle ring **290**, along with surface **291** and vanes **292**, can be a part of or an extension of turbine cover portion **250**, in which case, nozzle ring **290** may be fabricated of the same material as turbine cover portion **250**. Alternatively, nozzle ring **290**, along with surface **291** and vanes **292**, can be a separate component from turbine cover portion **250**. Moreover, turbine section **204** may also include a heat isolating shield **300** that substantially circumscribes at least a portion of second end portion **210** of rotor shaft **206**. In the exemplary embodiment, heat isolating shield **300** is positioned between nozzle ring **290** and turbine rotor **214**. Heat isolating shield **300** may be fabricated from any suitable material, such as a sheet metal.

[0045] Turbomachine assembly **112** also includes a center section **260** positioned between compressor section **202** and turbine section **204**. A housing assembly **262** substantially encloses at least a portion of center section **260** and is also positioned between compressor section **202** and turbine section **204**. Housing assembly **262**, in the exemplary embodiment, substantially circumscribes at least a portion of middle portion **211** of rotor shaft **206** and encloses components of center section **260** therein. For example, as discussed above, a combustor section (not shown) and/or energy sources (not shown) may be positioned within center section **260** and enclosed by housing assembly **262**.

[0046] Housing assembly **262** may be formed via a variety of manufacturing processes known in the art, such as, but not limited to, molding processes, drawing processes, or machining processes. One or more types of materials may be used to fabricate housing assembly **262** with the materials selected based on suitability for one or more manufacturing techniques, dimensional stability, cost, moldability, workability, rigidity, and/or other characteristic of the material(s). For example, housing assembly **262** may be at least partially formed from a metal material.

[0047] In the exemplary embodiment, housing assembly **262** includes two conduits **270** extending from compressor section **202** to turbine section **204** such that fluid can flow through each of the conduits **270** and be channeled between compressor section **202** and turbine section **204**. Housing assembly **262** also includes at least one regulating valve **272** that is/are each in flow communication with compressor section **202** and turbine section **204**. More specifically, in the exemplary embodiment, housing assembly **262** includes two regulating valves **272** such that each regulating valve **272** is positioned within a separate conduit **270**. Each regulating valve **272** is configured to be modulated such the respective conduit **270** may be opened, closed, or partially opened such that fluid flow may be controlled within each conduit. More specifically, each regulating valve **272** is configured to be modulated such that fluid flow may be directed in a first direction **280** towards compressor section **202** or in a second direction **282** towards turbine section **204**.

[0048] While two regulating valves **272** are included within the exemplary embodiment, housing assembly **262** may have any number of regulating valves **272** that enables turbomachine assembly **112** and/or power system **100** to function as described herein. Moreover, the location of regulating valves **272** are not limited to center section **260**. For example, regulating valve **272** may be positioned within compressor section **202**. More specifically, in some embodiments turbomachine assembly **112** may not have center section **260** included therein. As such, turbomachine assembly **112** would include compressor section **202** and turbine section **204** positioned adjacent to compressor section **202**, and at least one regulating valve **272** would be positioned within compressor section **202**.

[0049] Moreover, as discussed above, turbomachine assembly **112** also includes two shaft bearings **216** such that one bearing **216** is adjacent to at least a portion of first end portion **208** of rotor shaft **206** and one bearing **216** is adjacent to at least a portion of second end portion **210** of rotor shaft **206**. More specifically, each bearing **216** is positioned within center section **260** such that one bearing **216** is adjacent to at least a portion of first end portion **208** of rotor shaft **206** and one bearing **216** is adjacent to at least a portion of second end portion **210** of rotor shaft **206**. While bearings **216** are positioned within center section **260**, bearings are not limited to being positioned within center section **260**. For example, as discussed above, in some embodiments turbomachine assembly **112** may not have center section **260** included therein. As such, turbomachine assembly **112** would include compressor section **202** and turbine section **204** positioned adjacent to compressor section **202**, and one bearing **216** would be positioned within compressor section **202** and another bearing **216** would be positioned within turbine section **204**.

[0050] During operation of power system **100**, machine **102** and at least some portions of turbomachine assembly **112** generate waste heat. More specifically, the combustion gases generated and used by machine **102** to power machine **102** may cause the emission of exhaust gases. More specifically, when fuel such as natural gas and/or fuel oil, air, diluents, and/or Nitrogen gas (N_2), is injected into combustors **110** (shown in FIG. **1**) of machine **102**, and into the compressed air flow, the blended mixtures are ignited to generate high temperature combustion gases that are channeled towards turbine section **107** (shown in FIG. **1**) of machine **102**. While turbine section **107** converts a portion of the thermal energy from the gas stream to mechanical rotational energy, some of the thermal energy is emitted as exhaust gases via exhaust section **108** (shown in FIG. **1**) of machine **102**.

[0051] Similarly, the use of burner **258** within turbine section **204** of turbomachine assembly **112** may cause the generation of exhaust gases from turbine section **204**. For example, with regard to turbomachine assembly **112**, air is channeled to compressor section **202** via inlet opening **240**, wherein the air is compressed to a higher pressure and temperature. The air flows through channel **230** within flow path **232**. At this time, bypass valve **223** is not obstructing flow path **232** such that the air can be channeled in second direction **236** towards center section **260**. The compressed air may then be mixed with fuel and other fluids and ignited to generate combustion gases that are channeled towards turbine section **204**. A combustor (not shown) within center section **260** or burner **258** may ignite the fuel mixture to generate expanding high temperature combustion gases that are channeled towards turbine section **204** such that turbine section **204** can convert the thermal energy from the combustion gas stream to mechanical rotational energy. This process within turbomachine assembly **112** may cause the emission of exhaust gases.

[0052] The exhaust gases emitted by machine **102** can be channeled from exhaust section **108**, via conduit **113**, to turbine section **204** of turbomachine assembly **112**. Heat exchanger **259** can receive and recover the exhaust gases received from exhaust section **108** and/or the exhaust gases generated within turbine section **204**. As additional compressed air is channeled from compressor section **202** to turbine section **204**, energy from the waste heat recovered by heat exchanger **259** can be transmitted by heat exchanger **259** into the compressed air. When the waste heat is applied to the compressed air, the compressed air is energized. More specifically, at least one parameter of the compressed air is substantially increased. For example, the pressure, temperature, the velocity, and/or another aspect of the enthalpy of the compressed air is increased. Burner **258** may provide additional heat to the compressed air combined within the recovered waste heat to further energize the compressed air, such as increasing the temperature of the air.

[0053] The compressed air combined with the waste heat is channeled to nozzle ring **290**, which channels the compressed air combined with the waste heat over turbine rotor **214**. As fluid flow is channeled to turbine section **204**, nozzle ring **290** channels the fluid flow over turbine rotor **214**. In the exemplary embodiment, the shape and configuration of nozzle ring **290** can change the direction of the fluid flow as well accelerate the fluid flow. For example, vanes **292** may direct the fluid flow and facilitate accelerating the fluid flow that is channeled to turbine section **204**. Vanes **292** direct the fluid flow to be channeled over blades **219** to facilitate rotating rotor **214** and shaft **206** such that mechanical rotational energy can be generated. The mechanical rotational energy is converted to electrical energy via load apparatus **114** for a power output. This additional power output may be transferred to either machine **102** or to turbomachine assembly **112** to provide additional power to each, or the power output may be delivered to, for example, energy storage device **116** (shown in FIG. **1**).

[0054] Moreover, the fluid flow within turbomachine assembly **112** may be controlled via control system **117** (shown in FIG. **1**). For example, controller **120** (shown in FIG. **1**) can modulate each of bypass valve **223** and regulating valve **272** to control the flow of the compressed air within turbomachine assembly **114**. There may be additional components included within turbomachine assembly **112** and/or turbomachine assembly **112** may have various other functions. For example, turbomachine assembly **112** can comprise the turbomachine assembly and components therein described in co-pending U.S. patent application Ser. No. ______ entitled TURBOMACHINE ASSEMBLY AND METHOD OF USING SAME (attorney docket no. F9941-00008) filed May, 2013, which is incorporated herein by reference in its entirety.

[0055] As compared to known power systems that are configured to recover waste heat from within the system, the embodiments described herein provide a turbomachine assembly that facilitates an efficient solution to recovering waste heat that does not require a considerable amount of time and labor for installation and any existing machines within the system may not need to be taken apart or reassembled. More specifically, the embodiments described herein provide a turbomachine assembly for use in a power system that may be coupled to other components/machines within the power system and the turbomachine assembly is configured to recover waste heat from within the power system, such as from the attached machine, wherein the recovered waste heat can be used for power generation. The turbomachine assembly includes a compressor section that is configured to generate a compressed fluid flow and a turbine section that is in flow communication with the compressor section and configured to receive the compressed fluid flow. At least one heat exchanger is positioned within the turbine section, wherein the heat exchanger is configured to receive waste heat and to transmit the waste heat into the compressed fluid flow to increase at least one parameter of the compressed fluid flow such that a power output is generated by the waste heat. Accordingly, the turbomachine assembly is configured such that waste heat can be relatively easily recovered by the turbomachine assembly and used for power generation. By using a turbomachine assembly that is configured to recover and use waste heat, a user would not need to install externally located heat exchangers, along with the necessary externally located piping and control valves in order for the power system to be able to recover and reuse waste heat therein. Moreover, any existing machines within the system may not need to be taken apart or reassembled.

[0056] Exemplary embodiments of systems, apparatus, and methods are described above in detail. The systems, apparatus, and methods are not limited to the specific embodiments described herein, but rather, components of each system, apparatus, and/or method may be utilized independently and separately from other components described herein. For example, each system may also be used in combination with other systems and is not limited to practice with only systems as described herein. Rather, the exemplary embodiment can be implemented and utilized in connection with many other applications.

[0057] Although specific features of various embodiments of the invention may be shown in some drawings and not in others, this is for convenience only. In accordance with the principles of the invention, any feature of a drawing may be referenced and/or claimed in combination with any feature of any other drawing.

[0058] 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 language of the claims.

What is claimed is:

1. A turbomachine assembly for recovering waste heat, said turbomachine assembly comprising:

a compressor section configured to generate a compressed fluid flow and to channel the compressed fluid flow within said turbomachine assembly;

a turbine section coupled to said compressor section via a rotating member such that a first portion of the rotating member is positioned within said compressor section and a second portion of the rotating member is positioned within said turbine section, wherein said turbine section is in flow communication with said compressor section such that the compressed fluid flow is received by said turbine section; and

at least one heat exchanger positioned at least partly within said turbine section, wherein said at least one heat exchanger is configured to receive waste heat and to transfer energy from the waste heat into the compressed fluid flow so as to increase at least one parameter of the compressed fluid flow contributing to the generation of a power output.

2. A turbomachine assembly in accordance with claim **1**, wherein said at least one heat exchanger is configured to receive the waste heat from said turbine section.

3. A turbomachine assembly in accordance with claim **1**, wherein said at least one heat exchanger is configured to receive the waste heat from a machine that is coupled to said turbine section.

4. A turbomachine assembly in accordance with claim **1**, further comprising at least one burner positioned within said turbine section, wherein said at least one burner is configured to provide additional heat to the compressed fluid flow combined with the waste heat.

5. A turbomachine assembly in accordance with claim **1**, wherein said turbine section further comprises a rotor comprising an annular base portion that is configured to substantially circumscribe at least a portion of the second end portion of the rotating member, said rotor further comprises a plurality blades extending radially outwardly from a surface of said base portion.

6. A turbomachine assembly in accordance with claim **5**, further comprising at least one nozzle ring positioned within said turbine section, wherein said at least one nozzle ring is configured to channel the compressed fluid flow combined with the waste heat over said rotor to facilitate rotating the rotating member.

7. A turbomachine assembly in accordance with claim **1**, further comprising a center section positioned between said compressor section and said turbine section, wherein said center section includes at least one conduit that is configured to channel the compressed fluid flow from said compressor section to said turbine section.

8. A power system comprising:

a load apparatus comprising a load configured to convert mechanical rotational energy to electrical energy for a power output; and

a turbomachine assembly coupled to said load apparatus, said turbomachine assembly comprises:

a compressor section configured to generate a compressed fluid flow and to channel the compressed fluid flow within said turbomachine assembly;

a turbine section coupled to said compressor section via a rotating member such that a first portion of the rotating member is positioned within said compressor section and a second portion of the rotating member is positioned within said turbine section, wherein said turbine section is in flow communication with said compressor section such that the compressed fluid flow is received by said turbine section; and

at least one heat exchanger positioned at least partly within said turbine section, wherein said at least one heat exchanger is configured to receive waste heat and to transfer energy from the waste heat into the compressed fluid flow so as to increase at least one parameter of the compressed fluid flow contributing to the generation of the power output.

9. A power system in accordance with claim **8**, wherein said at least one heat exchanger is configured to receive the waste heat from said turbine section.

10. A power system in accordance with claim **8**, further comprising at least one machine coupled to said turbomachine assembly, wherein said at least one heat exchanger is configured to receive the waste heat from said at least one machine.

11. A power system in accordance with claim **10**, wherein said at least one machine comprises at least one gas turbine engine, said at least one heat exchanger is configured to receive the waste heat from exhaust gases generated by said at least one gas turbine engine.

12. A power system in accordance with claim **8**, wherein said turbomachine assembly further comprises at least one burner positioned within said turbine section, wherein said at least one burner is configured to provide additional heat to the compressed fluid flow combined with the waste heat.

13. A power system in accordance with claim **8**, wherein said turbine section further comprises a rotor comprising an annular base portion that is configured to substantially circumscribe at least a portion of the second end portion of the rotating member, said rotor further comprises a plurality blades extending radially outwardly from a surface of said base portion.

14. A power system in accordance with claim **13**, wherein said turbomachine assembly further comprises at least one nozzle ring positioned within said turbine section, wherein said at least one nozzle ring is configured to channel the compressed fluid flow combined with the waste heat over said rotor to facilitate rotating the rotating member.

15. A power system in accordance with claim **8**, wherein said turbomachine assembly further comprises a center section positioned between said compressor section and said turbine section, wherein said center section includes at least one conduit that is configured to channel the compressed fluid flow from said compressor section to said turbine section.

16. A method of using a turbomachine assembly for recovering waste heat, said method comprising:

providing a compressor section that is configured to generate a compressed fluid flow;

coupling a turbine section to the compressor section via a rotating member such that a first portion of the rotating member is positioned within the compressor section and a second portion of the rotating member is positioned within the turbine section, wherein the turbine section is in flow communication with the compressor section;

positioning at least one heat exchanger at least partly within the turbine section;

channeling the compressed fluid flow from the compressor section to the turbine section;

using the at least one heat exchanger to receive waste heat; and

transferring energy from the waste heat, via the at least one heat exchanger, into the compressed fluid flow to increase at least one parameter of the compressed fluid flow contributing to generation of a power output.

17. A method in accordance with claim **16**, wherein using the at least one heat exchanger to receive waste heat further comprises using the at least one heat exchanger to receive waste heat from the turbine section.

18. A method in accordance with claim **16**, wherein using the at least one heat exchanger to receive waste heat further comprises using the at least one heat exchanger to receive waste heat from a machine that is coupled to the turbine section.

19. A method in accordance with claim **16**, further comprising providing additional heat to the compressed fluid flow combined with the waste heat via at least one burner that is positioned within the turbine section.

20. A method in accordance with claim **16**, further comprising channeling the compressed fluid flow combined with the waste heat over at least one component within the turbine section via at least one nozzle ring positioned within the turbine section.

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