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(72) Inventor; and
(71) Applicant : **FILIPPONE, Claudio** [US/US]; 8708 48th Place, College Park, MD 20740 (US).

(74) Agent: **ASHBURN, Steven, L.**; MH2 Technology Law Group, 1951 Kidwell Drive, Suite 550, Tysons Corner, VA 22182 (US).

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(54) Title: WASTE HEAT RECOVERY AND CONVERSION

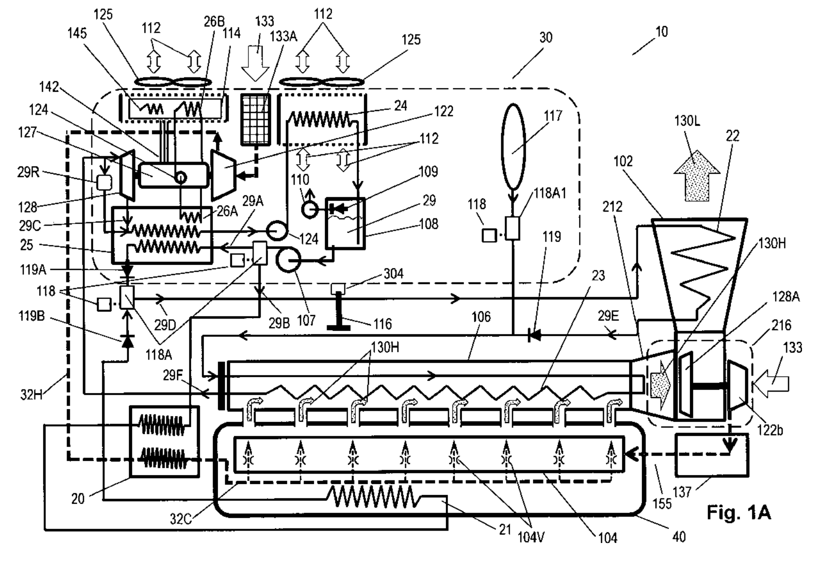

Fig. 1A

(57) Abstract: Embodiments in accordance with the present disclosure provide systems and methods for a waste heat recovery conversion. The waste heat recovery conversion system includes a housing non-invasively mountable onto an engine. The waste heat recovery conversion system also includes a power conversion unit (PCU) entirely within the housing. The PCU includes heat exchangers, an expander, an electrical power generator, and a fluid pump. The heat exchangers, the expander, the fluid pump, and the fluid reservoir form a thermodynamic loop that drives the electrical power generator using thermal energy from waste heat. Under various configurations the waste heat recovery conversion system offer pollutant reduction features all together with fuel savings.

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WASTE HEAT RECOVERY AND CONVERSION

Cross Reference to Related Applications

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 62/125,743, filed January 30, 2015, and U.S. Provisional Patent Application No. 62/110,596, filed February 1, 2015, the disclosures of which are hereby incorporated by reference herein in their entireties.

Background

[0002] Power systems that convert thermal energy into usable energy (e.g., mechanical energy and/or electrical energy) are generally comprised of independent components that are thermally coupled (e.g., hydraulically and electrically) by flexible hoses and rigid tubing via flanges, fittings, couplings, electric conduits, etc. These couplings interconnect various parts of the power system, including valves, sensors, breakers, auxiliary monitoring equipment, control equipment, etc. Such couplings can be sources of inefficiencies and failures. For example, implementations involving vibratory stresses (e.g., vehicles) can induce resonances on components that propagate through the entire power system via the couplings. Accordingly, such implementations use mechanical decoupling to avoid failures and/or increase lifespans. However, decoupling can impose other strains on power systems. For example, mechanically decoupling closed-loop thermal-hydraulic and electrical systems may induce fatigue and resonant cycling on thermal-hydraulic tubing and electrical connections.

[0003] Moreover, power systems use the above-described couplings to transfer fluids between independent components. For example, some components execute thermodynamic functions (e.g., expansion, condensation, pressurization, depressurization, and increase/decrease of the fluid energy content) to produce torque and/or electricity. As a result, the system's efficiency, reliability and endurance generally decrease as the length of the couplings between the independent components increases. Accordingly, there is a need to minimize the number and length of couplings in power systems that operate in high-vibration environments.

[0004] Additionally, power systems may employ waste heat recovery systems that include heat exchangers to capture waste heat and use it to improve performance, reduce fuel consumption and pollutant emissions. However, heat exchangers can also be sources of failures and inefficiencies. For example, clusters of pressurized tubes may be welded to the heat exchanger headers to operate as tube-shell heat exchangers. If any of the tubes develops mechanical malfunctions and/or leakages (e.g., due to corrosion, fatigue) their removal from the header may be impossible and, thus, their repair and maintenance can be costly. Additionally, the welding processes generally adopted to seal the tubes to the heat exchanger header may lead to metallurgical stresses and accelerate corrosion and/or mechanical failure. Accordingly, there is a need to minimize the cost and effort to maintain or replace heat exchangers in power systems.

[0005] Overall, increasing the reliability of non-invasive retrofittable waste heat recovery and conversion system components by integrating them to shorten their thermal-hydraulic connections and simultaneously enhance their protection with respect to vibratory stressors, represents economic and environmental advantages. Such a waste heat recovery and conversion system can reduce pollutant emissions and enhance public safety.

Summary

[0006] Embodiments in accordance with the present disclosure provide systems and methods for waste heat recovery conversion. The waste heat recovery conversion system includes a housing mountable onto an engine. The waste heat recovery conversion system also includes a power conversion unit within the housing. The PCU includes heat exchangers, an expander, an electrical power generator, and a fluid pump. The heat exchangers, the expander, the fluid pump, and the fluid reservoir form a thermodynamic loop that drives the electrical power generator using thermal energy from waste heat.

Brief Description of the Drawings

[0007] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate several embodiments of the present disclosure and together with the description, serve to explain the principles of the apparatus and methods describing the waste heat recovery and conversion systems and various components.

[0008] Figure 1A represents a block diagram illustrating an exemplary configuration of a waste heat recovery and conversion system in accordance with aspects of the present disclosure.

[0009] Figure 1B is a block diagram illustrating an exemplary power conversion unit (PCU) in accordance with aspects of the present disclosure.

[0010] Figure 1C is a block diagram illustrating a PCU in accordance with aspects of the present disclosure.

[0011] Figure 1D is a block diagram illustrating an exemplary PCU in accordance with aspects of the present disclosure.

[0012] Figure 2A illustrates a side view of an exemplary engine compartment in accordance with aspects of the present disclosure.

[0013] Figure 2B illustrates a side view of an exemplary engine compartment in accordance with aspects of the present disclosure.

[0014] Figure 3A illustrates a top perspective view of an exemplary PCU mounting assembly in accordance with aspects of the present disclosure.

[0015] Figure 3B illustrates a top perspective view of an exemplary locomotive engine compartment roof in accordance with aspects of the present disclosure.

[0016] Figure 3C illustrates a side perspective view of an exemplary PCU mounting assembly in accordance with aspects of the present disclosure.

[0017] Figure 4 illustrates a side perspective view of exemplary active isolators for a PCU mounting assembly in accordance with aspects of the present disclosure.

[0018] Figure 5 illustrates a side perspective view of an exemplary PCU fitted on the hood covering an engine compartment in accordance with aspects of the present disclosure.

[0019] Figure 6 illustrates a side perspective view of an exemplary PCU in accordance with aspects of the present disclosure.

[0020] Figure 7 illustrates a lower view of an exemplary PCU in accordance with aspects of the present disclosure.

[0021] Figure 8 illustrates a side perspective view of an exemplary PCU in accordance with aspects of the present disclosure.

[0022] Figure 9 illustrates a side perspective view of an exemplary PCU in accordance with aspects of the present disclosure.

[0023] Figure 10 illustrates a side perspective view of exemplary reinforcing structures for an engine compartment in accordance with aspects of the present disclosure.

[0024] Figure 11 illustrates side perspective vie of exemplary reinforcing structures in accordance with aspects of the present disclosure.

[0025] Figure 12A illustrates a side perspective view of exemplary vibration and impact attenuation system in accordance with aspects of the present disclosure.

[0026] Figure 12B illustrates a side perspective view of exemplary vibration and impact attenuation system in accordance with aspects of the present disclosure.

[0027] Figure 12C illustrates a side perspective view of exemplary vibration and impact attenuation system in accordance with aspects of the present disclosure.

[0028] Figure 13A illustrates a rear perspective view of an exemplary automotive vehicle platform in accordance with aspects of the present disclosure.

[0029] Figure 13B illustrates a rear perspective view of an exemplary PCU fitted to an automotive vehicle platform in accordance with aspects of the present disclosure.

[0030] Figure 13C illustrates a rear perspective view of an exemplary PCU fitted to an automotive vehicle platform in accordance with aspects of the present disclosure.

[0031] Figure 13D illustrates a rear perspective view of an exemplary PCU fitted to an automotive vehicle platform in accordance with aspects of the present disclosure.

[0032] Figure 13E illustrates a rear perspective view of an exemplary PCU fitted to an automotive vehicle platform in accordance with aspects of the present disclosure.

[0033] Figure 14 illustrates perspective views of an exemplary PCU fitted to a marine transport platform in accordance with aspects of the present disclosure.

[0034] Figure 15A illustrates a bottom perspective view of an exemplary PCUs coupled to a Diesel Multiple Unit (DMU) in accordance with aspects of the present disclosure.

[0035] Figure 15B illustrates a bottom perspective view of an exemplary PCUs coupled to a DMU in accordance with aspects of the present disclosure.

[0036] Figure 15C illustrates a bottom perspective view of an exemplary PCUs coupled to a DMU in accordance with aspects of the present disclosure.

[0037] Figure 16 illustrates a perspective view of an exemplary fitting of a heat exchanger to an exhaust gas manifold in accordance with aspects of the present disclosure.

[0038] Figure 17A illustrates a side perspective view of an exemplary fitting of a stack heat exchanger to an exhaust stack in accordance with aspects of the present disclosure.

[0039] Figure 17B illustrates a bottom perspective view of an exemplary fitting of a stack heat exchanger to an exhaust stack in accordance with aspects of the present disclosure.

[0040] Figure 18A illustrates a side perspective view of an exemplary system for non-permanently fitting high-pressure seal tubes to a tube sheet of a heat exchanger header in accordance with aspects of the present disclosure.

[0041] Figure 18B illustrates a side view of an exemplary system for non-permanently fitting high-pressure seal tubes to a tube sheet of a heat exchanger header in accordance with aspects of the present disclosure.

[0042] Figure 19A illustrates a side perspective view of an exemplary non-permanent fitting for high-pressure seal tubes in accordance with aspects of the present disclosure.

[0043] Figure 19B illustrates a side perspective view of an exemplary heat exchanger header in accordance with aspects of the present disclosure.

[0044] Figure 20A illustrates a functional assembly diagram of an exemplary system for fitting a stack heat exchanger to an exhaust gas stack in accordance with aspects of the present disclosure.

[0045] Figure 20B illustrates a fully integrated waste heat recovery and conversion system wherein the power conversion unit is embedded with the exhaust gas stack external structure in accordance with aspects of the present disclosure.

[0046] Figure 20C illustrates a fully integrated waste heat recovery and conversion system wherein the power conversion unit is embedded with the exhaust gas stack internal structure in accordance with aspects of the present disclosure.

[0047] Figure 21A illustrates a side perspective view of an exemplary fitting a manifold heat exchanger in accordance with aspects of the present disclosure.

[0048] Figure 21B illustrates a side perspective view of the internals of an exemplary manifold heat exchanger in accordance with aspects of the present disclosure.

[0049] Figure 21C illustrates a functional flow diagram of an exemplary process for fitting a manifold heat exchanger in accordance with aspects of the present disclosure.

[0050] Figure 22 illustrates an exemplary block diagram of a waste heat recovery system applied to a diesel powered vehicle and showing the conversion of thermal energy source (i.e. exhaust gases) into conditioned electricity for electric power distribution to the power train, batteries bank, and the electric grid by a power management system during acceleration and at cruising conditions, in accordance with aspects of the present disclosure.

[0051] Figure 23 illustrates exemplary block diagram of a waste heat recovery system applied to a diesel powered vehicle and showing the conversion of thermal energy source (i.e. exhaust gases) into conditioned electricity to support the power management system regulating power generated during braking to charge batteries, and to supply auxiliary loads in accordance with aspects of the present disclosure.

[0052] Figure 24 illustrates an exemplary block diagram of a waste heat recovery system applied to a diesel powered vehicle and showing the conversion of conditioned electricity from batteries bank to drive compressors to reduce pollutant emissions by compressing engine intake air in accordance with aspects of the present disclosure.

[0053] Figure 25 illustrates an exemplary block diagram of a waste heat recovery system utilizing waste energy fluids flowing through a manifold or channel to convert the thermal energy recovered via heat exchangers to mechanical torque, electricity and compressed air wherein the converted energy is managed by an Energy Conversion & Utilization system supported by power conversion units (PCUs), in accordance with aspects of the present disclosure.

[0054] Figure 26 illustrates a block diagram of an exemplary layout of the components forming a waste heat recovery and conversion system applied, for example, to convert waste thermal and mechanical energy represented by the operations of a Diesel Multiple Unit (DMU) vehicle (or any transport platform) in accordance with aspects of the present disclosure.

[0055] Figure 27 illustrates a perspective view of a cluster of waste heat recovery and conversion PCUs configured to transmit monitoring and operational data among each unit and to a data monitoring and collection center in accordance with aspects of the present disclosure.

Detailed Description

[0056] Reference will now be made in detail to the exemplary embodiments of the present disclosure, examples of which are illustrated in the referenced drawings grouped by Figures. Whenever possible, the same reference numbers or letters will be used throughout the drawings to refer to the same or like parts.

[0057] The present disclosure generally relates to systems and methods for integral, non-invasive, reversibly retrofittable waste heat recovery and conversion. More specifically, systems and methods disclosed herein extract waste thermal energy from one or more fluids sources by networking heat exchangers to form one or more thermodynamic closed-loops. Access to various specialized heat exchangers may be managed by a computer controller that maximizes the waste heat recovery efficiency when the waste thermal energy source (e.g., one or more fluid sources) is highly dynamic as, for example, for automotive, rail, marine applications as well as for stationary applications including power plants and generally all applications that discharge thermal energy to the environment.

[0058] Additionally, systems and methods disclosed herein provide a waste heat recovery system including a mounting assembly for mounting one or more Power Conversion Units (PCUs) to an internal combustion (IC) engine (e.g., rail, automotive, marine, mine haulers, dump trucks, mobile power plants, etc.) that is a minimally invasive, retrofittable, maintainable, and reversible. In accordance with aspects of the present disclosure, the mounting assembly decouples the PCUs and the heat exchangers in the waste heat recovery system from the engine using passive and/or active isolators that attenuate vibrations and impacts during the operation of the engine. As the PCUs disclosed herein can be retrofitted onto existing platforms that were not designed to accommodate thermal-hydraulic and electrical coupling with add-on power systems, the mounting system of the present disclosure, all together with the PCUs, is configured to be minimally invasive by minimizing or avoiding interference with the configurations of components provided by the original equipment manufacturer (i.e. engine equipment and equipment located within the engine compartment).

[0059] Moreover, systems and methods disclosed herein provide a non-permanent integral tube sealing and mechanical supporting system configured to seal tubes to a tube sheet of a heat exchanger header. The integrated non-permanent tube sealing system may be applied to heat exchanger headers with one or multiple number of holes and can be sized to match any tube size utilized in, for example, implementations of the a waste heat recovery system disclosed herein that involve tube attachment. The non-permanent integral tube sealing system allows for replacement of leaky or damaged tubes forming heat exchangers by avoiding removal of permanently welded tubes. Thus, the non-permanent integral tube sealing system reduces time and cost to replace leaky tubes, while increasing reliability of the heat exchanger.

[0060] Figure 1A is a schematic diagram illustrating an exemplary configuration of a highly integrated, compacted, waste heat recovery and conversion (WHRC) system10 with minimized or eliminated thermal hydraulic tubing and electrical conduits capable of operating in highly vibratory environments in accordance with aspects of the present disclosure. The WHRC system 10 may be configured to include a number of heat exchangers 20, 21, 22, 23, 24, 25, 26A and 26B, and 145. These heat exchangers are referred to herein as intercooler recuperator heat exchanger (IR-HEX) 20, engine cooling system heat exchanger (EC-HEX) 21, stack heat exchanger (S-HEX) 22, manifold heat exchanger (M-HEX) 23, condenser heath exchanger (C-HEX) 24, expander recuperator heat exchanger (EX-HEX) 25, generator/motor cooling heat exchanger (GEN-HEX) 26A and 26B, and electronic power module heat exchanger (EPM-HEX) 145. Heat exchangers 20, 21, 22, 23, 24, 25, 26A, 26B, 145 operate in conjunction with at least one integral power conversion unit (PCU) 30, and a waste thermal energy source (WTES) from an engine 40. In this embodiment, the WTES is represented by high- and low-temperature waste fluids hereafter referred to hereinafter as “second fluid 130,” wherein numbers 130L and 130H denotes the second fluid 130 with low-temperatures and high-temperatures, respectively. The referenced heat exchangers 20, 21, 22, 23, 24, 25, 26A, 26B, 145 may be configured to transfer thermal energy between the second fluid 130 and a working fluid 29 (e.g., water, organic fluids, liquid metals, heat transfer engineered fluids), referred to hereinafter as "first fluid 29," circulating within the components of the WHRC system 10. The first fluid 29 executes conversion of thermal energy from second fluid 130 to mechanical and electrical energy by means of Rankine power cycle components (i.e. turbine, pump, heat exchangers).

[0061] In accordance with aspects of the present disclosure, the engine 40 may be represented by an internal combustion engine (e.g., gasoline-, diesel-, gas-fueled engine). However, the integral WHRC system 10 of the present disclosure may be coupled to and non-invasively be retrofitted with any thermal source. In embodiments, engine 40 may be configured to include a high-temperature exhaust gas manifold 106 wherein high-temperature second fluid (high temperature exhaust gases) 130H flows, a relatively low-temperature exhaust gas stack 102, wherein low-temperature second fluid (low temperature exhaust gases) 130L flow, and an air intake manifold 104. In this embodiment, the referenced manifolds 106 and the stack 102 can be original equipment manufacturer (OEM) components. The heat exchangers (e.g., EC-HEX 21, S-HEX 22, and/or M-HEX 23) mounted and/or thermally coupled at the locations represented by manifolds106 and stack 102, can vary from one engine to another, may be configured to non-invasively and reversibly retrofit engine OEM components without modifying these components. Additionally, while not detailed in Figure 1A, the heat exchangers 20, 21, 22, 23, 24, 25, 26A, 26B, and/or 145 and other components forming thermal-hydraulic closed Rankine cycle loops of the WHRC system 10, may be configured to minimize or eliminate connecting tubes and electrical cabling normally networked among various thermal-hydraulic components forming the Rankine cycle, as the components of the WHRC system 10 can be integrated entirely within a housing forming the PCU 30. In some implementations in which OEM component constraints may induce adoption of connecting tubes, the WHRC system 10 may be configured to include flexible, high-pressure, insulated tubing highly reduced in number and length as key waste heat recovery and conversion components are integrated with the PCU 30, thus eliminating thermal-hydraulic connections represented by couplers, fittings, rigid tubes and the like.

[0062] The PCU 30 converts thermal energy from the first fluid 29 heated by the heat exchangers 20, 21, 22, 23, 24, 25, 26A, 26B and/or 145 into electrical energy and/or mechanical energy, which may be utilized to augment power of engine 40, reduce fuel consumption, reduce pollutant emissions, and/or supply electric and/or mechanical power to auxiliary loads. In accordance with aspects of the present disclosure illustrated in Figure 1A, the PCU 30 and the heat exchangers 20, 21, 22, 23, 24, 25, 26A, 26B and/or 145 can be reversibly retrofitted with OEM components of the engine 40. Therefore, one of the advantages represented by the WHRC 10 is represented by the ability of its components to adapt to the engine 40 and physical constraints of its engine compartment.

[0063] In embodiments, the PCU 30 may be configured as a single, compact, modular housing unit that provides optimized thermal-hydraulic coupling by flanging components so as to minimize tubing length In embodiments, the maximum distance between components of the PCU (e.g., C-HEX 24, E-HEX 25, GEN-HEX 26, fluid pump 107, fluid reservoir 108, check valve 109, gas ejector 110, controller 114, three-way valves 118A, pressurized vessel 117, pressure regulator (TV-PR) 118, check valve 119, turbo-compressor 122, power generator/motor 127, expander 128) is a few feet (e.g. two (2) feet or less). Additionally, in embodiments, components of the PCU 30 are entirely contained within the housing such that all tubes and wires interconnecting the components of the PCU 30 are entirely contained within the housing. As such, the components of the PCU 30 are thermal-hydraulically and electrically coupled. The PCU 30 may be configured to increases efficiency, reliability, and maintainability of the WHRC system 10. In some implementations, several PCUs 30 modules may be fitted in parallel or series configurations with a single engine 40 or a single WTES.

[0064] The PCU 30 may comprise and integrate the C-HEX 24, the EX-HEX 25, and the GEN-HEX 26A and 26B (collectively referred to herein as GEN-HEX 26). Additionally, the PCU 30 can include and integrate at least one of each of the following components: first fluid pump 107, first fluid reservoir 108, check valve 109, gas ejector 110, actively- or passively-cooled electronic controller enclosure 114 hereafter referred to as “controller 114,” reinforcing structure 116, active and/or passive vibration isolators 304, pressurized vessel 117, three-way valve pressure regulator (TV-PR) 118, three-way valve 118A, check valve 119, electrically- and turbine expander-driven turbo-compressor 122, recuperator control pump 124, fans 125, power generator/motor 127, intercooler recuperator heat exchanger (I-HEX) 20, and expander 128. In accordance with aspects of the present disclosure, the above components may be fully integrated and entirely housed within a single modular PCU 30 having all the components thermal-hydraulically and electrically coupled by channels and electrical connections embedded with their respective housing, thus minimizing or eliminating tubing and electrical cables within and outside of the PCU module 30.

[0065] The controller 114 can include redundant electronic control systems, configured to monitor and control parameters of the thermodynamic and electrical variables characterizing generator/motor 127 operational modes. Therefore, controller 114 regulates voltage output and manages the recovered and conditioned electric power. To execute high-accuracy control of energy recovered by the WHRC system 10, controller 114 can also be configured to regulate the mass flow rate of first fluid 29 so as to condition the electricity generated by the expander 128 driving the generator/motor 127. As a result, controller 114 may control operational modes of the generator/motor 127 in real time, e.g., as a function of the duty cycle of the engine 40. For example, depending on the duty cycle (and total WTES generated), the controller 114 may control the motor/generator 127 to operate as generator to provide electricity and compressed air, or as motor to provide compressed air only. When the generator/motor 127 is operating as a motor, the controller 114 manages the electric power generated by the engine 40 as the electrical source, or electric power from batteries (see, e.g., Figure 25, 3501) to compress intake air 32H via the turbo-compressor 122, thereby reducing pollutants in accordance with aspects of the present disclosure.

[0066] Embodiments of the waste heat recovery system 10 can operate as follows. Reservoir 108 contains the first fluid 29 pressurized by the pump 107, whose discharge pressure may be regulated by the controller 114. The mass-flow-rate and pressure of first fluid 29 may be regulated via speed and torque control of pump 107, and/or by a combined or independent actuation of three-way valves 118A, and the three-way valve pressure regulator TV-PR 118, wherein check valves 119A and 119B coupled to the inlets of the TV-PR 118 prevent fluid flow reversal. After being pressurized at the discharge of pump 107, the first fluid 29 may be split into a first portion 29A supplied to the I-HEX 20, and a second portion 29B supplied to the EX-HEX 25. The controller 114 via control of the TV-PR 118 and pump 107 characteristics, controls and regulates the total mass-flow rates of first fluid 29 circulating throughout the WHRC system 10, and the mass-flow-rates of each of these portions of first fluid 29, namely first fluids 29A and 29B respectively.

[0067] In accordance with embodiments disclosed herein, reference numbers 29A, 29B, 29C, 29D, 29E, and 29F represent the first fluid 29 in the WHRC system 10 at different energy content (i.e. different pressure, temperature and mass-flow-rates). Alternatively, and non-exclusively, in some embodiments the first fluids 29, 29A, 29B, 29C, and 29D represent physically different working fluids, wherein each working fluid is optimized for high performance while circulating within dedicated heat exchangers forming the power cycle of the WHRC system 10. When the first fluid 29 is represented by various working fluids 29A, 29B, 29C, 29D, 29E, and 29F that cannot mix, the heat exchangers integrated within the PCU 30 as well as the first fluid reservoir 108 and pump 107 (e.g., heat exchangers 23, 24, 25, 26A, 26B and/or 145), may be configured to operate with isolation among the various fluids. Accordingly, the heat exchangers may be configured to execute the functions of thermally coupling the various fluids in a manner that none of the first and second fluids mix.

[0068] In an exemplary implementation, the first portion 29A of first fluid 29 inletting EX-HEX 25 gains thermal energy via thermal coupling with first fluid 29C provided to EX-HEX 25 after expansion processes occurred within expander 128. This implementation of the WHRC system 10 can provide higher recovery efficiency because EX-HEX 25 recuperates losses of the turbine expander 128. The first fluid 29A, regulated by controlled TV-PR 118, outlets the EX-HEX 25 and may be supplied to S-HEX 22 non-invasively integrated with and/or mounted within the exhaust gas stack 102. This portion of first fluid 29 gains thermal energy in the exhaust gas stack 102 via thermal exchange with low-temperature waste energy second fluids 130L (the term "fluids," plural, is utilized to address waste energy fluids mixtures as, for example, those represented by engine 40 exhaust gases). In the embodiments, second fluids 130L may represent the exhaust gases discharged by the turbocharger 216, which can be an OEM component of the engine 40. As the first fluid 29D flows through the S-HEX 22 it increases its thermal energy content through thermal coupling with second fluid 130L flowing through stack 102. At the outlet of S-HEX 22, first fluid 29E may be configured to inlet M-HEX 23 to further increase its energy content. Second fluid 130H is directly pumped into exhaust gas manifold 106 as a result of the combustion processes occurring within engine 40. As a result, second fluid 130H represent the hottest waste heat fluids. If the working fluid selected for the WHRC system 10 is an organic fluid, check valve 119 may be configured to prevent or reduce back flow into the S-HEX 22 when a pressurized inert gas, contained in pressure vessel 117, may be released by means of valve 118A1 actuation under control of the controller 114. This feature may be activated when the first fluid 29E is represented by an organic fluid which may be damaged by the high-temperatures (relative to the organic fluid constraints) characterized by second fluid 130H at various locations within exhaust gas manifold 106 and possibly portions of stack 102 at the turbocharger exhaust gas turbine discharge 128A. In other words, when second fluid 130 represent high temperatures (second fluids 130H), and exceeding the organic fluid operating temperatures, controller 114 activates valve 118A1. As a result, an inert, non-combustible pressurized gas (i.e. CO2, Argon) contained in the pressure vessel 117 displaces the first fluid 29 inventory contained in the channels forming the M-HEX 23, thus removing first fluid 29 (when represented by organic fluids) from the WTES areas that might temporarily generate temperatures in excess of the organic fluids tolerable temperatures. The inert gas in the pressure vessel 117 is, therefore, utilized as a safety feature to prevent damage to the organic-based fluids when utilized as the first fluid 29. When this feature is activated, the inert gas is vented through an automatic de-gassing system represented by check valve 109 and a gas ejector 110 (e.g., vacuum pump). Specifically, the inert gas contained in pressure vessel 117 effectively displaces the organic-based working fluid 29 flashing it out of the M-HEX 23, through the expander 128, the EX-HEX 25, and the C-HEX 24. The resulting volume of inert gas ends up occupying a portion of the first fluid reservoir 108 volume. Check valve 109 and ejector 110 vent the corresponding inert gas volume, thus resetting the hydraulic loops to be automatically refilled solely with the working fluid 29 when resuming normal operations of the WHRC system 10.

[0069] The portion of the first fluid 29B supplied via regulation of TV-PR 118 and three-way valve 118A to the I-HEX 20 increases its energy content via thermal coupling with hot compressed air 32, hereafter referred to as hot "third fluid 32H," produced by the air compressor 122 integrated with the PCU 30. As the first fluid 29B exits the I-HEX 20, it enters the EC-HEX 21, which can be fitted and/or mount (non-invasively) with the intake manifold 104 (e.g., an OEM component). The EC-HEX 21 may also include thermal coupling with the engine 40 oil cooling system, so as to recover thermal energy from the engine coolant system and from the engine oil cooling system. In embodiments, the EC-HEX 21 may be a jacketed engine cooling system thermally coupled to non-invasive heat exchanger surfaces co-located with engine 40 equipment integrated within the PCU 30. The EC-HEX 21 further increases the energy content of the first fluid 29B prior to mixing it with the portion of the first fluid 29A exiting the EX-HEX 25 and inletting the S-HEX 22 in the exhaust gas stack 102 as pre-heated first fluid 29D.

[0070] In the exhaust gas stack 102, the S-HEX 22 increases the thermal energy content of first fluid 29D (formed by any proportion of working fluids 29A and 29B) by heat energy transferred from the second fluid 130L. At this point, the first fluid 29E inlets the M-HEX 23 in the exhaust manifold 106. As the working fluid 29E flows through the M-HEX 23, its thermal energy content is further increased and, depending on type of working fluid, superheating of first fluid 29E to higher energy content first fluid 29F. After flowing through the heat exchangers described, the first fluid 29, now superheated to first fluid 29F, inlets the turbine expander 128, which is mechanically coupled to generator/motor 127. As the first fluid 29F expands within turbine expander 128, its energy content is decreased. As an additional safety feature, the first fluid 29F may be vented through relief valve 29R. This safety feature prevents the rotary components of the PCU 30 to over-speed, for example, due to loss of electric load when motor/generator 127 is producing electricity. During abnormal operations, the relief valve 29R, which is controlled and actuated passively, or actively by the controller 114, may bypass the first fluid 29F to reduce the speed of the turbine expander 128. During normal operations, at the discharge of the turbine expander 128, the first fluid 29C inlets the EX-HEX 25 for transferring thermal energy content to the cooler first fluid 29A, counter-flowing from the fluid reservoir 108 as a result of pump 107 operation. The first fluid 29C exiting the EX-HEX 25, enters the C-HEX 24 (e.g., a condenser or radiator) passively by gravity and pressure differential, or actively by means of recirculation pump 124, and returns back in a liquid state by thermal transfer with a fourth fluid 112, which can be cool air from the environment outside the engine 40. The first fluid 29 is now reset back into first fluid reservoir 108.

[0071] The WHRC system 10 can include a series of thermodynamic closed-loops that maximize transfer of the WTES represented by the engine 40 to the first fluid 29 via the I-HEX 20, the EC-HEX 21, the S-HEX 22, the M-HEX 23, the C-HEX 24, the EX-HEX 25, and the GEN-HEX 26A and 26B. The WTES is therefore converted into mechanical energy via turbine expander 128. The mechanical energy may be directly (via direct drive) or indirectly (via gear box) transferred to the electric generator/motor 127 rotary components to generate electrical energy controlled and conditioned by the controller 114. As described, the controller 114 can also distribute the converted pollutant-free electric power to augment performance of the engine 40, reduce pollutant emissions, and supply additional electricity to auxiliary electric loads (i.e. air conditioners, lights, compressors, servo-actuators). Additionally, the pollutant-free converted electric and mechanical power produced by the PCU 30 may be used to drive motors of cooling fans 112 and provide, features for special applications. For example, as detailed below with regard to Figures 13C, 13D, and 15A, the special applications may comprise vehicle propulsion (e.g., by driving a motor coupled to an axle, see 1331 Figure 13D). The WHRC system 10 operating according to the embodiments disclosed herein can provide a minimum of 5% to a maximum of 23% in fuel savings and corresponding pollutant emissions reduction, thus substantially improving engine 40 efficiency.

[0072] Additionally, in accordance with aspects of the present disclosure, to further reduce pollutant emissions, while decreasing fuel consumption, the WHRC system 10 may be configured to compress intake air inside intake air manifold 104. In this configuration, as mentioned, rotary components of the PCU 30 forming the motor/generator 127 may be directly or indirectly coupled to one or multiple compressor turbines. Turbo-compressor turbine 122 may be configured to represent a compressor system formed by various turbine stages and turbine types (i.e. radial, axial). Hot third fluid 32H is the result of environmental air 133 flowing through filter 133A by means of turbo-compressor turbine 122. Depending on engine 40 duty cycle and controller 114 settings, the PCU 30 may be driven by electrically powering motor/generator 127. The compressor turbine 122 may also be driven independently or in combination with the mechanical coupling of the motor/generator 127 rotary components to expander turbine 128. Hot compressed third fluid 32H inlets the IR-HEX 20 so as to reduce temperature of compressed third fluid 32C prior to inletting the engine 40 intake manifold 104.

[0073] In some embodiments, the compressor system forming the OEM turbocharger 216 may be configured to operate in tandem with compressor turbine 122. In this configuration, the OEM turbo-charger compressor 122b provides hot compressed air to the OEM intercooler system 137 and inlets cooler compressed air into the intake manifold 104. To avoid utilization of check valves and flow reversal toward the compressor turbine 122, the cold compressed third fluid 32C generated by the WHRC 10 pollution reduction features inlets intake air cylinder ports (not shown) via non-invasive venturi jets 104V retrofitted with the intake manifold 104. In this configuration compressor turbine 122 supplies electrically-driven cold compressed air 32C to the engine 40 air intake ports when the expansion turbine 128 does not provide mechanical energy to compressor turbine 122, and when the OEM turbocharger 216 provides insufficient compressed air (i.e. idle, and low power settings operations). When engine 40 is operated at intermediate and high power settings, the compressor turbine 122 is driven by expander turbine 128. Therefore, the OEM compressor system formed by turbocharger 216, exhaust gas turbine 128A, and intercooler 137 may be configured to be supplemented with additional, independently intercooled, compressed air 32C to increase pressurization of the intake manifold 104 when engine 40 is idling and at low power settings. Alternatively, in some embodiments, the compressor turbine 122 may be configured to substitute turbocharger 216 and intercooling system 137.

[0074] Figure 1B shows a block diagram of an exemplary PCU 30, which can be the same or similar to that previously described herein. Accordingly, the PCU 30 may include the C-HEX 24, the EX-HEX 25, and the GEN-HEX 26. Additionally, the PCU 30 may comprise the components forming the electronic controller 114, electronic power module and conditioner enclosure 141 hereafter referred to as "conditioner 141," and the electronic power module heat exchanger 145 (EPM-HEX). The power conditioner 141 comprises the electronic components that execute electric power rectification and regulates voltage, frequency and current to process electric power output conditioned to/from the power generator/motor 127. The EPM-HEX 145 recovers waste thermal energy generated by the controller 114 and the all of the components comprised by conditioner 141. The PCU 30 also includes GEN-HEX 26, which recovers waste thermal energy generated by the electrical generator/motor 127. The heat exchangers 24, 25, 26 may utilize the first fluid 29 as means to transfer thermal energy between components to be cooled (i.e. motor/generator 127 rotor, stator, bearings, the power modules forming the controller 114, and the power modules comprised by conditioner141), while, at the same time, waste energy represented by the PCU 30 components, once transferred to first fluid 29, increases the working fluid energy content, thus the WHRC system efficiency. In Figure 1B, the conditioner 141 can be an enclosure in which a forth fluid 112 (cooling air) may flow to provide cooling of the controller 114 and its power modules, in addition to cooling represented by first fluid 29 provided after pressurization via pump 107. The fourth fluid 112 may flow passively, or actively by operating fans 125. The fans 125 may be controlled by the controller 114 and powered by electricity provided by the PCU 30 or by engine 40.

[0075] In addition to the PCU 30 features described in Figures 1A and 1B, a minimum of two four-way valves and pressure controllers 118B, or multiple TV-PRs 118 (shown Figure 1A) may be utilized to increase precision of the portions of first fluid 29 mass flow rates circulated through the EPM-HEX 145, the GEN-HEX 26, and the EX-HEX 25, as shown in Figure 1C. More specifically, Figure 1C illustrates an embodiment of PCU 30 similar to that described above with regard to Figures 1A and 1B. In this embodiment, the controller 114 controls mass flow rates of the first fluid 29 through components of the PCU 30, as well as through the IR-HEX 20, EC-HEX 21, S-HEX 22, and M-HEX 23 (all heat exchangers) by using pumps 124 controlled by controller 114 in addition to pump 107. The combined operations of pumps 124 and 107, the 4-way valves 118B, and three-way valves 118A, controlled by the controller 114, enables fine regulation of mass flow rates of the first fluid 29 s circulating in the various thermal-hydraulic loops shown. In this configuration, fine temperature control of the motor/generator 127 may be established by means of accurate regulation of the first fluid 29 mass flow rate flowing through GEN-HEX 26.

[0076] Figure 1D is a block diagram illustrating another embodiments of PCU 30, which is similar to that previously described herein. In accordance with aspects of the present disclosure, the PCU 30 incorporates another configuration of M-HEX 23 and/or S-HEX. More specifically, the PCU 30 may include a conduit or manifold 149 (e.g., insulated pipe or conduit), wherein waste energy second fluids 130 flow (i.e. high- or low-temperature exhaust gases 130H and 130L respectively). As second fluid 130 flow through manifold 149, it transfers thermal energy to the working fluid 29, circulating within M-HEX 23 or S-HEX 22 (high- or low-temperature restrictions imposed by first fluid 29 thermal-physical properties) without mixing with second fluids 130, as these fluids are only thermally coupled by means of the heat exchangers (i.e. M-HEX 23 and/or S-HEX 22). In this embodiment, the first fluid 29 from working fluid reservoir 108 flows through the various components of the PCU 30 as a result of pressurization executed by pumps 107, and pumps 124, with fine regulation of the first fluid 29 mass flow rates executed by active actuation of valves 118A and 118B. In this arrangement, the PCU 30 can be retrofitted with WTESs (e.g., second fluid 130) in a minimally invasive manner by coupling the OEM engine exhaust gas conduit or exhaust manifold to conduit 149 after the OEM turbocharger, wherein conduit 149 may be embedded with the integral PCU 30 components and entirely housed within the enclosure representing PCU 30. Additionally, in this arrangement, the back pressure represented by M-HEX 23, or S-HEX 22 does not impact OEM turbocharger performance as the second fluid 130 transfers thermal energy to the WHRC system 10 only after having expanded within the OEM turbocharger. By regulating the first fluid 29 mass flow rate through M-HEX 23 in the configuration shown in Figure 1D, the second fluid 130 may be cooled at temperatures that trigger condensation of the water vapors contained in the combustion products of engine 40. Accordingly, the back pressure manifested within conduit 149 may be represented by a vacuum, thus further increasing OEM turbocharger and overall engine 40 performance and efficiency.

[0077] In accordance with aspects of the present disclosure, the WHRC system 10 can be retrofit onto combustion engines dedicated to various applications. As an example, engine 40 may be represented by a locomotive engines, however, any internal combustion engine dedicated to mobile or stationary applications may be non-invasively retrofitted with the WHRC system 10 of the present disclosure.

[0078] Figures 2A and 2B illustrate side views of an exemplary locomotive engine compartment 200 consistent with embodiments disclosed herein. As shown in Figure 2A, the locomotive engine compartment 200 includes engine 40 and exhaust gas stack 102, which can be the same or similar to the exhaust gas stack previously described herein. Additionally, the locomotive engine compartment 200 includes removable roof lids 206 and reinforcing structures 208. The removable roof lids 206 allow for replacement of a non-invasive mounting of an enclosure comprising PCU 30 components in accordance with aspects of the present disclosure. The reinforcing structures 208 may be configured to comprise an assembly of metal tubes mounted around the engine compartment to support the weight of PCU 30 non-invasively retrofitted with engine 80 without interfering with OEM components located within the engine compartment 200. The reinforcing structures 208 may be non-invasively mechanically coupled (e.g., bolted or welded) around the frame of the engine compartment 200 and removable roof lids 206. Figure 2B depicts the exhaust gas manifold 106 of engine 40 housed within engine compartment 200, which can be the same or similar to the exhaust gas manifold 106 previously described. Additionally, Figure 2B illustrates a manifold transition part 212 and the housing of OEM turbocharger 216, which are coupled to piston-cylinder assemblies (not shown) equipping engine 40.

[0079] Figures 3A, 3B, and 3C illustrate perspective views of the locomotive engine compartment 200 including reinforcing structures 208, which can be similar or the same as those previously disclosed herein and referenced with number 116 in Figure 1. In accordance with aspects of the present disclosure, the locomotive engine compartment 200 is retrofitted with PCU 30, which can be the same or similar to that previously disclosed herein. More specifically, the PCU 30 may be retrofitted with the engine compartment 200 using mounting rails 301 (Figure 3C) and a mounting enclosure 302, which may incorporate the various components of the WHRC system 10 as a single module. To simplify the illustrations represented by Figures 3A, 3B and 3C, the various components (i.e. PCU 30) installed within the mounting enclosure 302 are not illustrated. In these illustrations, the mounting enclosure is a skeletal representation of PCU 30.

[0080] Figures 3A, 3B and 3C illustrate PCU 30 retrofitted on a locomotive engine compartment (e.g., engine compartment 200) by removing the roof lid(s) 206 and replacing it (them) with the mounting enclosure 302 shaped so as to maintain the functions of roof lids 206 by means of extended lid surfaces 306 extending from the basic structure of the mounting enclosure 302. Referring to Figures 3A and 3C, vibration isolators 304 (e.g., vibration absorbers, dampers, etc.), which may be the same or similar to those previously described herein, decouple the PCU 30, the mounting rails 301, and a mounting enclosure 302 from the vibrations and shocks of the engine compartment 200. In embodiments, the vibration isolators 304 are coupled between a reinforcing structure retrofitted on the engine compartment (e.g., reinforcing structure 208) and the mounting rails 301, or the mounting enclosure 302. In embodiments, the vibration isolators 304 may be actively controlled by a dynamic vibration attenuation system. Figures 3A, 3B, and 3C only illustrate a frame of the PCU 30 and mounting enclosure 302 for simplicity, as PCU 30 comprises the components previously described herein with regard to Figures 1A, 1B, 1C and 1D.

[0081] Figure 4 illustrates exemplary active isolators 403 in accordance with aspects of the present disclosure. In this configuration, active isolators 403 may be represented by a bladder forming the isolators. In embodiments, active vibration control software (e.g., executed by controller 114) controls the active isolators 403. For example, based on shocks or vibrations of on the engine compartment 200 (detected, e.g., by one or more accelerometers) the active vibration control software can output a vibration control signal 405 that causes the active isolators 403 to actively change their shock dampening characteristics.

[0082] Figure 5 illustrates a perspective view of PCU 30 retrofitted on the structure housing a locomotive engine compartment (e.g., engine compartment 200). In this configuration, PCU 30 is equipped with a cooling system 501 utilizing forth fluid 112 (i.e. environmental air), and access doors 503. The cooling system 501 may be configured to include one or more C-HEXs 24 and fans 125, which can be the same or similar to those previously described herein. As depicted in Figure 5, the cooling system 501 is located on top of the PCU 30. However, cooling systems 501 may be configured to exchange thermal energy with the forth fluid 112 at different locations with respect to the PCU 30. For example, some of all components of the cooling system 501 can be located on the sides or bottom of the PCU 30.

[0083] Figures 6, 7, 8, and 9 show exemplary configurations one or more of cooling vents 702, 601, 602, 701, 801, and 901 that may be disposed at various locations of PCU 30, based on the flow direction of cooling fluid of different retrofitting applications.

[0084] Figures 10 and 11 show exemplary perspective views of multiple PCUs 30 non-invasively replacing top lids (e.g., top lids 206) of a locomotive engine compartment (e.g., a locomotive engine compartment 200) and reinforcing structures 116 and 208 forming an exoskeleton, which can be non-invasively retrofitted with the locomotive engine compartment to distribute the weight of one or multiple PCUs 30 in accordance with aspects of the present disclosure. The reinforcing structures 208 and 116 are non-invasive in that they do not interfere with existing structures or components in a fielded system. For example, an engine compartment (e.g., engine compartment 200) of a fielded locomotive may be retrofitted with the reinforcing structures 208 and 116 to assist in supporting the weight of the PCUs 30. Notably, the PCU 30 may be configured to output different or same power ratings based on different engine duty cycles (e.g., of engine 40). As described in the examples, embodiments consistent with the present disclosure provide a locomotive mounting system forming the support and shield of the PCU 30 that is non-invasive to the existing structure 206 of locomotive engine compartment 200.

[0085] Figures 12A, 12B, and 12C illustrate an exemplary vibration and impact attenuation system 1200 in accordance with aspects of the present disclosure. The vibration and impact attenuation system 1200 includes mounting rails 301 and vibration isolators 304, which can be the same or similar to those previously described herein. Additionally, the vibration and impact attenuation system 1200 includes a roller 1202, x-axis translators 1203, y-axis translator 1204 and z-axis translator 1205. Further, the vibration and impact attenuation system 1200 includes a rotary mass 1365 representing the PCU 30 rotary components integrated with the motor/generator 127.

[0086] For the sake of clarity, Figure 12A illustrates the vibration and impact attenuation system 1200 in isolation. The vibration and impact attenuation system 1200 can be mounted on mounting rails 301 and vibration isolators 304, which can be the same or similar to those previously disclosed herein. For reference Figure 12A depicts the primary x-, y-, and z-axes of motion, wherein the x-axis and the y-axis are in the plane of the ground, and the z-axis is vertical with respect to the ground. The vibration and impact attenuation system 1200 includes roller 1202, x-axis translators 1203, y-axis translator 1204 and z-axis translator 1205, which permit the vibration and impact attenuation system 1200 to translate vertically, laterally, and longitudinally. For each axis translator, dedicated active or passive attenuation dampened systems 1207 are coupled to the impact attenuation system 1200. The attenuation dampening systems 1207 may be represented by spring-loaded shock and dampening absorbers (i.e., passive), or by active dampening system controlled by controller 114. Further, embodiments of the vibration and impact attenuation system 1200 may include rotary masses 1206 coupled (e.g., by bearings) to brackets of z-axis translator 1205, which mitigates or neutralize vibrations, shocks, and impacts to the rotary mass and couplers in a PCU (e.g., electrical generator/motor 127, turbine expander 128, compressor turbine 122, couplers, and rotary components of bearing systems).

[0087] Figure 12B illustrates the vibration and impact attenuation system 1200 incorporating exemplary PCU 30, which can be the same or similar to that previously described herein. Additionally, the PCU 30 includes a housing 1208 and a volute 1209 containing bearings, multistage turbine stators and rotors, seals and pressure inlet(s) for a fluid (e.g., first fluid 29) to expand via turbine expander 128. The volute 1209 may be coupled to a diffuser system 1211. The diffuser 1211 may be configured to increase the turbine expander 128 discharge efficiency of the first fluid 29 (e.g., working fluid) exiting turbine expander 128, prior to entering the EX-HEX 25, by reducing back pressure at the expander 128 discharge while structurally supporting a flow deflector for the first fluid 29 discharging from the EX-HEX 25 and entering the C-HEX 24 wherein pump 124 may be integrated within housing 1406.

[0088] Figure 12C illustrates additional features of the integral internal components forming PCU 30 housed and coupled by the vibration and impact attenuation system 1200. More specifically, a structural component 1215 mechanically couples electric generator/motor 127, the expander 128, the volute 1209, diffuser 1211, and the EX-HEX 25 (as well as the portions of C-HEX 24 in Figure 12B comprised within housing 1406) to provide a rigid system supported by the secondary vibration and impact attenuation system 1200, mounting rails 301, and primary vibration isolators 304, which extends protection of all components of the PCU 30 from vibrations and impacts. Notably, the coupling 1217 provides an interface for compressor system (e.g., turbine compressor 122) to be mechanically coupled to the rotary components of the electric generator/motor 127.

[0089] Figures 13A to 13E illustrate an exemplary PCU 30 implemented on an automotive platform 1300. The PCU 30 can be the same or similar to that previously described herein. In accordance with aspects of the present disclosure, the PCU 30 can be non-invasively retrofitted on an existing and/or a previously fielded automotive platform 1300. Consistent with examples previously described herein, the automotive platform 1300 includes an engine (e.g., engine 40), exhaust stack 102 wherein relatively low-temperature second fluids 130L (e.g. exhaust gases) are vented to atmosphere. Additionally, in accordance with aspects of the present disclosure, the automotive platform 1300 includes a primary vibration attenuation system (e.g., isolators 304) and a secondary vibration and shock attenuation system (e.g., vibration and impact attenuation system 1200), which can be the same or similar those previously described herein. Figure 13B illustrates an example the PCU 30 mounted on the rear of the automotive platform 1300. As shown, the PCU 30 may be configured to encompass and/or to incorporate at least a portion of the exhaust stack 102 so as to integrate conduit 149 described in Figure 1D. The PCU 30, including C-HEX 24, fans 125, can be the same or similar to those previously described herein. Further, the PCU 30 includes cooling vents 1311, 1312, 1313, and 1314 that, along with fans 125 and C-HEX 24, may operate at varying rates based on the air-cooling flows surrounding the automotive platform 1300. Exemplary embodiments of PCU 30 non-invasively retrofitted on automotive platform 1300 may be configured to provide cooling forth fluid 112 flows (e.g. environmental air), through air flow baffles (not shown), proportionally to the speed of automotive platform 1300, thereby minimizing or eliminating the need for PCU 30 cooling fans 125.

[0090] As described previously, the PCU 30 is part of a WHRC system (e.g., waste heat recovery and conversion system 10) that generates electrical power using waste thermal energy sources (WTESs) as those represented by the operation of the internal combustion engine (e.g. engine 40). In accordance with aspects of the present disclosure, Figure 13C illustrates a traction motor 1321 coupled to a wheel 1325 of automotive platform 1300. The traction motor 1321 comprises an electronic motor that (induction or permanent magnet) directly or indirectly drives the wheel 1325. In accordance with aspects of the present disclosure previously described herein, the PCU 30 transforms waste thermal energy into electricity that can be utilized to support the automotive platform 1300 auxiliary electric loads (e.g., refrigeration units for special transports), as well as propulsion, which reduces fuel consumption and pollutant emissions. In embodiments, the PCU 30 may also charge battery packs that can be charged by regenerative braking energy generated by the traction motor 1321. Figure 13D illustrates the automotive platform 1300 fitted with one or multiple traction motors 1331 driven by the PCU 30, which may be on the automotive platform 1300 and may integrate battery packs representing an electric energy storage mechanism recharged by regenerative breaking and by motor/generator 127 comprised by PCU 30. Figure 13E describes various configurations of the PCU 30 that utilize air-cooling flows 1341, generated by the motion of automotive platform 1300, to increase the efficiency of the PCU 30, reduce the size of the C-HEX 24 and fans 125. In this configuration the PCU 30 cooling surfaces may be positioned in a manner that generate minimum friction with respect to the air flow generated by motion of the automotive platform 1300. As shown, one or multiple PCU 30 may be configured for installation on top, sides, or bottom of automotive platform 1300. The PCU 30 represented is not to scale.

[0091] The WHRC system (e.g., waste heat recovery system 10) and PCUs (e.g., PCU 30) in accordance with the present disclosure are not limited to implementations on locomotives and automobiles. For example, Figure 14 illustrates one or multiple PCU systems 30 clustered in the vicinity of stacks 102 so as to convert waste thermal energy produced by a marine platform 1400. In this configuration the electricity produced by conversion of second fluids 130 (e.g. exhaust gases) from one or multiple marine diesel engines equipping, for example, a transoceanic marine vessel, may be conditioned by the PCUs 30 (e.g., using controller 114, electrical generator/motor 127, and power conditioner 141) for distribution to a marine platform switchyard and electric bus. In this configuration, a single PCU 30 may be scaled to match the power rating represented by the waste energy contained in second fluids 130. Alternatively clusters of PCU 30 modules may be clustered (e.g. as shown in the magnified “area A” illustrated in Figure 14) to match the total energy represented by second fluid 130.

[0092] Figure 15A illustrates an exemplary PCU 30 coupled to a Diesel Multiple Unit (DMU) 1500 having one or multiple engine 40 in accordance with aspects of the present disclosure. The PCU 30 and engine 40 can be the same or similar to those previously described herein. The PCU 30 can be mounted to the DMU 1500 using a primary vibration and shock attenuation system (vibration isolators 304 and/or active isolators 405) and a secondary vibration and shock attenuation system (e.g., vibration and impact attenuation system 1200) in a manner that is the same or similar to that previously descried herein. Further vents (e.g., vents 1311, 1312, 1313 and 1314), C-HEX (e.g., C-HEX 24) and fans (e.g., fans 125), which can be the same or similar to those previously described herein, can be configured to not interfere with existing equipment of the DMU 1500 and to maximize air-cooling flows for high PCU 30 conversion efficiency.

[0093] As previously described herein, the PCU 30 can convert waste heat generated by the engine 40 (e.g., thermal energy of electrical and exhaust systems) to electric power, which may be then distributed to the various loads. For example, electricity generated by the PCU 30 (e.g., using electric generator/motor 127 and turbine expander 128), may be distributed to support auxiliary loads (e.g., cooling systems) and batteries, as well as OEM or retrofitted traction motors 1505. Additionally, in some examples, the PCU 30 may distribute power to an electrical supply grid via a third rail connection or a pantograph connection. Traction motors 1505 may be configured as a permanent magnet or as an induction machine retrofitted and coupled with at least one of the DMU axels 1506. Figures 15B and 15C illustrate examples of the DMU 1500 including a fitting of the exhaust gas stack 102 in Figure 15B to a modified stack 1525 (Figure 15C) to allow retrofitting of S-HEX 22.

[0094] Figure 16 illustrates an exemplary fitting (or retrofitting) of M-HEX 23 through exhaust gas manifold 106 of DMU 1500 in accordance with aspects of the present disclosure. The M-HEX 23, the exhaust gas manifold 106, and the DMU 1500 can be the same or similar to those previously described herein. The exemplary M-HEX 23 includes a sealing header

1605, tube bundles 1609, and inlets/outlets 1613. The sealing header 1605 may be configured to be non-invasive and reversibly retrofitted to the exhaust gas manifold 106 by coupling and sealing it to an end portion of the exhaust gas manifold 106. The first fluid 29 may circulate through the tube bundles 1609 by means of inlets and outlets 1613, while on the "shell side" now formed by manifold 106, high temperature second fluid 130H circulates as a result of engine 40 operation. An exemplary configuration of tube bundles 1609 is also shown in Figure 21A.

[0095] Figures 17A and 17B illustrate perspective views an exemplary fitting (or retrofitting) of S-HEX 22 through the exhaust stack 102. The S-HEX 22 and the exhaust stack 102 can be the same or similar to those previously described herein. The exemplary S-HEX 22 includes a sealing header 1705, tube bundle 1709, and inlets/outlets 1713. The dashed arrow indicates the direction for final positioning the tube bundle 1709 (e.g. S-HEX 22) in the exhaust stack 102. The sealing header 1705 may be non-permanently fit to the exhaust gas header 102 by couple to an end portion of the exhaust gas manifold 102 and sealing the non-permanent tube sealing header 1709 in the exhaust gas manifold 106. The first fluid 29 may circulate through the tube bundles 1709 by means of inlets and outlets 1713, while the low temperature second fluid 130L (e.g. exhaust gases after expansion in the OEM turbocharger) circulate on the "shell side" now formed by the outer surfaces of tube bundle 1709 and the inner surfaces of stack 102.

[0096] Figures 18A and 18B illustrate a non-permanent, high-pressure heat exchanger sealing header mechanism 1800 (e.g., sealing header 1605 and sealing header 1705), which may be the same or similar to those previously described herein. The sealing header 1800 utilizes mechanical means to seal a tube 1805 (e.g., tube bundles 1609 and 1709) to tube sheet 1809 by utilizing a hole 1801 (e.g., a custom profiled hole) in the tube sheet 1809 that receives a nut 1817 (e.g., a custom designed or standard nut), a cutting ring 1821 and a ferrule 1825 for a close fitting into conical seat 1826 concentric with hole 1801. More specifically, the nut 1817 mechanically engages the tube sheet 1809 (e.g. by thread) and compresses the cutting ring 1821 and the ferrule 1825 against the seat 1826 (e.g., a specially designed seat) inside the hole 1801 to force the cutting ring 1821 and the ferrule 1825 into the outer wall of the tube 1805. The cutting ring 1821 aligns the ferrule 1825 between the cutting ring 1821 and the nut 1817, thereby sealing and enhancing mechanical coupling of the assembly, even under severe vibrations. The contact between the cutting ring 1821 and ferrule 1825, the tube sheet 1809 and the tube 1805 executed by tightening the nut 1817 secures the tube 1805 in the tube sheet 1809 and provides a high-pressure seal between the tube 1805 and the tube sheet 1809. The high pressure seal allows any fluid to inlet the header cap 1829 through the inlet/outlet 1833 into the header cavity 1837 and ensures that a fluid may inlet or outlet tube 1805 without leakage at the interface between the tube sheet 1809 and tube 1805. The header cap 1829 and the tube sheet 1809 may be mechanically coupled and sealed by seal 1813. The integrated nature of the custom or special hole profile allows for this method and apparatus to be applied to heat exchanger headers with any number of holes/tubes and can be adjusted for any size tube utilized in any application involving tube sealing and mechanical support. This non-permanent tube sealing feature allows for replacement of leaky or damaged tubes without major equipment requirements to remove permanently affixed tubes and thus reduce the time and cost to replace a leaky tube from heat exchangers.

[0097] Figures 19A and 19B illustrate a large tube header 1900 fitted with high-pressure heat exchanger sealing tube-header interface similar to that described in Figures 18A and 18B. More specifically, Figure 19A shows a sealing method between the sealing header 1809 and a header cup 1829 of a single exemplary tube 1805. Figure 19B shows a large tube header 1900, wherein tube header 1909 may be configured to seal multiple tubes 1805 (not shown) through holes 1901. Holes 1901 are configured to accommodate internally conical seats similar or the same as those shown in Figures 18A, 18B and 19A (e.g. conical seat 1826). The exemplary embodiment of large tube header 1900 may be configured to have partitions to separate a given number of tubes 1901 from another given number of tubes 1901 sealed to the same tube header 1909. For example, tubes 1805 sealed to the portion of tube header 1902 symmetrical to the portion of tube header 1903 may be configured to seal two different first fluids 29 as seal 1913 separates and seals these symmetrical tube headers portions. The shape of the tube header 1900 may be any suitable shape, such as circular, rectangular, square, triangular, polygonal, and curved. Accordingly, the shape of the header cup may have a shape matching that of the tube header 1909.

[0098] Figure 20A illustrates an exemplary method for retrofitting exhaust stack 102 with a specialized or customized S-HEX 22. The exhaust stack 102 and the S-HEX 22 can be the same or similar to those previously described herein. In accordance with aspects of the present disclosure, the S-HEX 22 is configured to non-invasively fit or retrofit the exhaust stack by mounting within the internal volume of the exhaust stack 102 by removing an existing flange 2005, and inserting from the top the S-HEX 22. Top flanges 2009 and bottom flanges 2011 allow the S-HEX 22 to align with the exhaust stack 102 internals and mechanically couple with it for structural robustness, while preventing the heat exchanger from being ejected. Each structural component forming the S-HEX 22 may be geometrically shaped to offer minimum fluid drag and may be equipped with holes 2006 to maximize turbulence while maintaining low back pressure on the second fluid 130 flowing through the shell side (e.g., exhaust gas side) of the heat exchanger. The S-HEX 22 may be configured to represent a series of tube bundles 2013 with tubes bent with a tapered shape so as to closely mimic the inner geometry of the particular stack 102 shown in this Figure. The embodiment includes a top non-permanent sealing tube header 1909, and a bottom non-permanent sealing tube header 1909. Inlet and/or outlets 2025 and 2027 (symmetrical in this configuration), coupled to the tube header caps (not shown) enable sealed circulation of first fluid 29 (e.g., working fluid 29). When S-HEX 22 is lowered into the stack 102, it can be secured through perforated symmetrical flanges or lids 2009 with holes 2006 with various diameters to decrease backpressure and acoustic signature.

[0099] Figure 20B shows an OEM stack 102, non-invasively retrofitted with S-HEX 22 wherein the inlet and outlet of the heat exchanger are coupled directly to the PCU 30 integrated with the stack 102. In this configuration, the components forming the PCU 30 are comprised within the stack 102 or positioned externally to the stack 102, so as to minimize or eliminate the thermal-hydraulic connections between the S-HEX 22 and the PCU 30 components. Figure 20B shows, as an example, PCU 30 configured to be coupled to the external structures of stack 102. Figure 20C shows, as another example, the PCU 30 configured to be fully integrated with the structures of stack 102. In this configuration, the surfaces of C-HEX 24 would be exposed to forth fluid (e.g. environmental air) 112 by positioning and integrating the C-HEX 24 on top or sides of exhaust stack 102, and the symmetrical S-HEX 22 inlets/outlets (e.g. 2027 and 2025) would be eliminated as the heat exchanger header caps may be integrated with the expander turbine 122 volute and the EX-HEX 25 outlet.

[00100] Figures 21A, 21B, and 21C illustrate an exemplary fitting (or retrofitting) of M-HEX 23 in an OEM exhaust manifold 106 in accordance with aspects of the present disclosure. M-HEX 23 may be formed by the tube bundle 1609, a non-permanent sealing

header 1605, interchangeable inlets/outlets 1613, which can be the same or similar to that previously described herein. Additionally, the M-HEX 23 can include sliding supporting vanes 2112. The sliding supporting vanes 2112 redirect the hot second fluid 130H flow while circulating inside the exhaust gas manifold 106. Additionally, sliding supporting vanes 2112 support the tube bundle 1609. The sliding supporting vanes 2112 include suitable shapes and passages to maintain structural strength while minimizing backpressure. In this configuration, tubes 1805 forming the tube bundle 1609 can freely expand and contract inside the exhaust gas manifold 106 as this heat exchanger can slide inside the gas manifold 106. A non-invasive retrofitting installation of M-HEX 23 configured as tube bundle 1609 consists of sliding the whole tube bundle 1609 and sealing flange 1605 inside the OEM exhaust gas manifold 106 without need to modify said exhaust gas manifold.

[00101] Figure 21B illustrates an embodiment 2100 of the tube bundle 1609 with details on the sliding supporting vanes 2112. As shown the supporting vanes 2112 may be configured to allow tubes 1805 to expand and contract by sliding over the inner walls of exhaust gas manifold 106. The sliding and supporting vanes 2112 are mechanically coupled to a support tube 2114A by locking mechanism 2114. To reduce backpressure while driving the flow of secondary fluid 130H as shown in Figure 21A, the supporting and sliding vanes 2112 may be equipped with pass through holes 2013 and 2015.

[00102] Figure 21C illustrates sealing header 1605 being non-invasively fitted in exhaust gas manifold 106 in accordance with aspects of the present disclosure. The exemplary method of non-invasively recovering thermal energy from exhaust gases (e.g. second fluid 130) by retrofitting straight portions of exhaust gas manifolds 106 with tube bundles 1609 and sealing the exhaust gas manifold by means of a seal 1813 and a compression clamp, not shown, or via any other flanging method. In this example, fuel bundle 1609, representing M-

HEX 23, may be non-invasively retrofitted by sliding the heat exchanger into the exhaust gas manifold from the end of exhaust gas manifold 106 opposite to the OEM turbocharger system 216 (Figure 1A). Accordingly, as tube bundle 1609 is fully inserted within exhaust gas manifold, a clamp coupling the end portion of exhaust gas manifold 106 and the tube header 1605 exerts a compression force compressing seal 1813 of the tube header 1605, thereby ensuring sealing of the “shell side” now formed by the outer surfaces of the tubes comprised by tube bundle 1609 and the inner walls of exhaust gas manifold 106. As engine 40 cylinders mechanically coupled to exhaust gas manifold 106 via port and flange 106B, manifest movement during operation in combination with thermal expansion and contraction of the exhaust gas manifold 106, flexible members 106C allow for the exhaust gas manifold to freely expand or contract. In this configuration, mechanical movement manifested by the exhaust gas manifolds 106 does not cause stresses to the tube bundle 1609 as the tubes are supported by sliding vanes 2112 (shown in Figures 21A and 21B).

[00103] Figures 22-24 illustrate exemplary block diagrams showing “power flows” from a WHRC system (e.g., WHRC system 10) retrofitted on combustion engine 40 platforms (i.e. locomotive, automotive, DMUs, marine, stationary) with the PCU 30 configured to hybridize and increase efficiency of the combustion engine by integrating electric storage systems (e.g. batteries) and including with the retrofit a customized traction motor (e.g. 1321, 1331, 1506) to augment the combustion engine power and to recover electric energy during regenerative braking.

[00104] Figure 22 illustrates an exemplary embodiment of the PCU 30 of the WHRC system of the present disclosure for automotive and rail applications wherein the vehicle is operated in acceleration and cruise modes. As shown, under the accelerating/cruising operational modes, the arrow “Power” flows in the direction of the converter, wherein a

portion of the recovered energy maybe stored through battery banks, conditioned for electrical auxiliary loads operating with 2 or 3 phases, or inverted to drive the traction motor (e.g. 1321, 1331, 1506). Power management is executed by controller 114.

[00105] Figures 23 describes a block diagram summarizing the configuration of the PCU 30 of the WHRC system of the present disclosure for automotive and rail applications wherein the vehicle is decelerating or braking. Under these operational modes, the traction motor may be configured to operate as a generator to recharge batteries and/or to dispatch energy to auxiliary loads (or to the grid via, for example, third rail 1510 Figure 15C). Similarly, controller 114 may be configured to manage regenerative braking when the vehicle is decelerating.

[00106] Figure 24 describes a block diagram summarizing the configuration of the PCU 30 of the WHRC system of the present disclosure for automotive and rail applications wherein the vehicle is idling or at start-up and the battery system of the PCU 30 may be configured to provide power to augment engine air-intake and reduce pollutant emissions in agreement with the PCU 30 pollution reduction features described herein.

[00107] Figure 25 illustrates an exemplary block diagram of a configuration of the integral PCU 30 for the hybridization of vehicles and stationary platforms powered by combustion engines (e.g. 40) in accordance with aspects of the present disclosure. The diagram shown in this Figure summarizes the thermal energy recovery components and the conversion electrical components for the generation and distribution of conditioned electrical power. Figure 25, generalizes the various operational modes (i.e. acceleration/cruising, deceleration and regenerative braking, and pollution reduction via compressed air produced by the electrically driven compressor turbine 122. In this summarizing representation the heat exchanger is represented by the cumulative effects of most of the heat exchangers described

herein (e.g. Ex-HEX 25, IR-HEX 20, EC-HEX 21, S-HEX 22, M-HEX 23, and GEN-HEX 26). In this configuration C-HEX 24 is integrated with reservoir 108.

[00108] Figure 26 illustrates a block diagram of an exemplary layout of the WHRC system 10 comprising the PCU 30, engine exhaust gas manifold 149, and other components described herein in accordance with aspects of the present disclosure.

[00109] Figure 27 illustrates a cluster of PCUs 30 retrofitted with a locomotive engine (e.g. engine 40), wherein each PCU 30 may be configured to provide power ratings that best match locomotive operations and duty cycle. In this configuration, the PCU systems 30 may be configured to output maximum efficiencies at low, intermediate and maximum locomotive power settings. In this configuration, a given PCU may be optimized to operate with organic fluid, as first fluid 29, to recover very low waste heat energy generated by the engine when idling and/or operating at low power settings. Another PCU may be configured to operate with a different organic fluid, as first fluid 29, so as to maximize efficiency for waste heat energy characteristics matching locomotive engine operations at intermediate power settings, the remaining PCU 30 may be configured to operate with water, as first fluid 29, to maximize power recovered power without the temperature limitations represented by organic fluids. Additionally, the PCUs 30 forming the cluster, may be configured to maximize total production of conditioned recovered electric energy by electronically and thermal-hydraulically transfer power from one PCU to another. In this configuration, at any moment, each individual PCU 30 may increase or decrease its electric power production proportionally to the amount of waste energy being recovered and depending on the real-time locomotive engine duty cycle. Additionally, in case of failure of any of the units forming the PCU cluster, the remaining PCUs 30 may automatically reconfigure to increase electric production so as to not impact the net amount of electricity produced and the proportional fuel savings.

Under this scenario, the faulty unit or any of the remaining operational unit may wirelessly alert a remote receiver so as to organize PCU swapping at the earliest and most convenient opportunity for the locomotive operators. The wireless communication transceivers 2701, which may be integrated with the controller 114 or managed independently as stand-alone transceivers, may also be utilized to transmit technical data under standard data transmission protocols. Data collected by controller 114 and (wirelessly) transmitted by transmitters 2701 may include electricity/power rates, cumulative production rates (i.e. kWhr), thermodynamic parameters, vibration and wear and tear parameters, which may be utilized for real-time technical and economic performance evaluations and to plan refurbishing of replacing components prior to undergoing damages or failures.

[00110] The present disclosure is not to be limited in terms of the particular examples described in this application, which are intended as illustrations of various aspects. Many modifications and variations can be made without departing from its spirit and scope, as will be apparent to those skilled in the art. Functionally equivalent methods and apparatuses within the scope of the disclosure, in addition to those enumerated herein will be apparent to those skilled in the art from the foregoing descriptions. Such modifications and variations are intended to fall within the scope of the appended claims. The present disclosure is to be limited only by the terms of the appended claims, along with the full scope of equivalents to which such claims are entitled. It is also to be understood that the terminology used herein is for the purpose of describing particular examples only, and is not intended to be limiting.

[00111] With respect to the use of substantially any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations may be expressly set forth herein for sake of clarity.

[00112] It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as “open” terms (e.g., the term “including” should be interpreted as “including but not limited to,” the term “having” should be interpreted as “having at least,” the term “includes” should be interpreted as “includes but is not limited to,” etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases "at least one" and "one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to examples containing only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., “a” and/or “an” should be interpreted to mean “at least one” or “one or more”); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should be interpreted to mean at least the recited number (e.g., the bare recitation of "two recitations," without other modifiers, means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to “at least one of A, B, and C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., “ a system having at least one of A, B, and C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or

A, B, and C together, etc.). In those instances where a convention analogous to "at least one of A, B, or C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., " a system having at least one of A, B, or C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that virtually any disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms. For example, the phrase "A or B" will be understood to include the possibilities of "A" or "B" or "A and B." In addition, where features or aspects of the disclosure are described in terms of Markush groups, those skilled in the art will recognize that the disclosure is also thereby described in terms of any individual member or subgroup of members of the Markush group.

[00113] While various aspects and examples have been disclosed herein, other aspects and examples will be apparent to those skilled in the art. The various aspects and examples disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

CLAIMS

What is claimed is:

1. A waste heat recovery conversion system (10) comprising:

a housing (402) configured to mount onto an engine (40); and

a power conversion unit (30) within the housing, the PCU comprising:

a plurality of heat exchangers (24, 25, 26);

an expander (128);

an electrical power generator (127); and

a fluid pump (107).

wherein the plurality of heat exchangers, the expander, the fluid pump, and the fluid reservoir form a thermodynamic loop that drives the electrical power generator using thermal energy from waste heat.

2. The waste heat recovery conversion system of claim 1, further comprising a plurality of vibration isolators (304) configured to mount between the housing and the engine.

3. The waste heat recovery conversion system of claims 1 or 2, wherein the plurality of heat exchangers comprising the PCU include a condenser.

4. The waste heat recovery conversion system of any of claims 1 to 3, wherein the plurality of heat exchangers comprising the PCU include a generator heat exchanger (26) that transfers waste heat from the electrical power generator to a first fluid.

5. The waste heat recovery conversion system of any claims 1 to 4, wherein the PCU further comprises a power module heat exchanger (145) mounted to electronics of the PCU, and configured to transfer waste heat from the electronics to a first fluid.

6. The waste heat recovery conversion system of any of claims 1 to 5, wherein maximum length of wires and tubes between the plurality of heat exchangers, the expander, the electrical power generator, and/or the fluid pump is about two feet.

7. The waste heat recovery conversion system of any of claims 1-6, further comprising an engine cooling system heat exchanger (21) configured to:

mount to an intake manifold (104) of the engine; and

transfer waste heat from the intake manifold to the first fluid.

8. The waste heat recovery conversion system of any of claims 1-6, further comprising a stack heat exchanger (22) configured to:

mount within an exhaust stack (102) of the engine; and

transfer waste heat from a second fluid flowing through the exhaust stack to the first fluid.

9. The waste heat recovery conversion system of any of claims 1-6, further comprising a manifold heat exchanger (23) configured to:

mount on an exhaust gas manifold (106) of the engine; and

transfer waste heat from a second fluid flowing through the exhaust gas manifold to the first fluid.

10. The waste heat recovery conversion system of claim 9, wherein the manifold heat exchanger is configured to fit on the exhaust gas manifold within the engine.

11. The waste heat recovery conversion system of claim 9, wherein the manifold heat exchanger is located within the housing.

12. The waste heat recovery conversion system of any of claims 1 to 6, wherein the vehicle is a locomotive.

13. The waste heat recovery conversion system of claim 12, wherein mounting structure is mounted above an engine compartment of the locomotive.

14. The waste heat recovery conversion system of claim 12, wherein mounting structure is mounted below an undercarriage of the locomotive.

15. The waste heat recovery conversion system of any of claims 1 to 6, wherein the vehicle is an automotive platform.

16. The waste heat recovery conversion system of any of claims 1 to 6, wherein the vehicle is a marine platform.

17. A method comprising retrofitting an engine (40) with a waste heat waste heat recovery and conversion system (10) as recited in any of claims 1 to 6.

18. The method of claim 17, further comprising retrofitting an intake manifold of the engine with a manifold heat exchanger (21) that transfers waste heat from the intake manifold to a first fluid.

19. The method of claim 17 or 18, further comprising retrofitting an exhaust stack of the engine with a stack heat exchanger (22) that transfers waste heat of a second fluid flowing through the exhaust stack to a first fluid.

20. The method of any claims 17-19, further comprising retrofitting an exhaust gas manifold (106) with a manifold heat exchanger (23) that transfers waste heat of the second fluid flowing through the exhaust gas manifold to the first fluid.

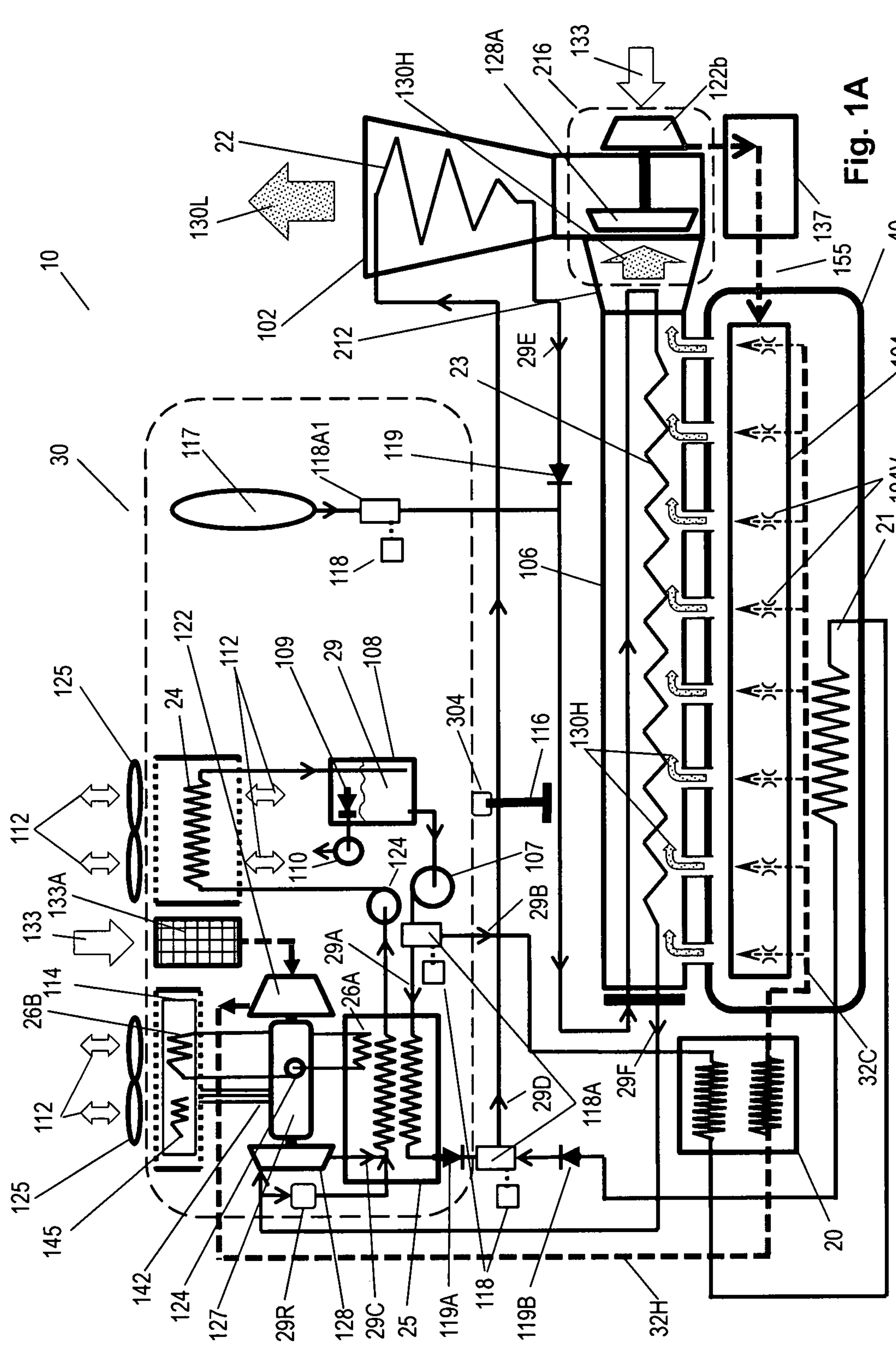
10
30
117
118A1
118
119
29E
212
102
22
130L
130H
128A
216
133
122b
137
155
40
104
104V
21
23
106
116
304
130H
125
112
24
122
112
109
29
108
110
124
107
133
133A
114
26B
29B
29A
26A
112
125
145
142
124
127
29R
128
29C
25
119A
118
119B
32H
29D
118A
29F
20
32C

Fig. 1A

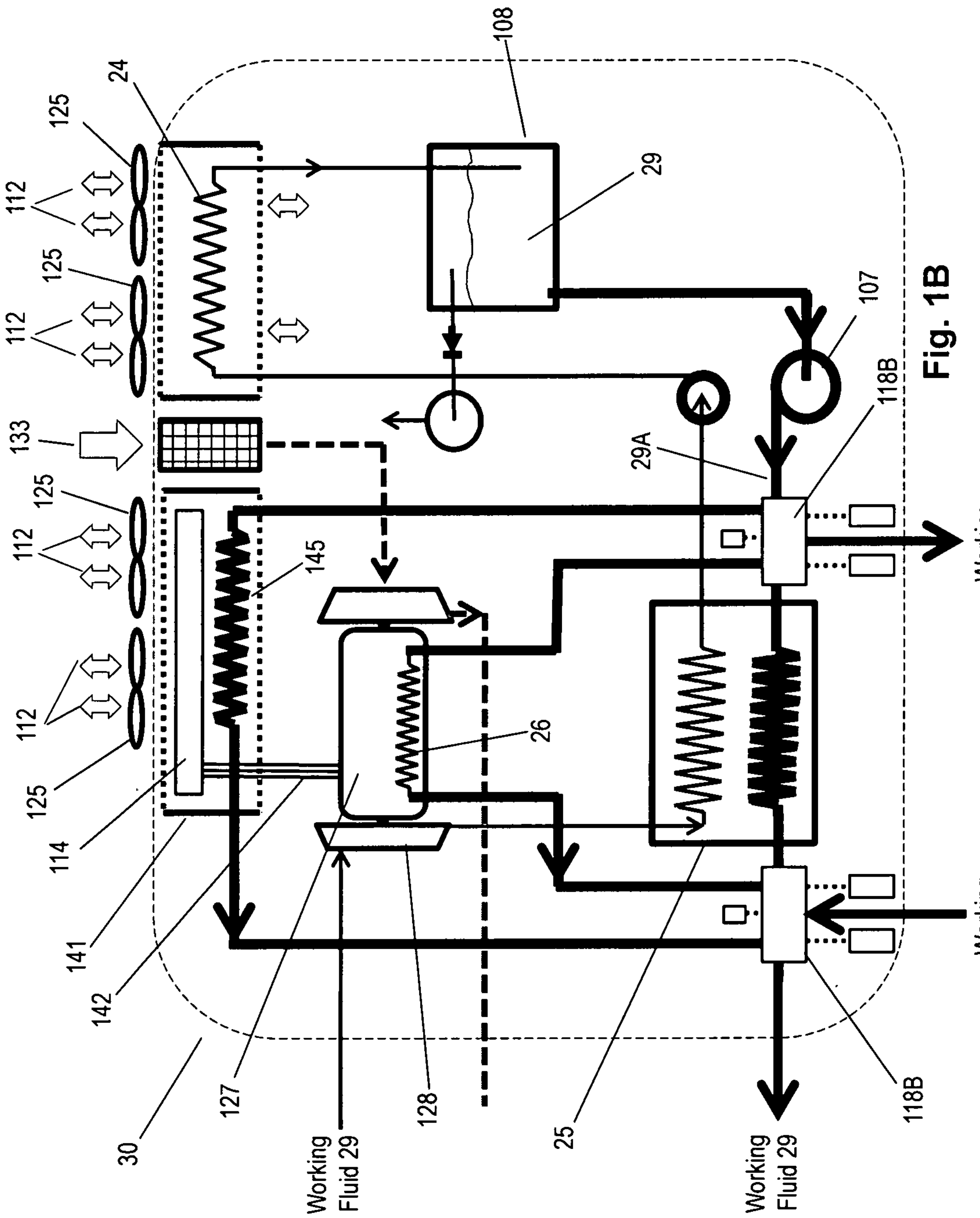
108
24
125
112
29
107
133
118B
29A
Working Fluid 29
145
26
114
141
142
30
127
128
25

Fig. 1B

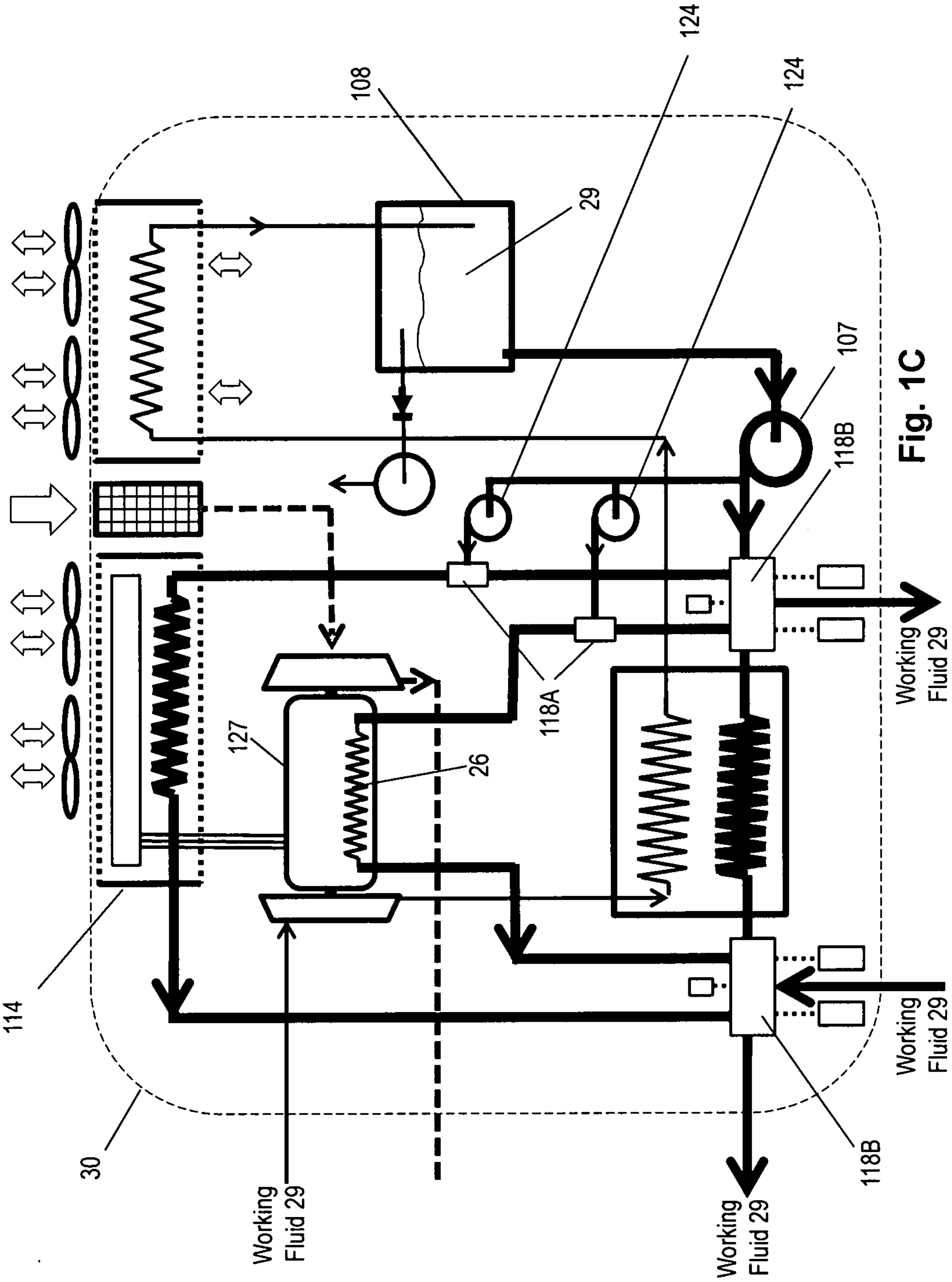
108
124
124
29
107
118B
118A
127
26
114
30
118B
Working Fluid 29
Working Fluid 29
Working Fluid 29
Working Fluid 29

Fig. 1C

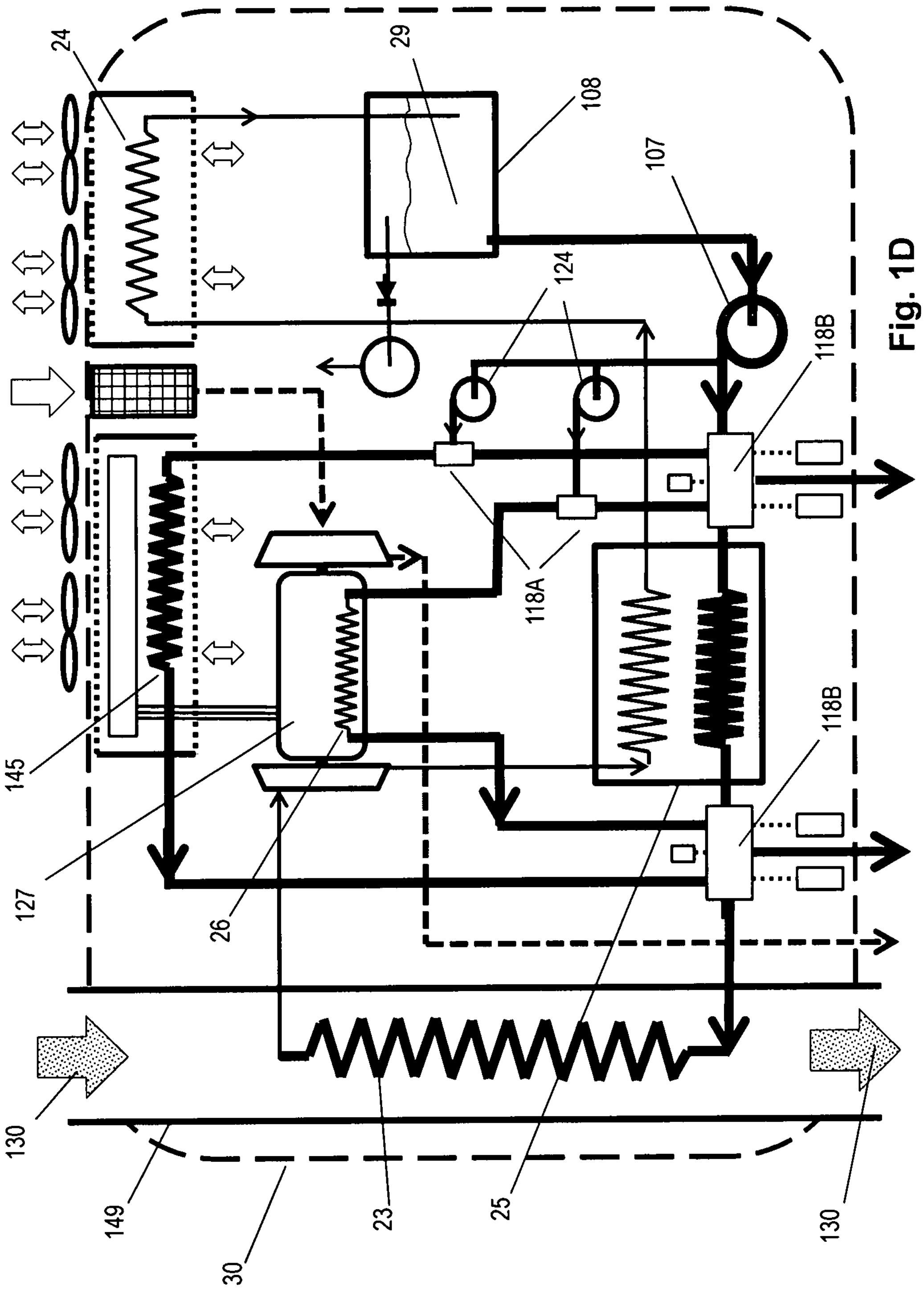

Fig. 1D

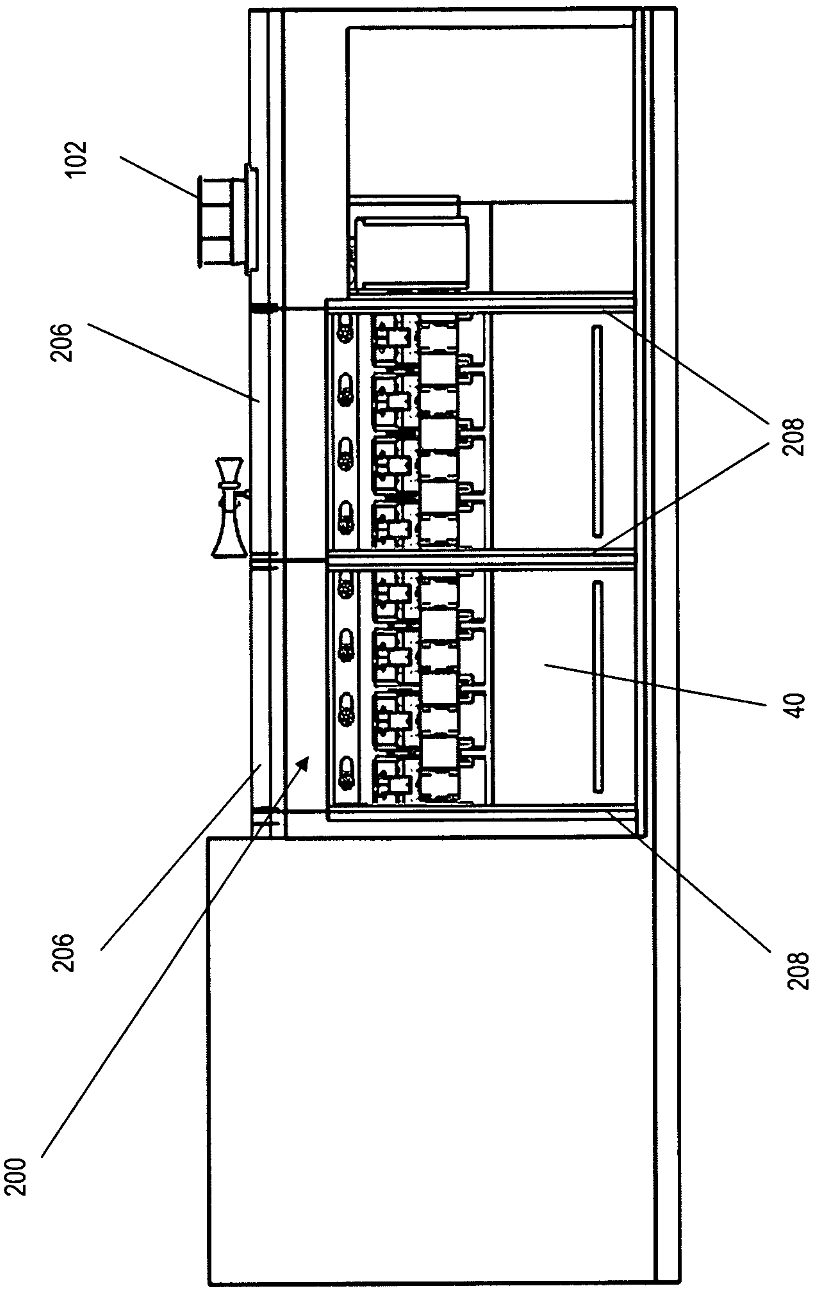

Fig. 2A

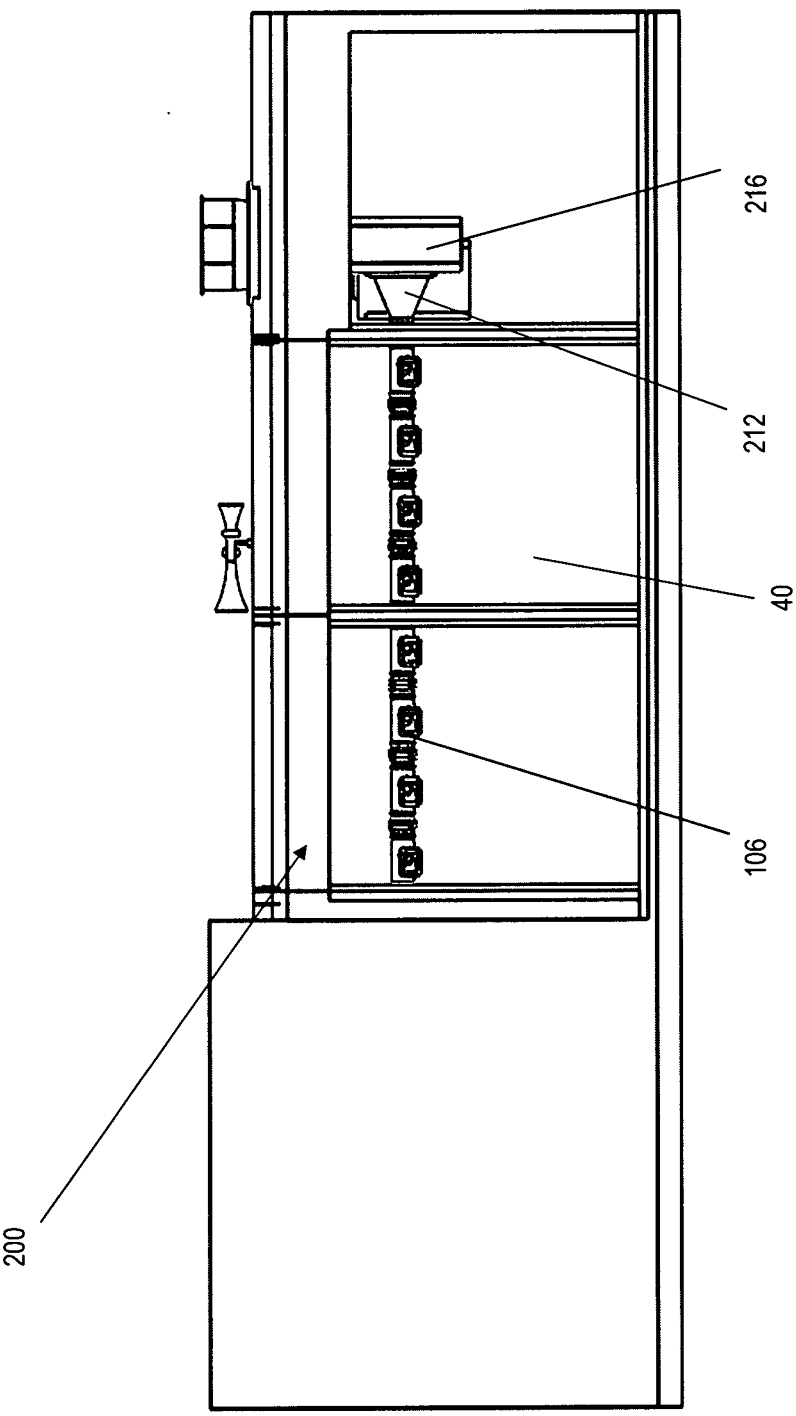

Fig. 2B

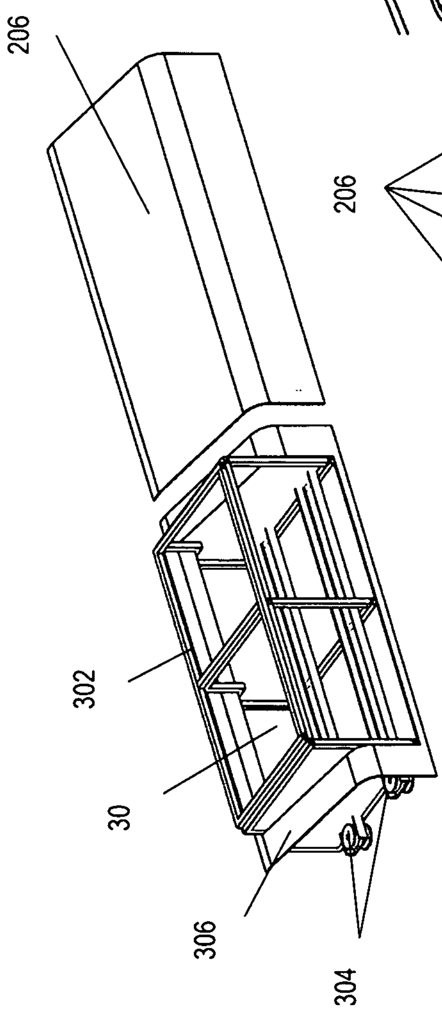

Fig. 3A

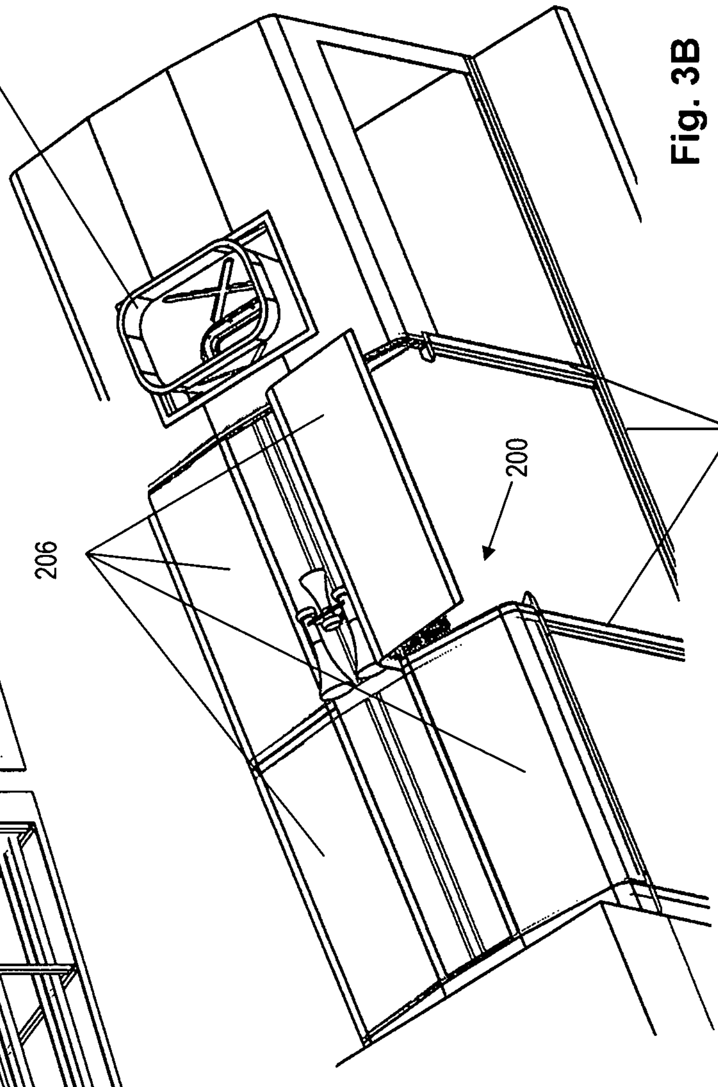

Fig. 3B

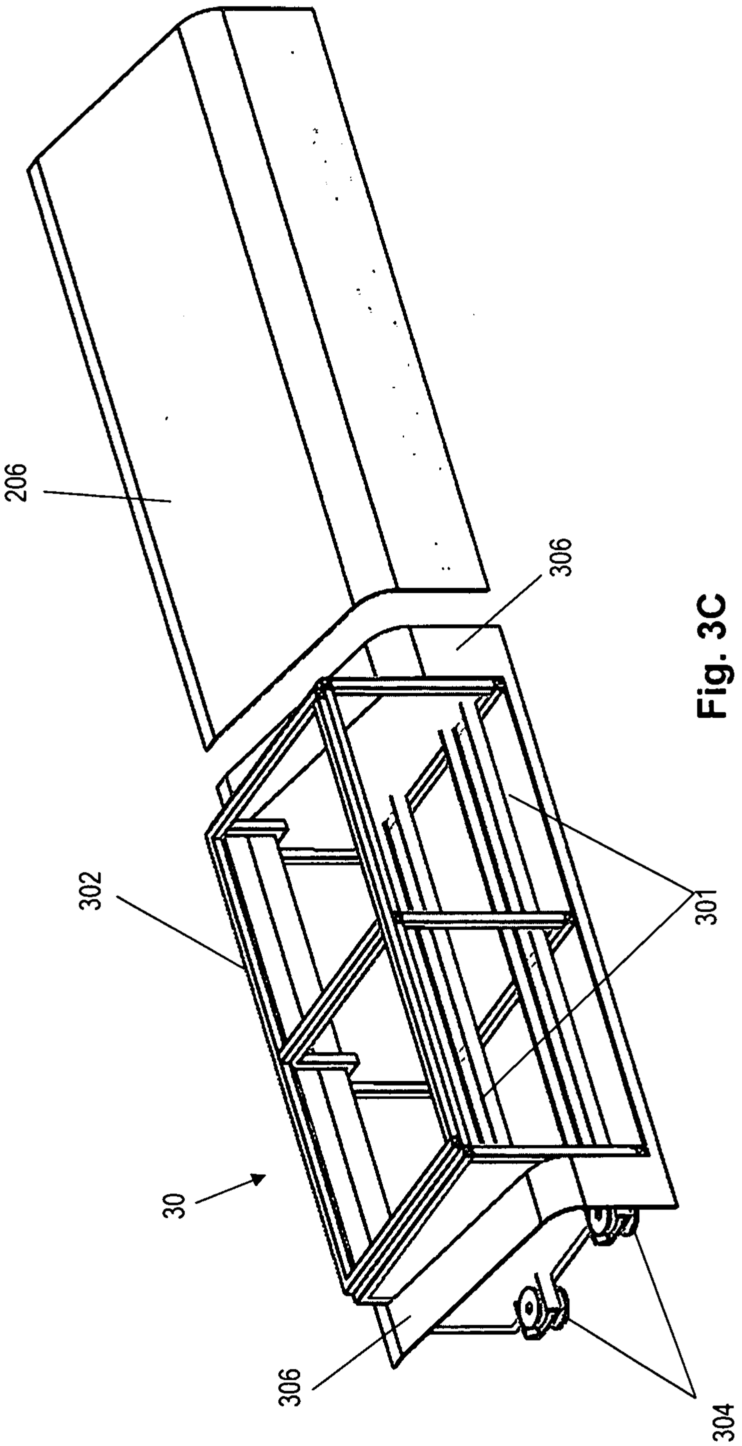

Fig. 3C

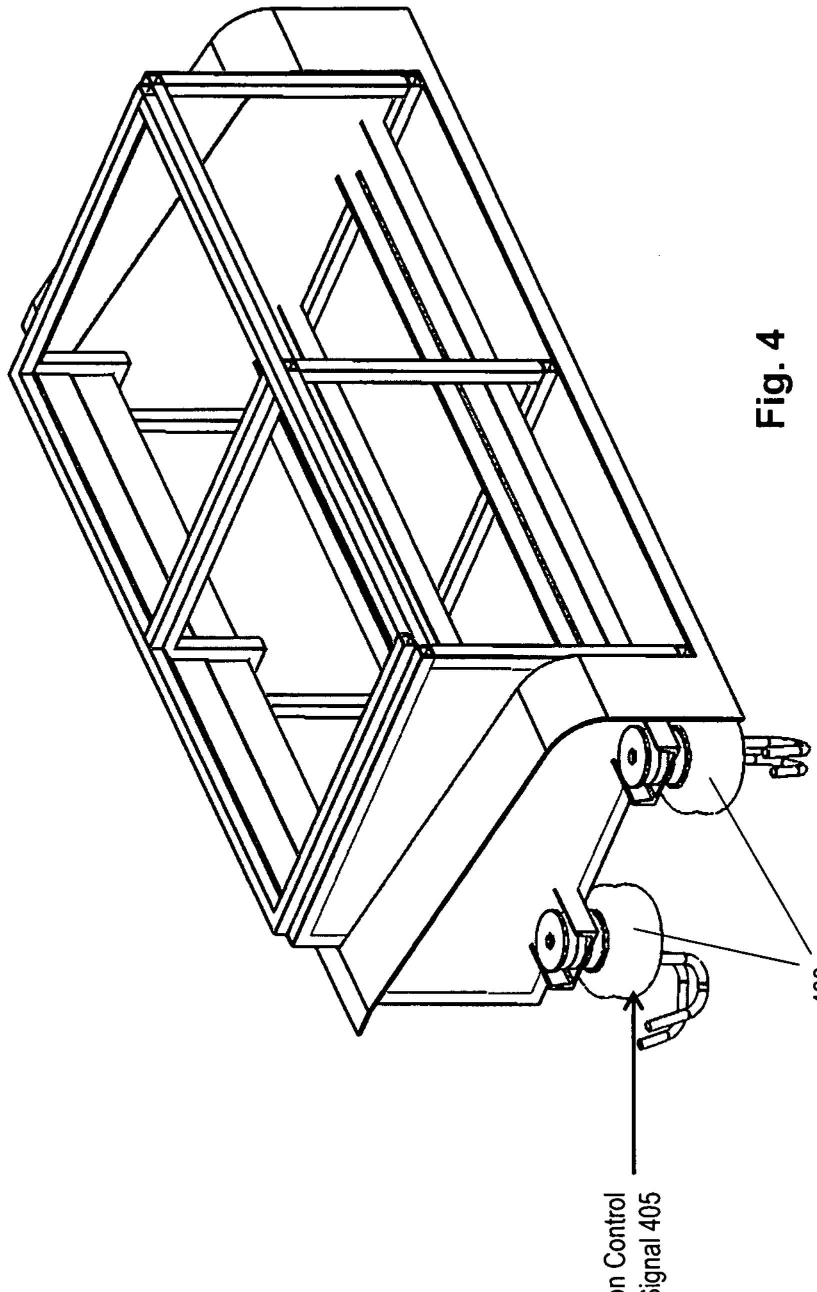

Fig. 4

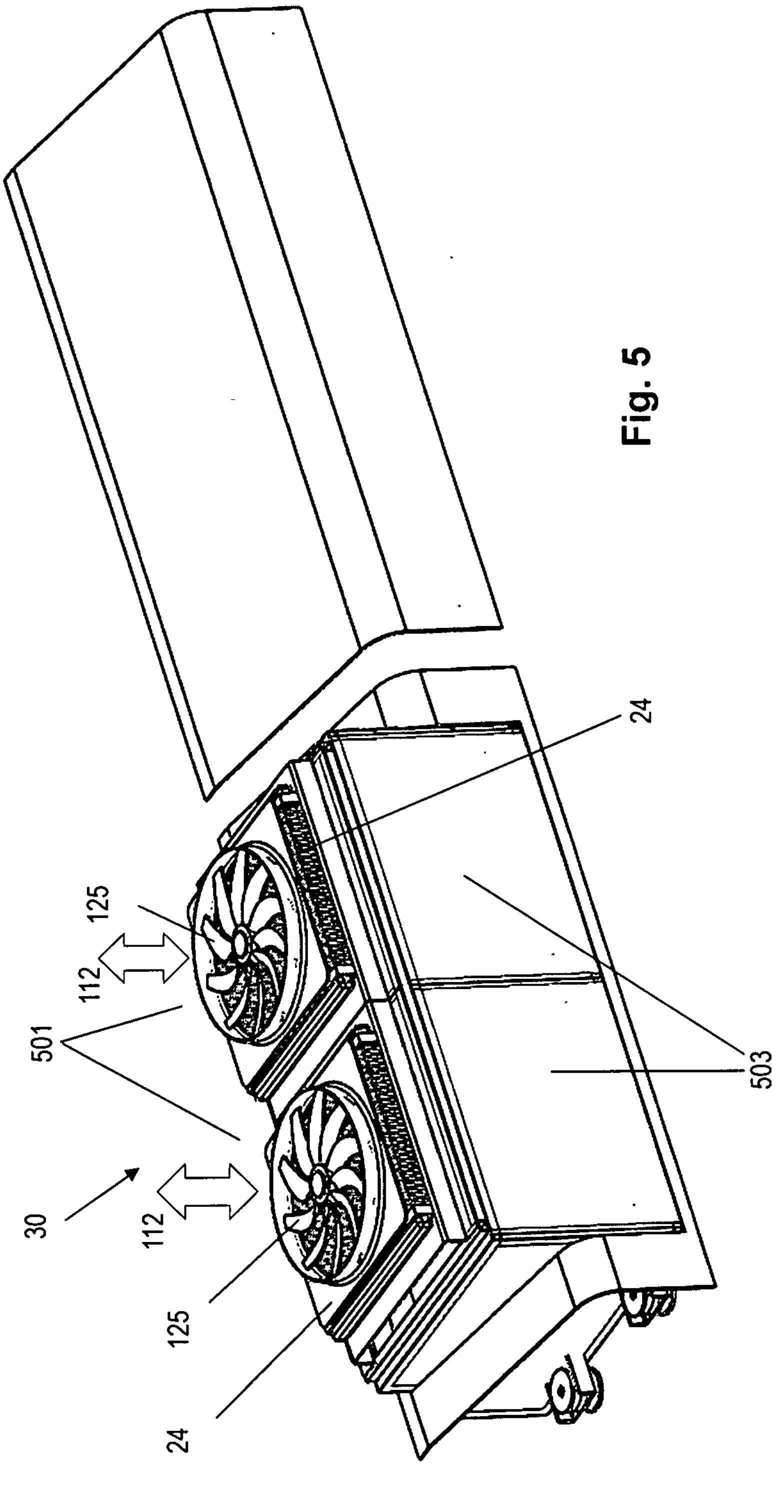

Fig. 5

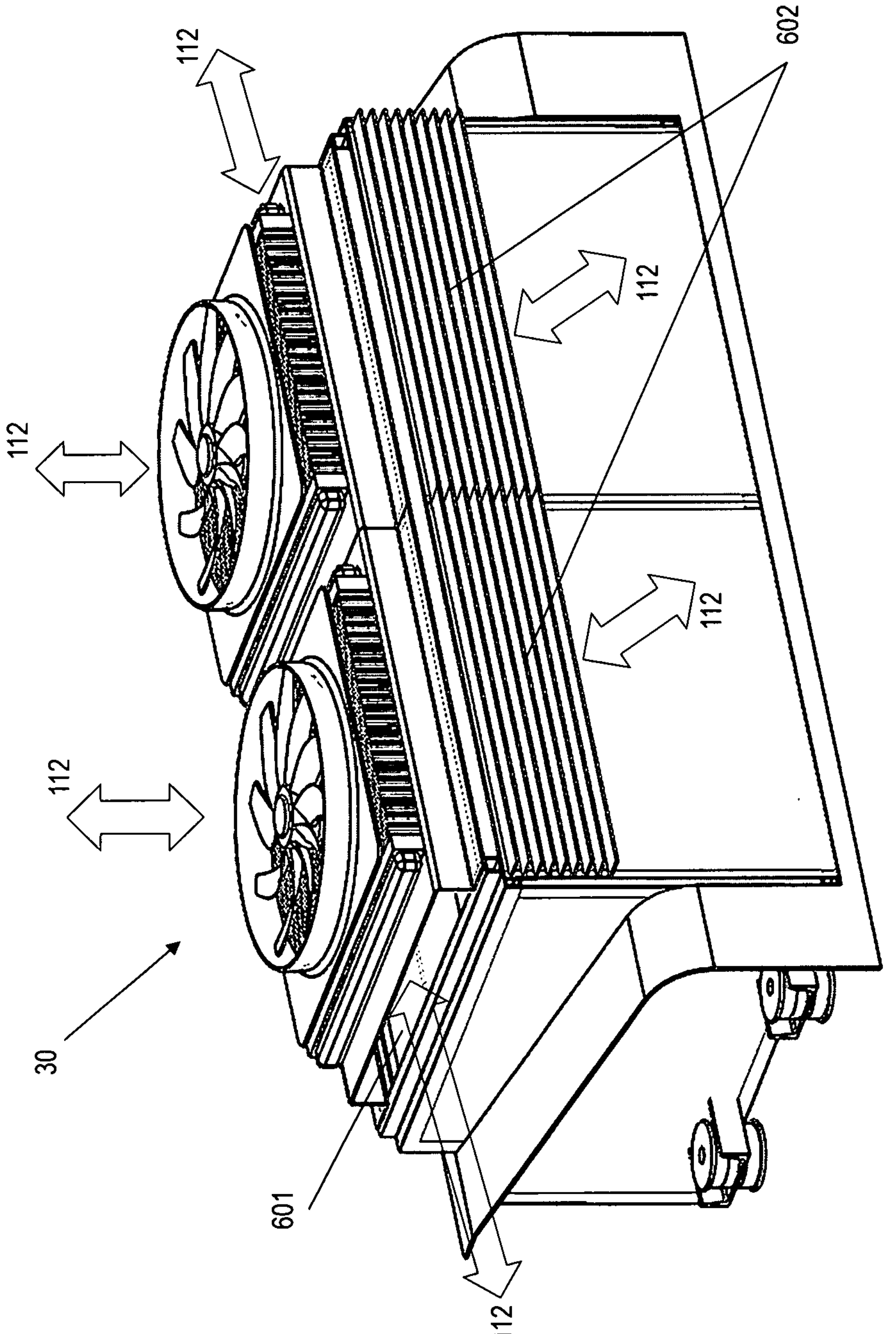

Fig. 6

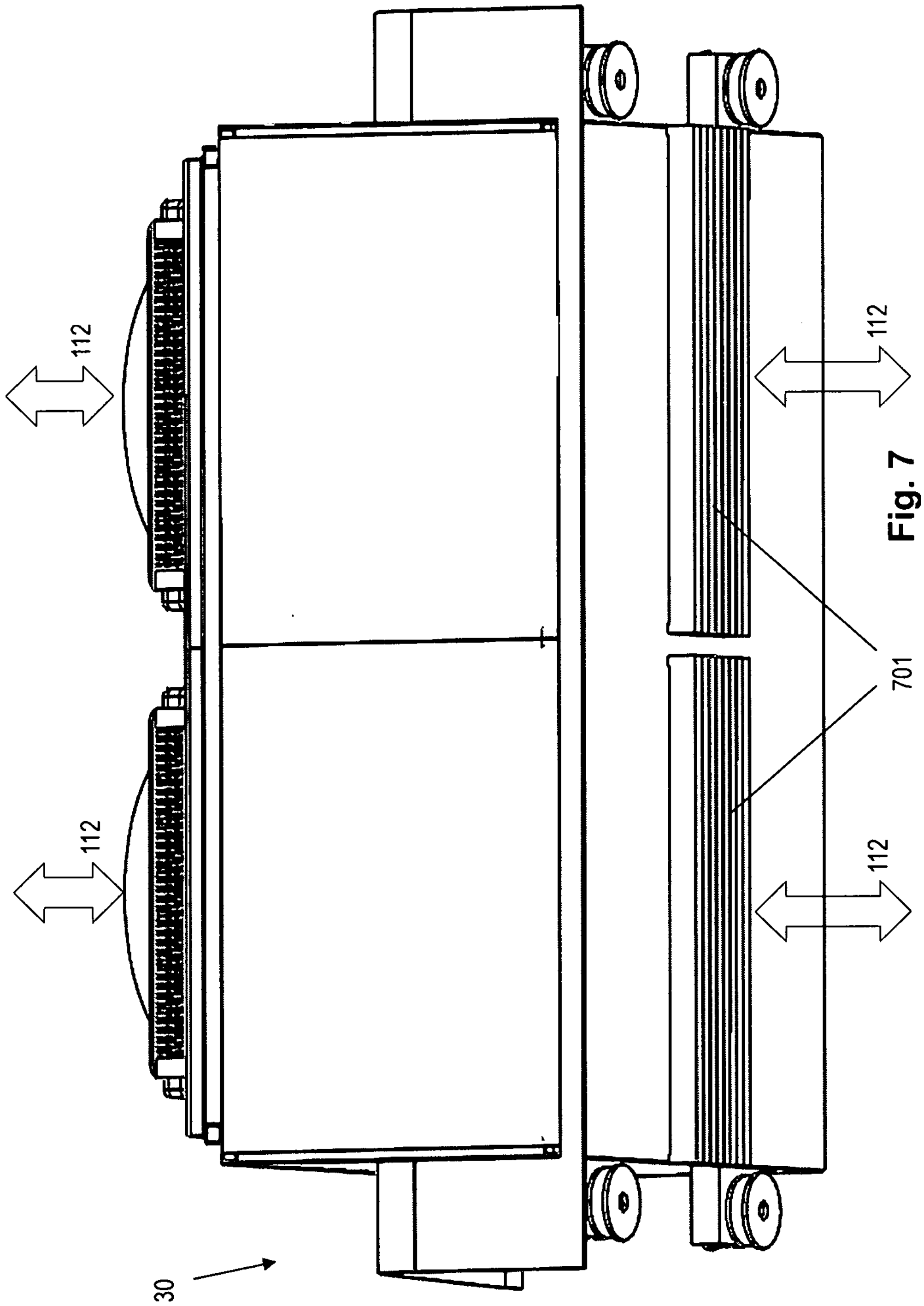

Fig. 7

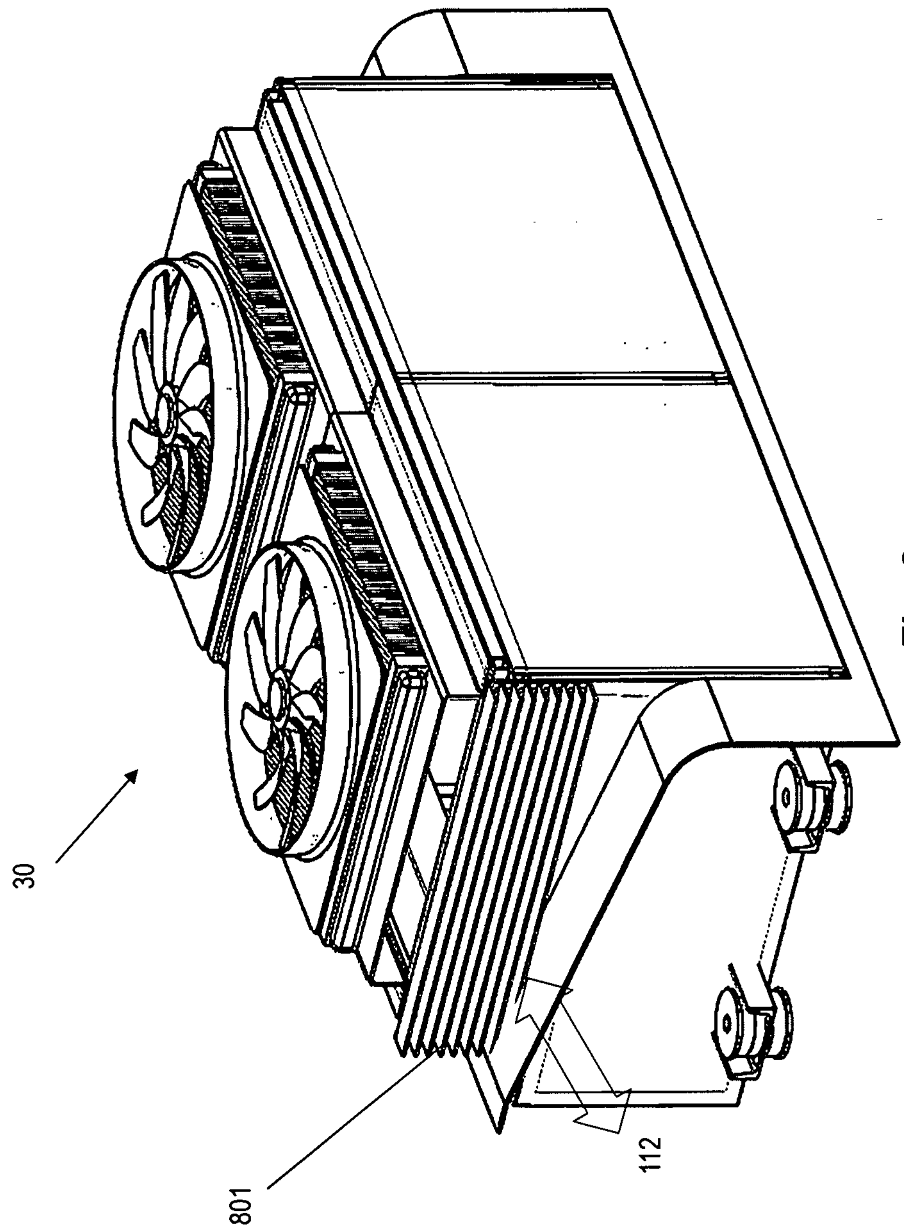

Fig. 8

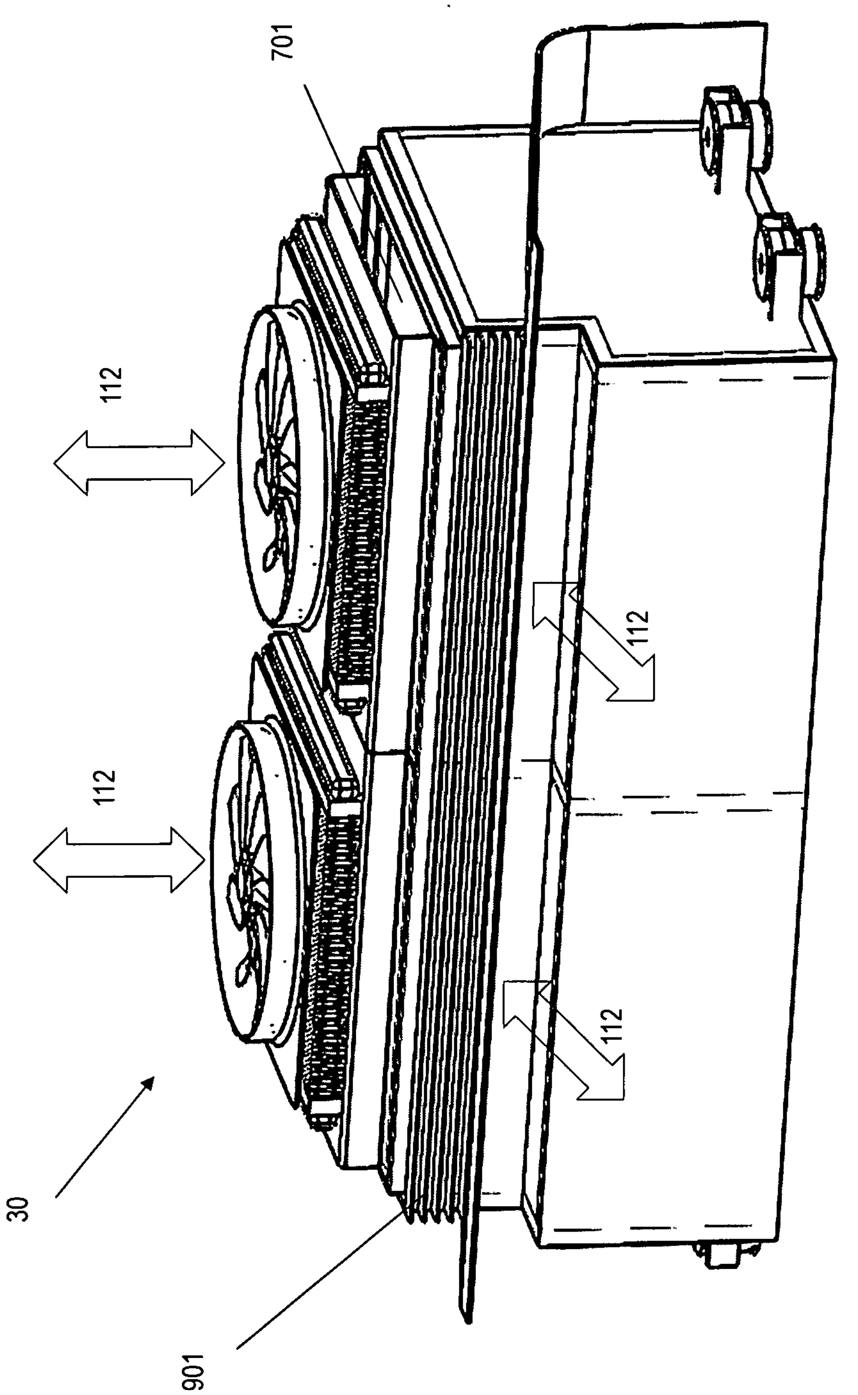

Fig. 9

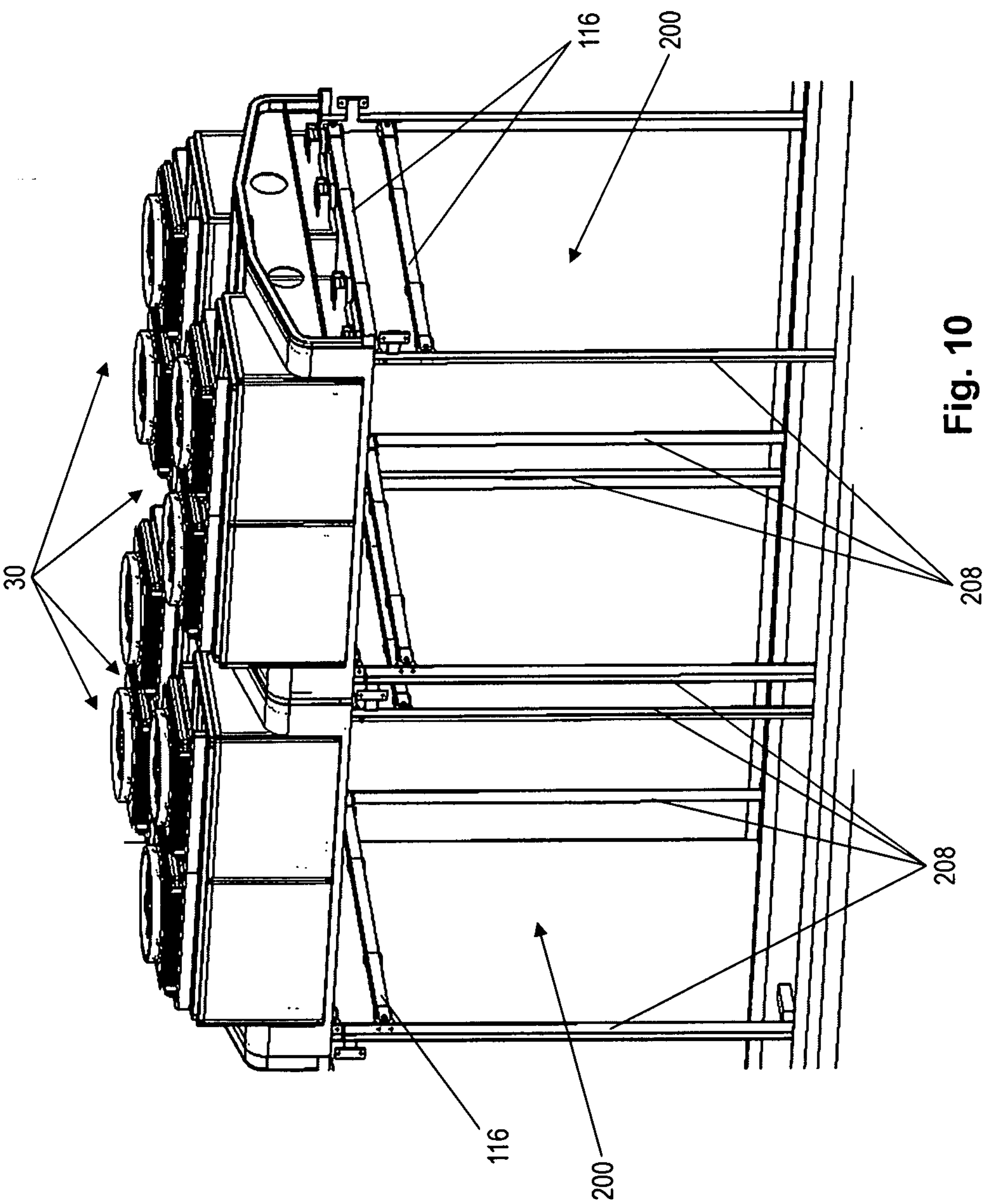

Fig. 10

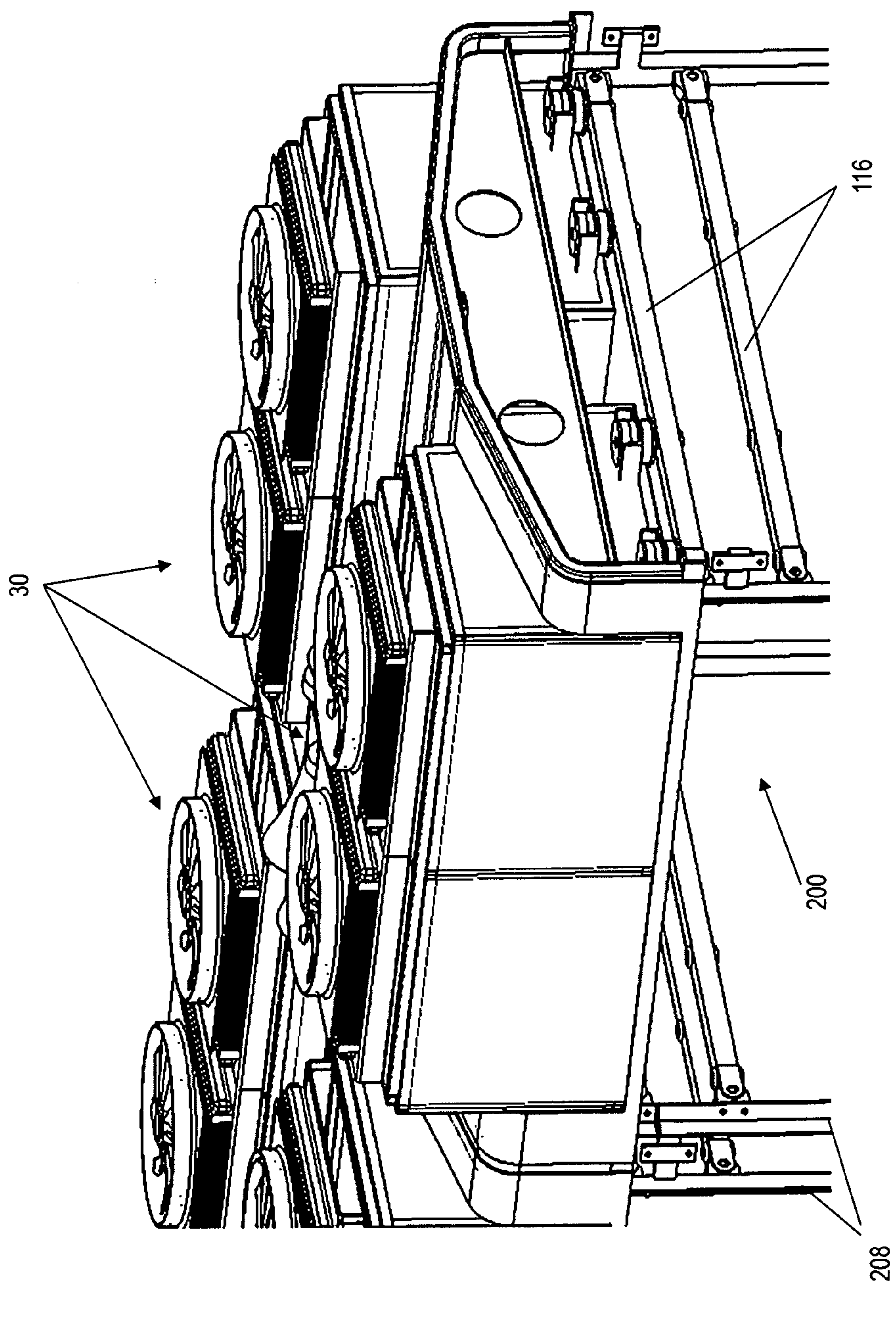

Fig. 11

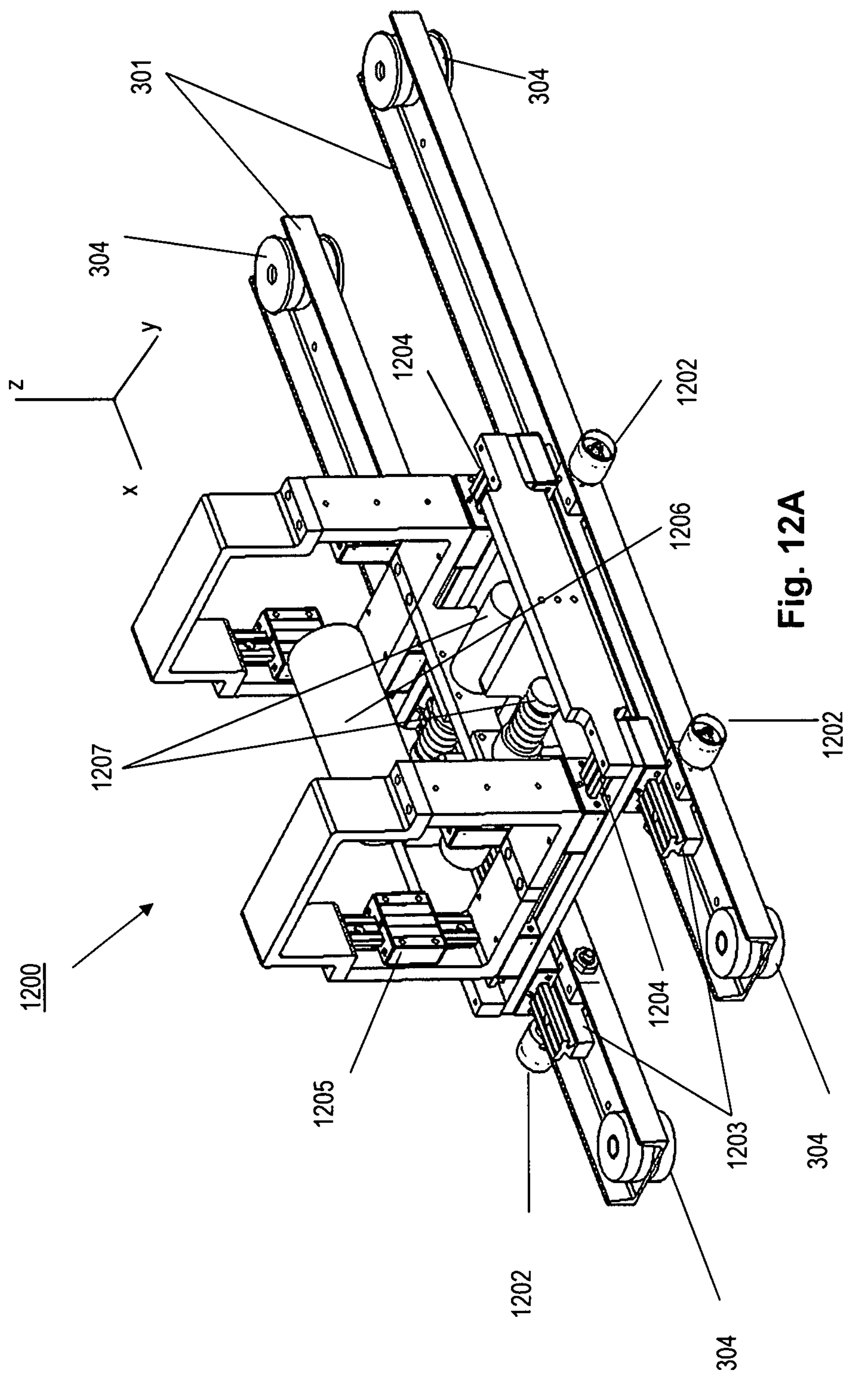
301
304
304
1204
1202
1206
1207
1202
1200
1205
1204
1203
304
1202
304
x
y
z

Fig. 12A

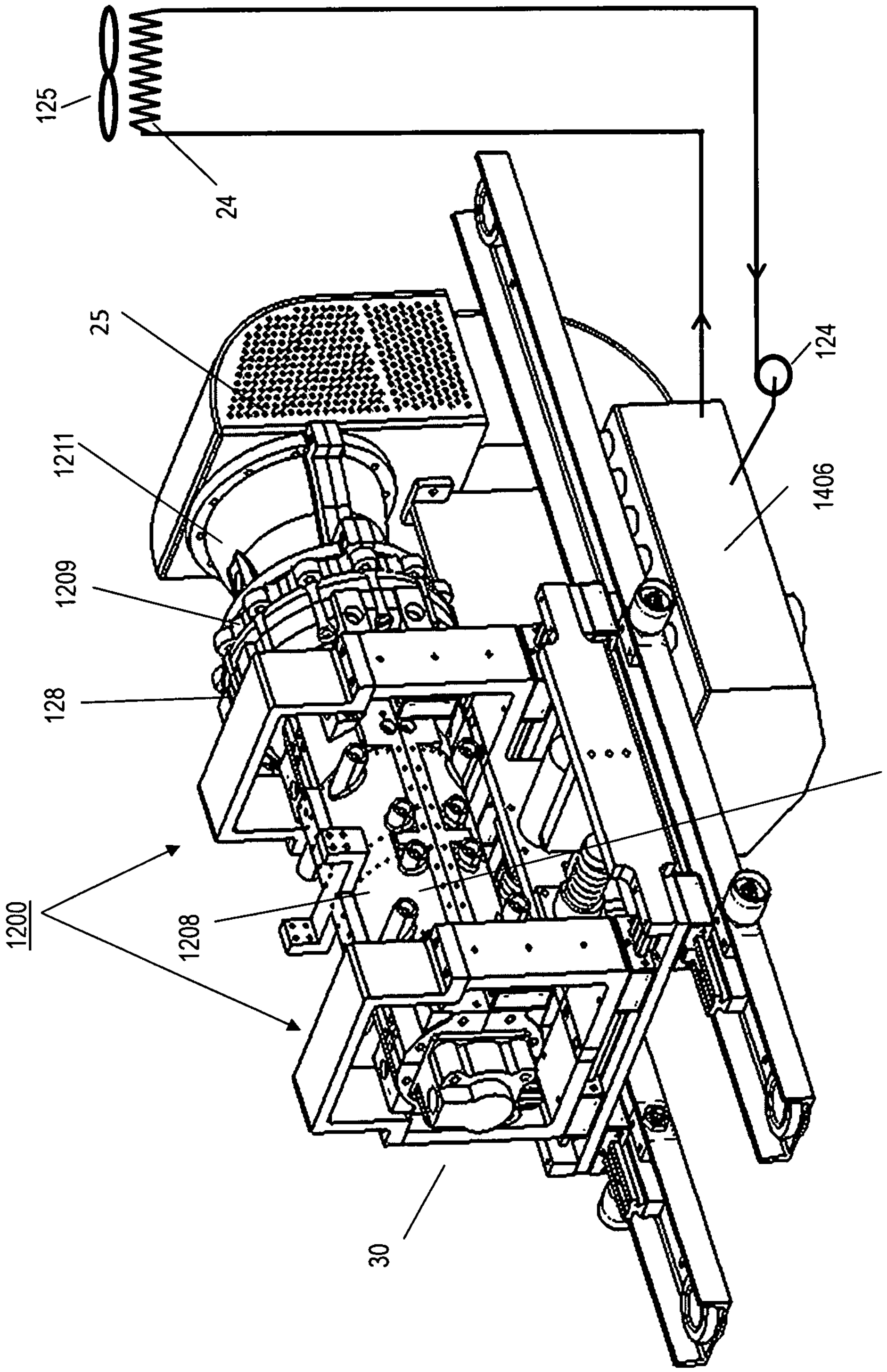

Fig. 12B

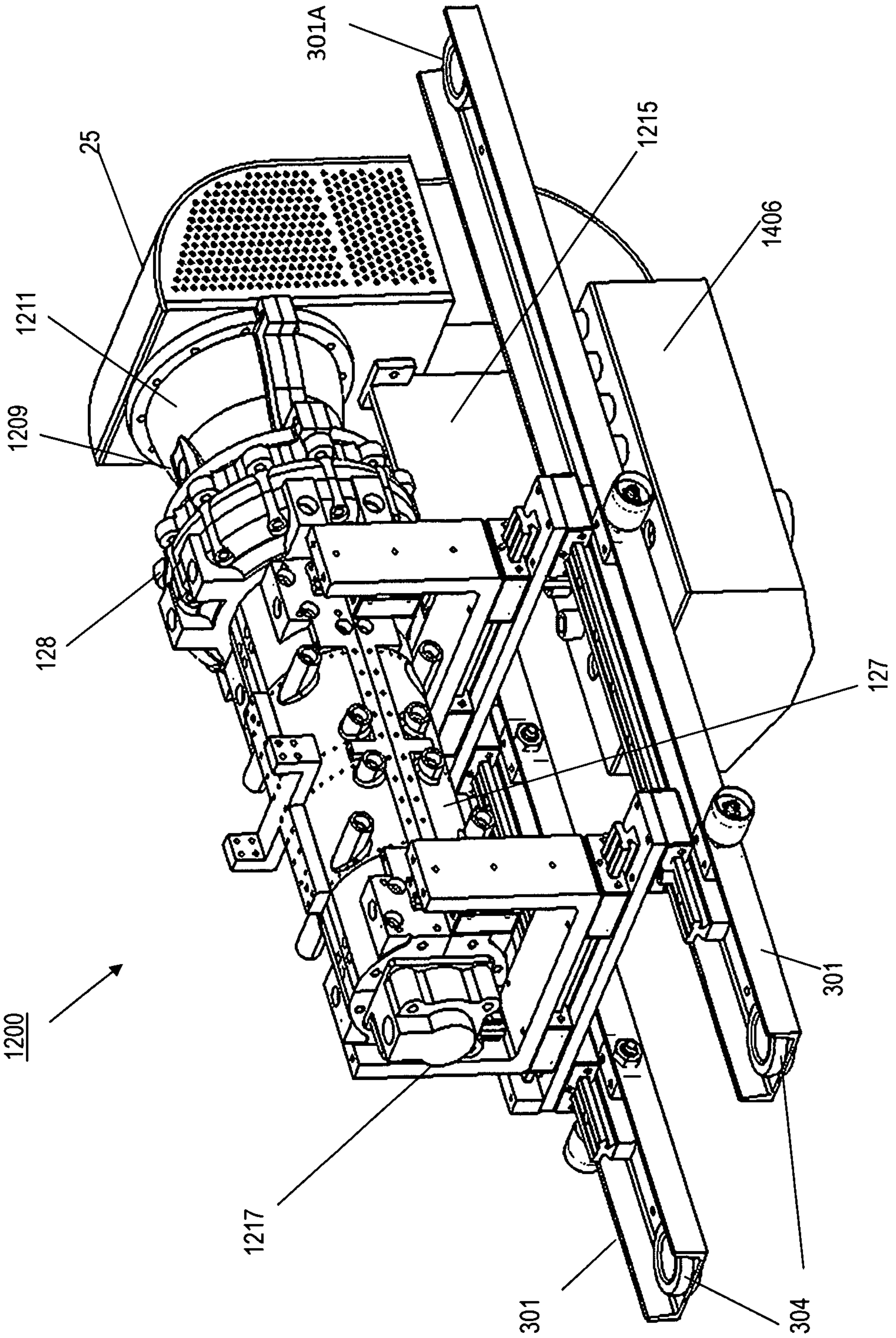

Fig. 12C

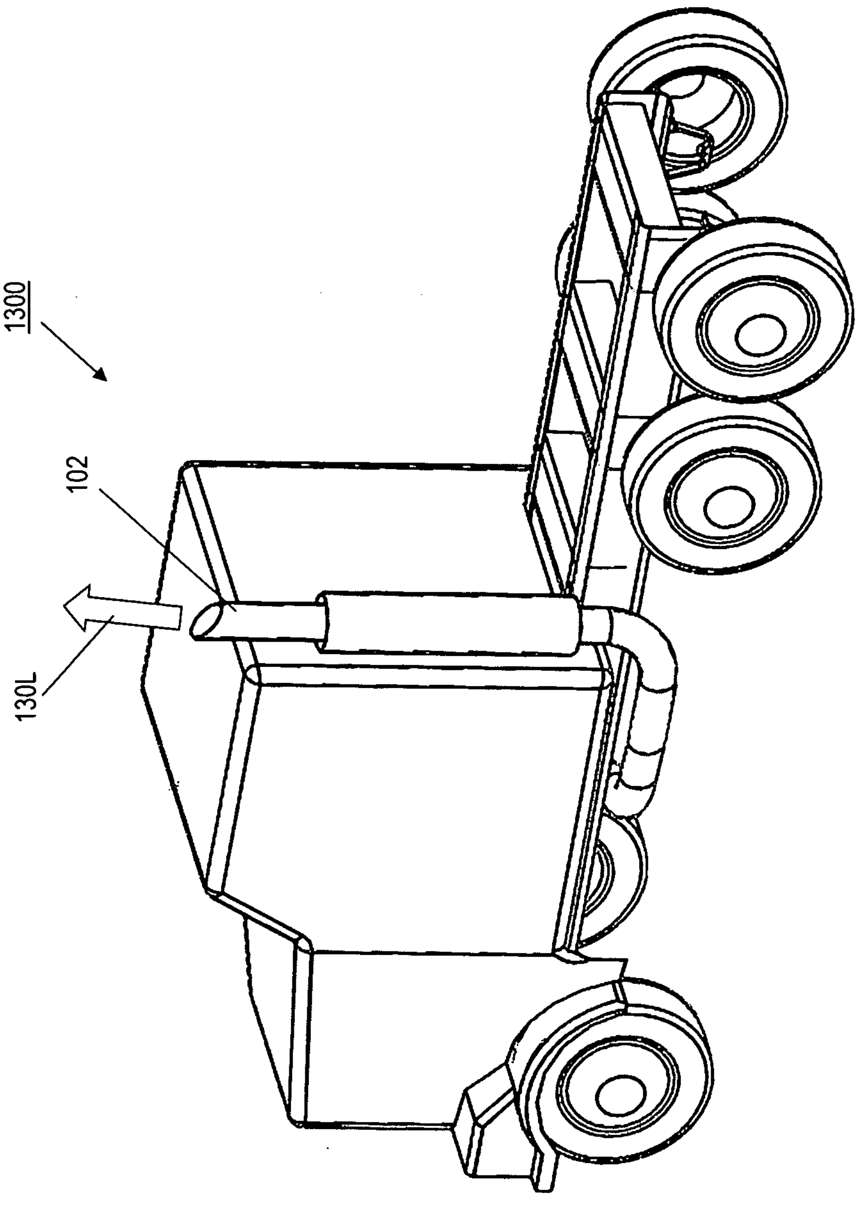

Fig. 13A

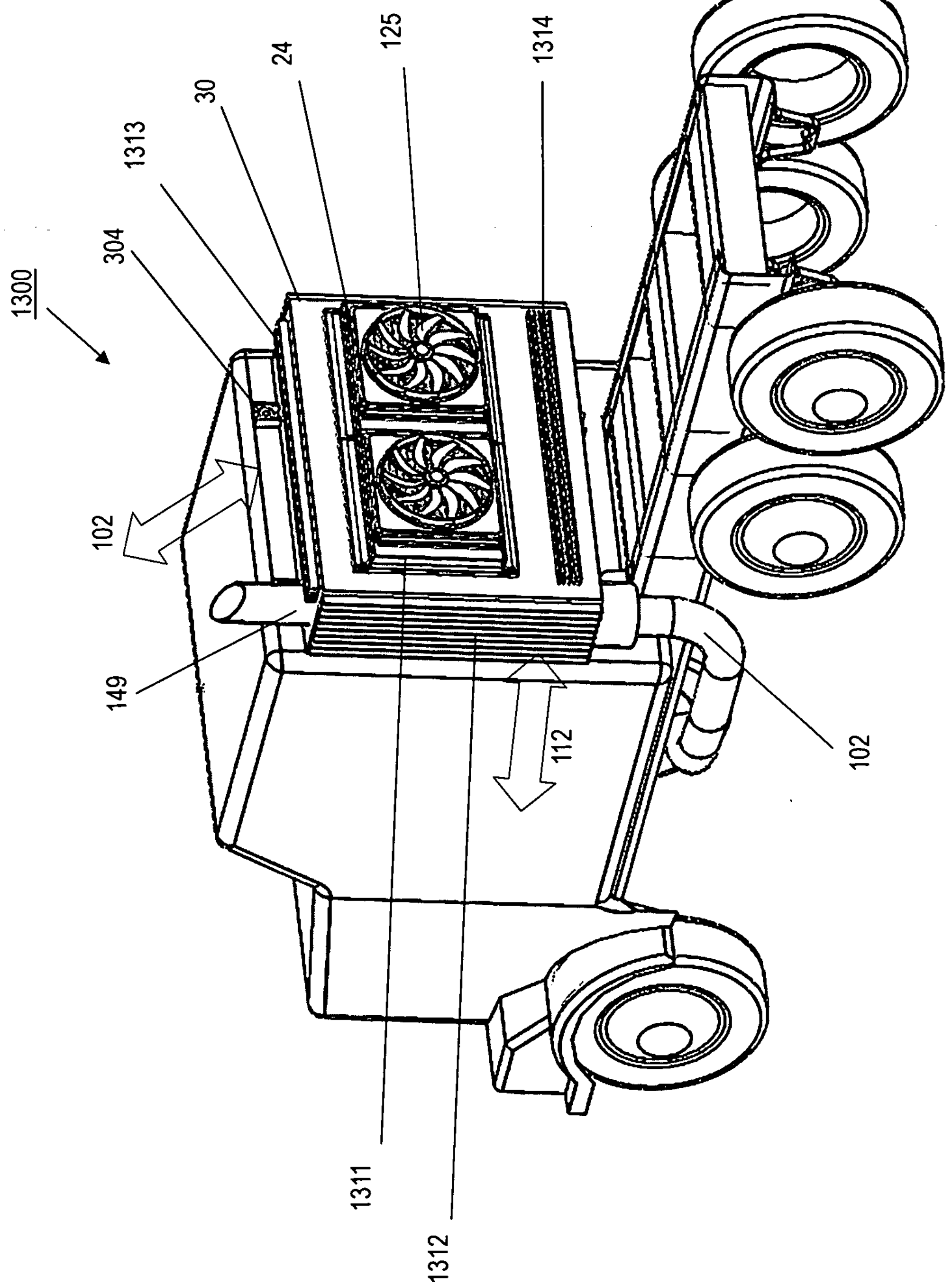

Fig. 13B

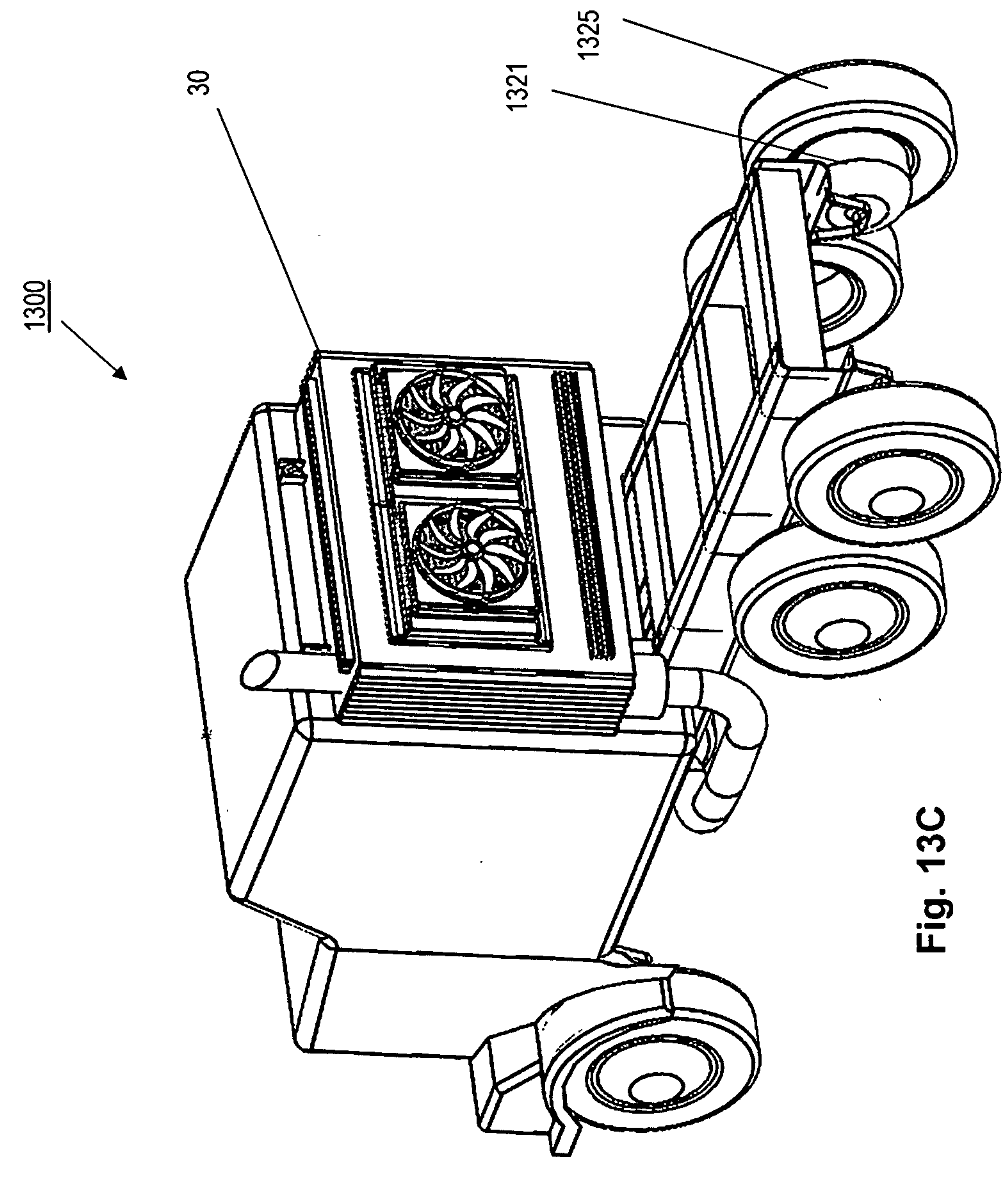

Fig. 13C

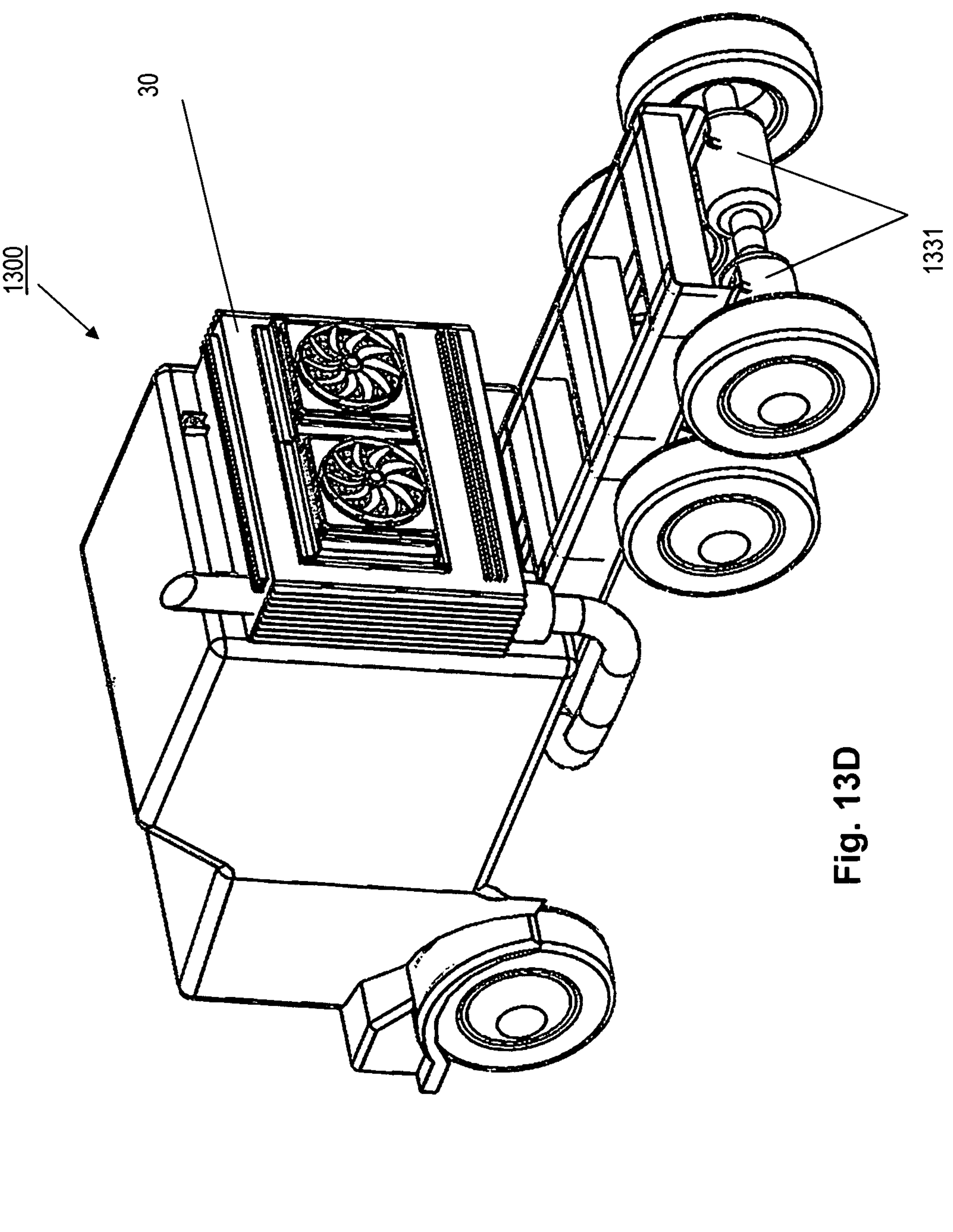

Fig. 13D

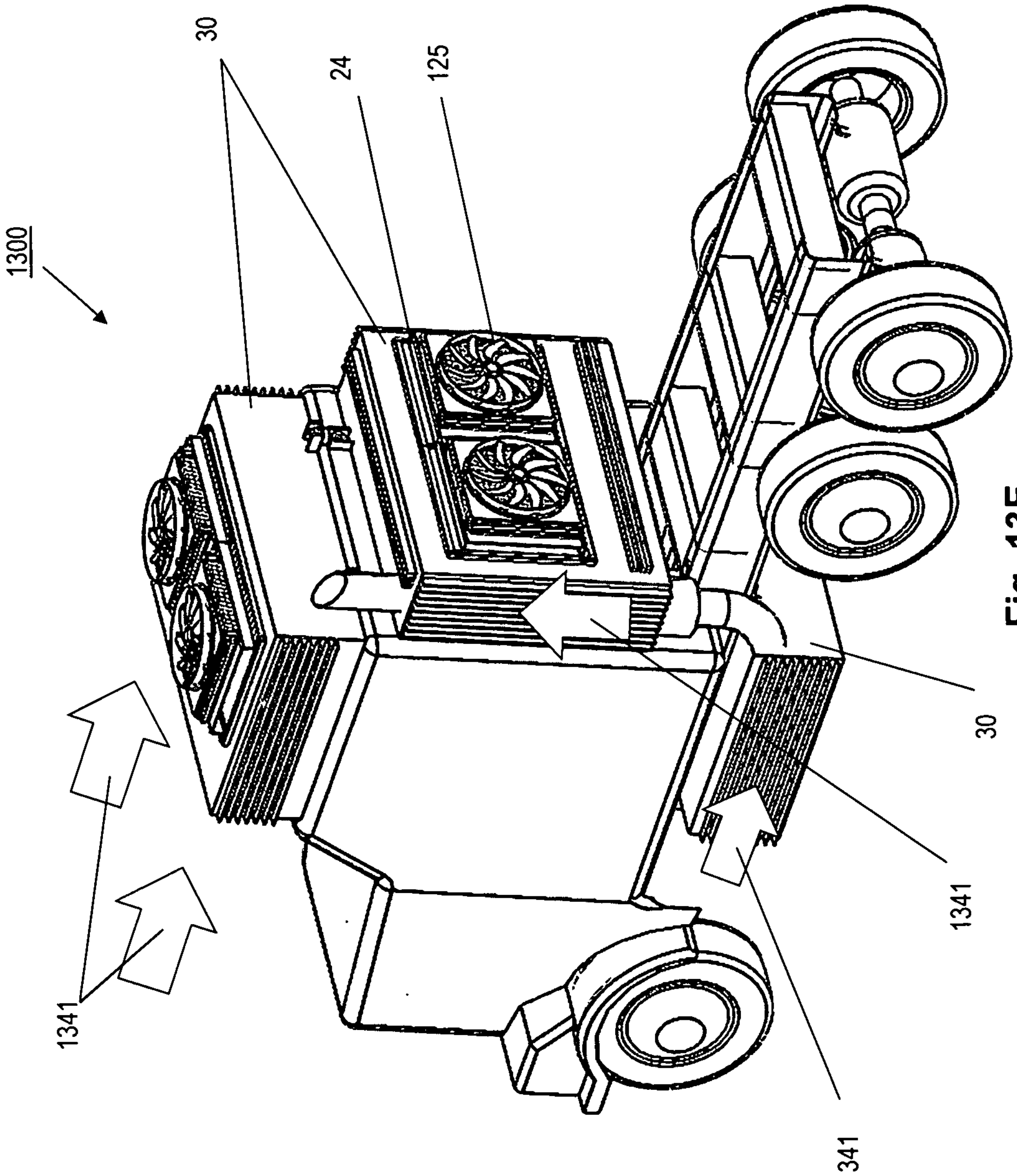

Fig. 13E

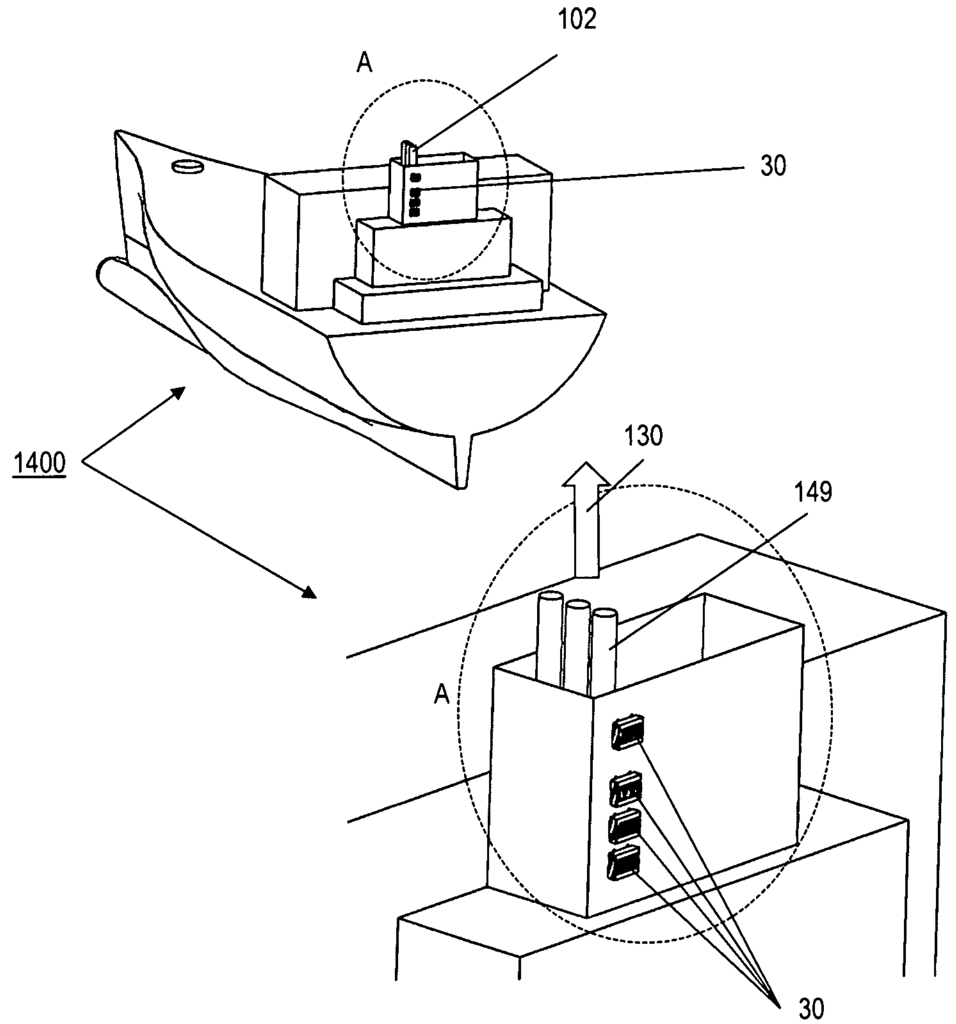

Fig. 14

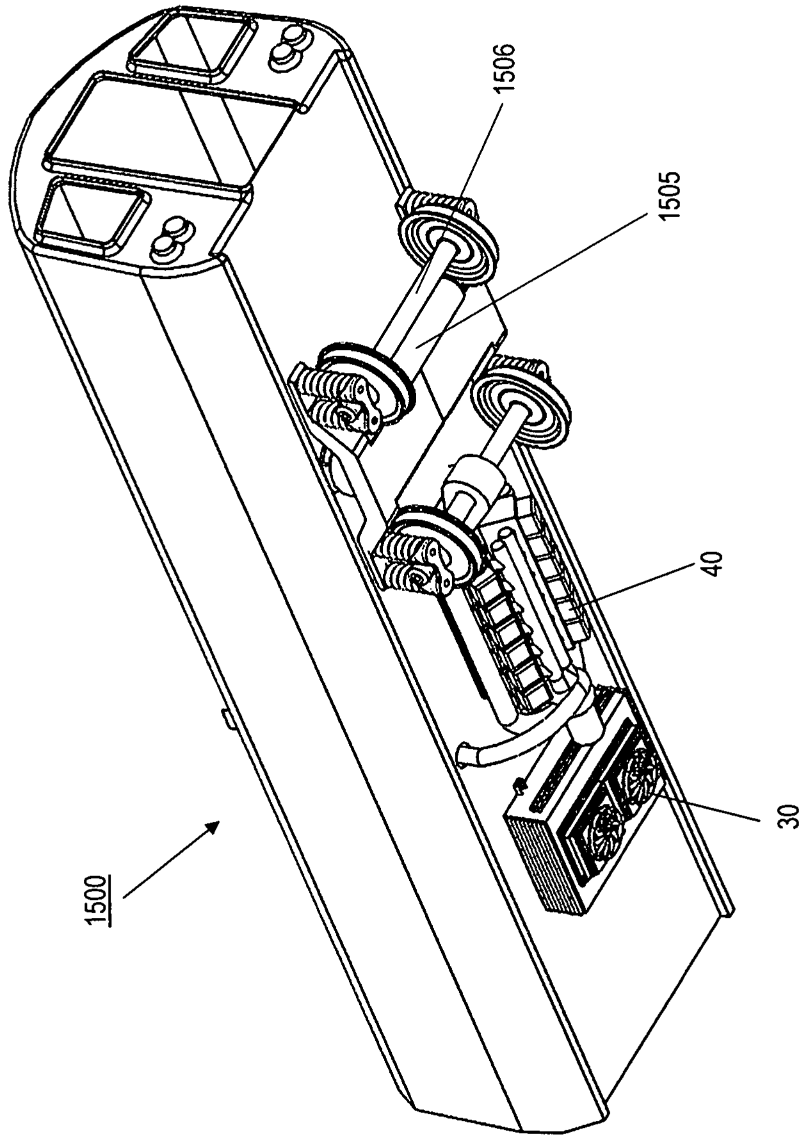

Fig. 15A

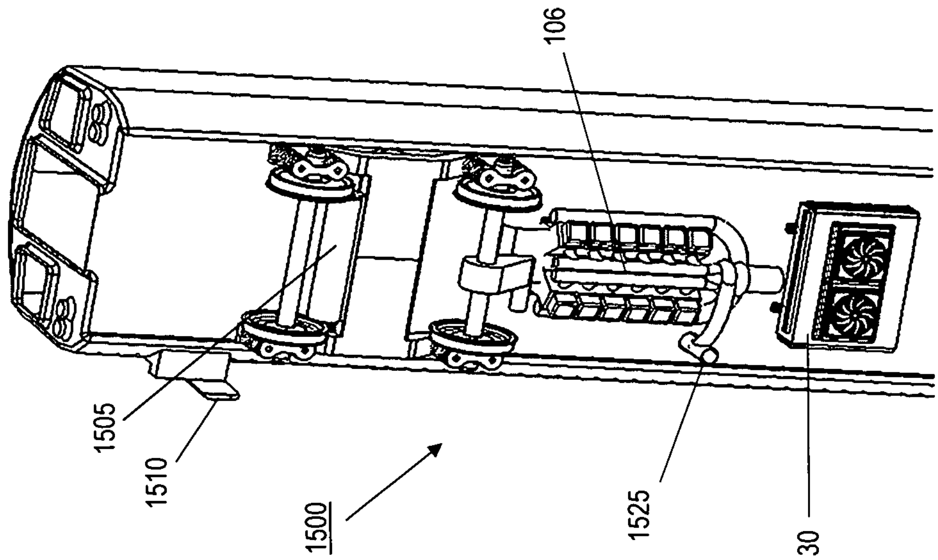

Fig. 15C

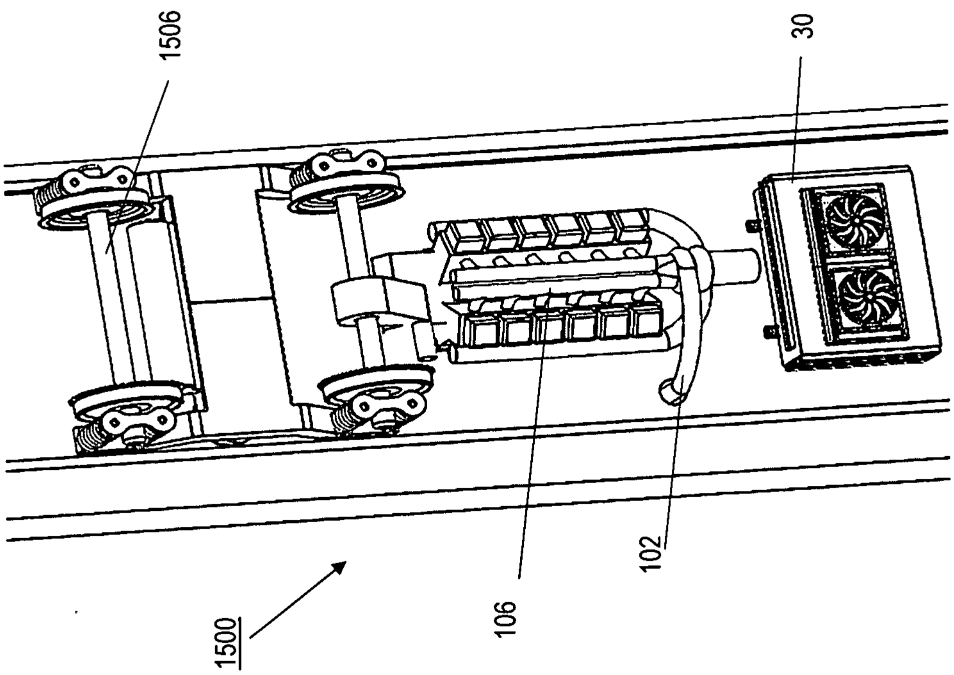

Fig. 15B

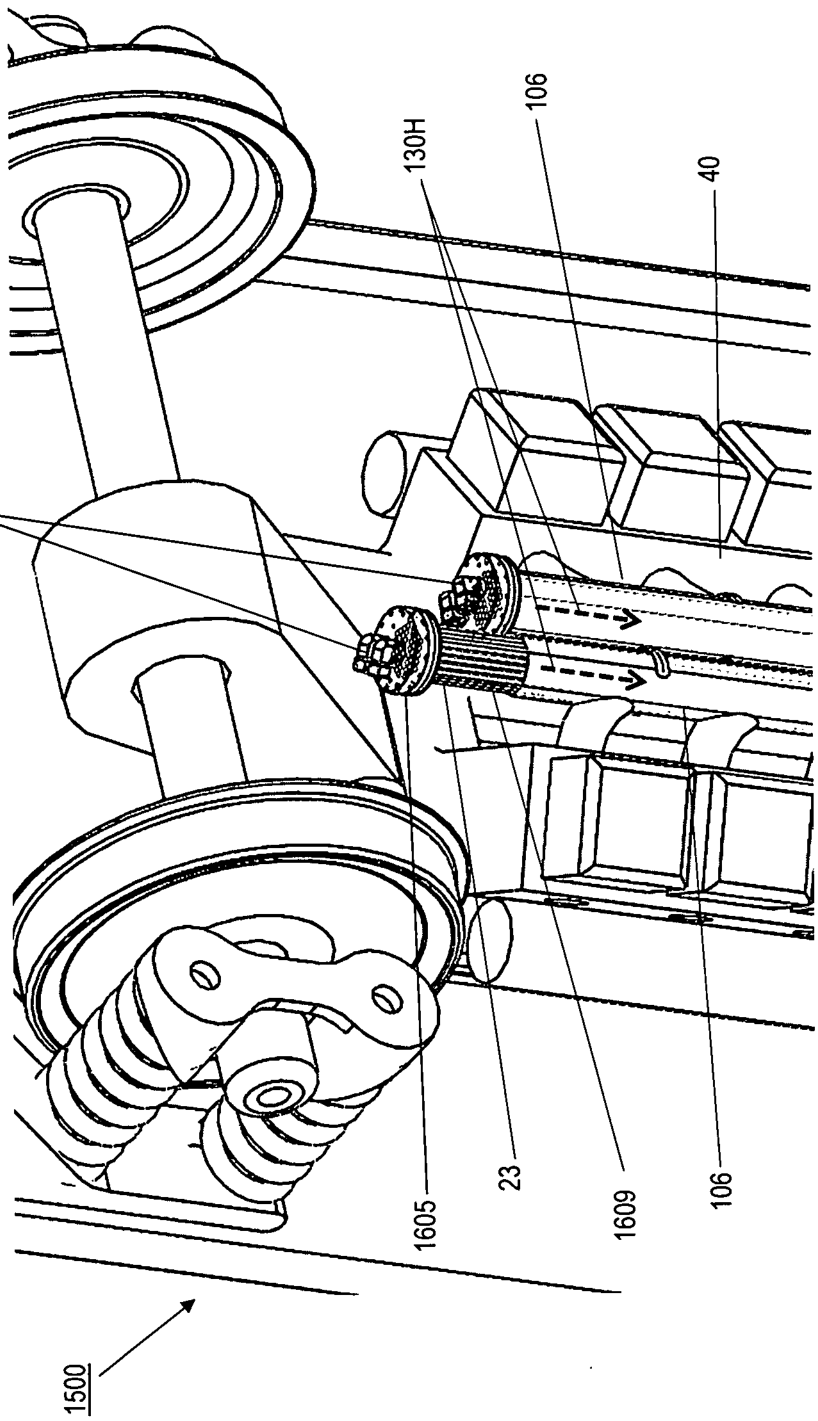

Fig. 16

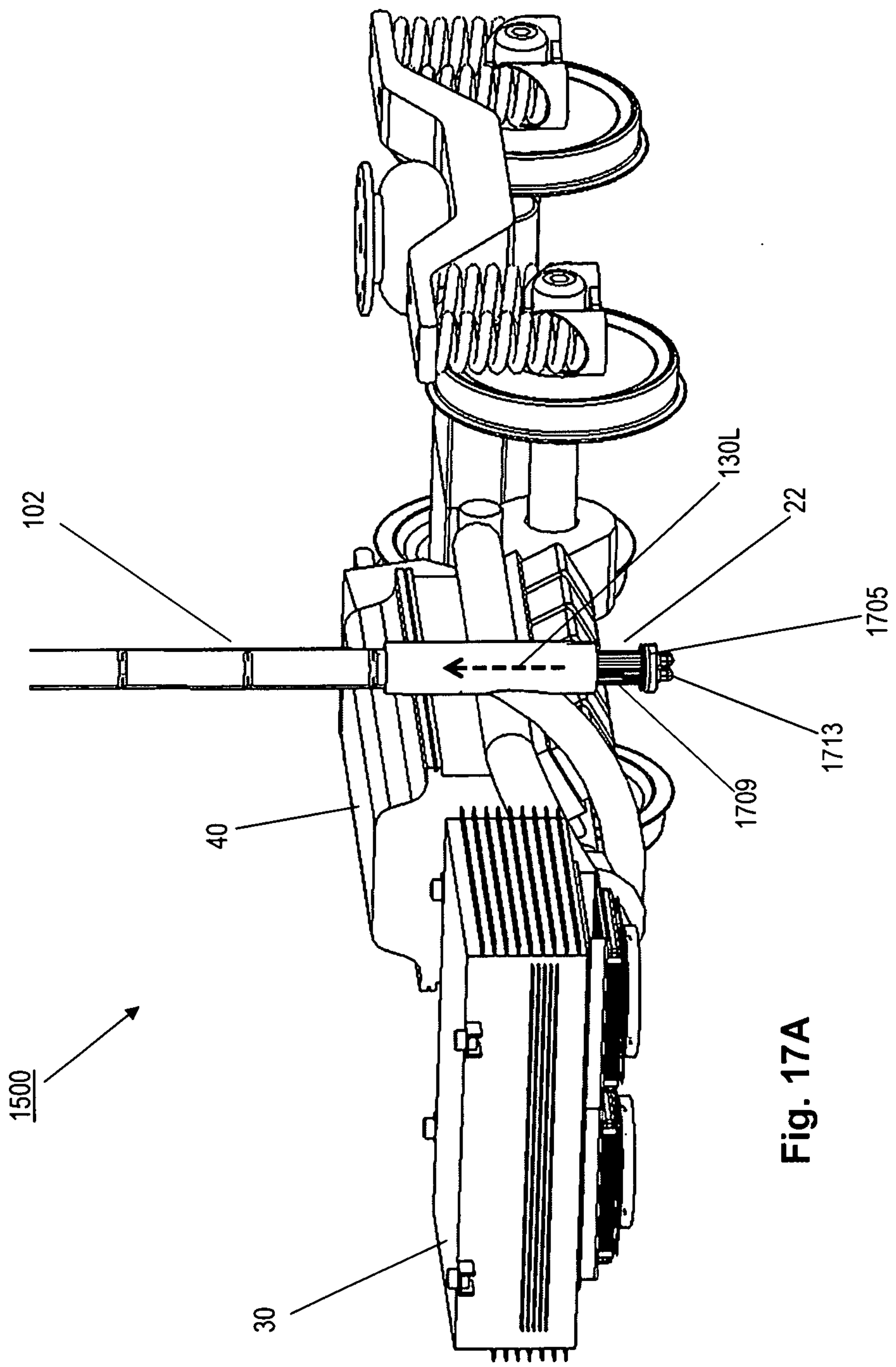

Fig. 17A

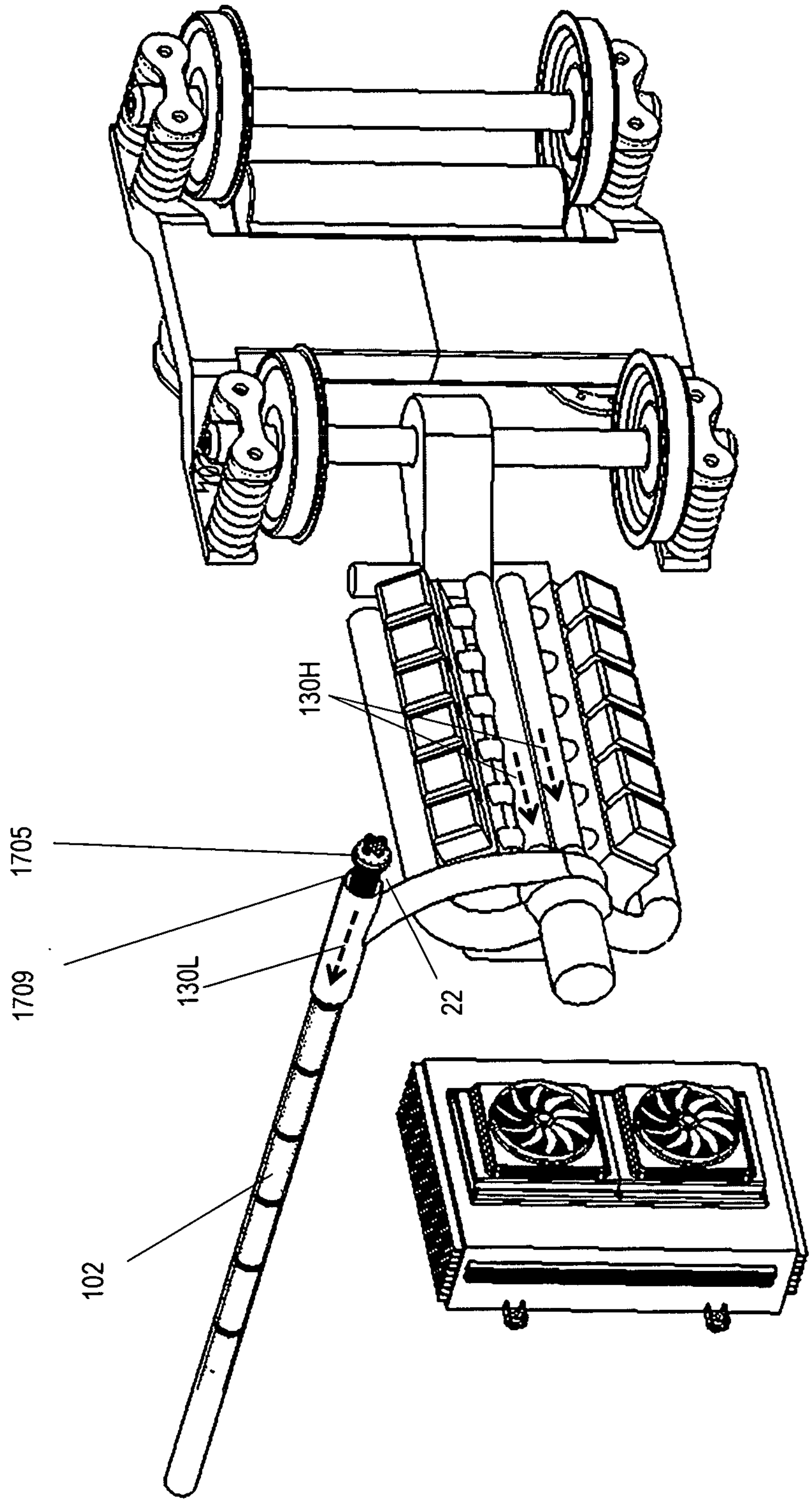

Fig. 17B

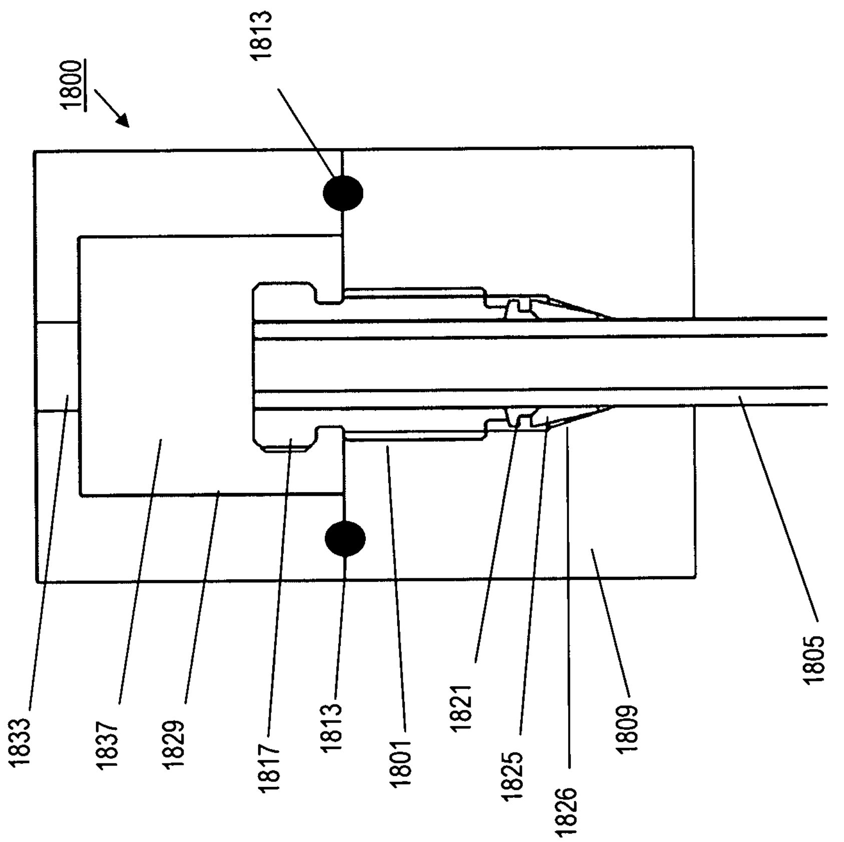

Fig. 18B

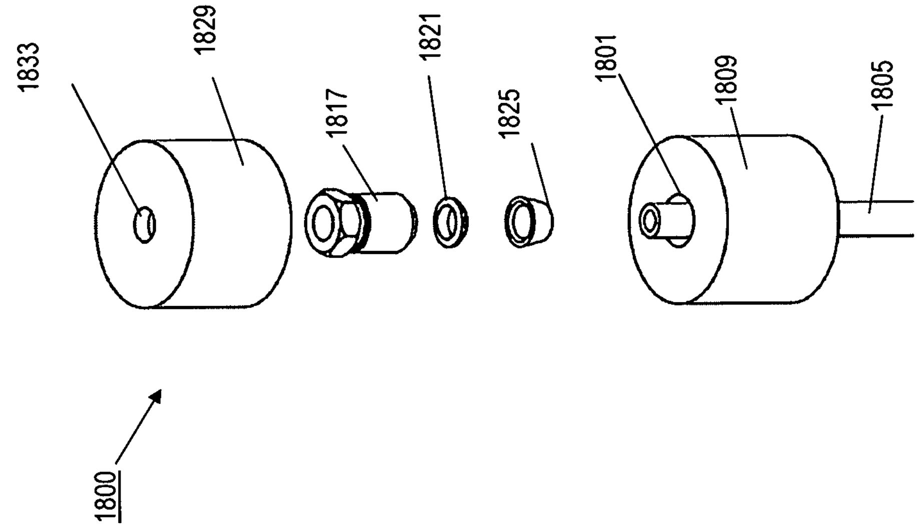

Fig. 18A

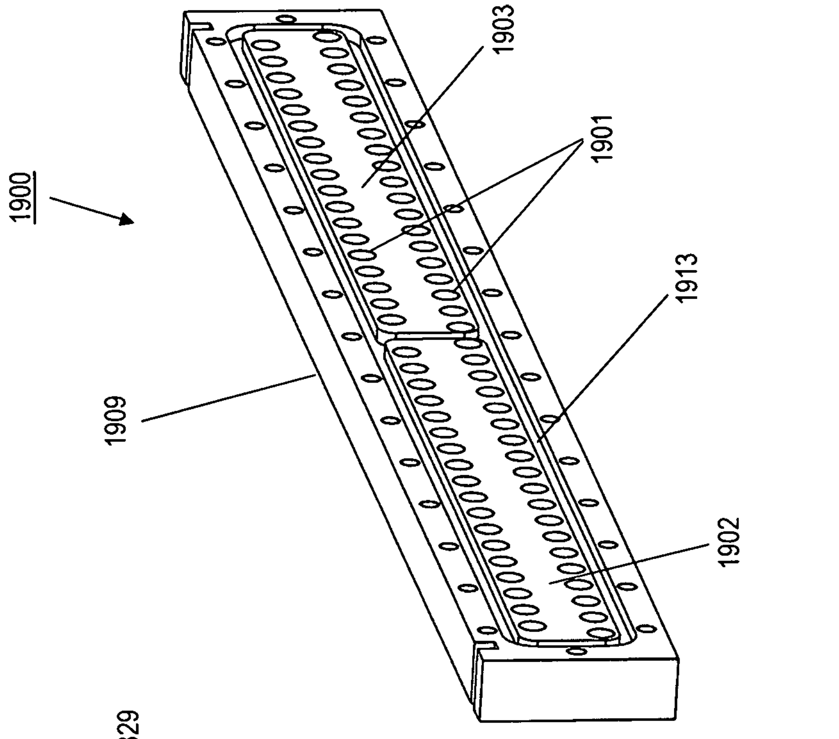

Fig. 19B

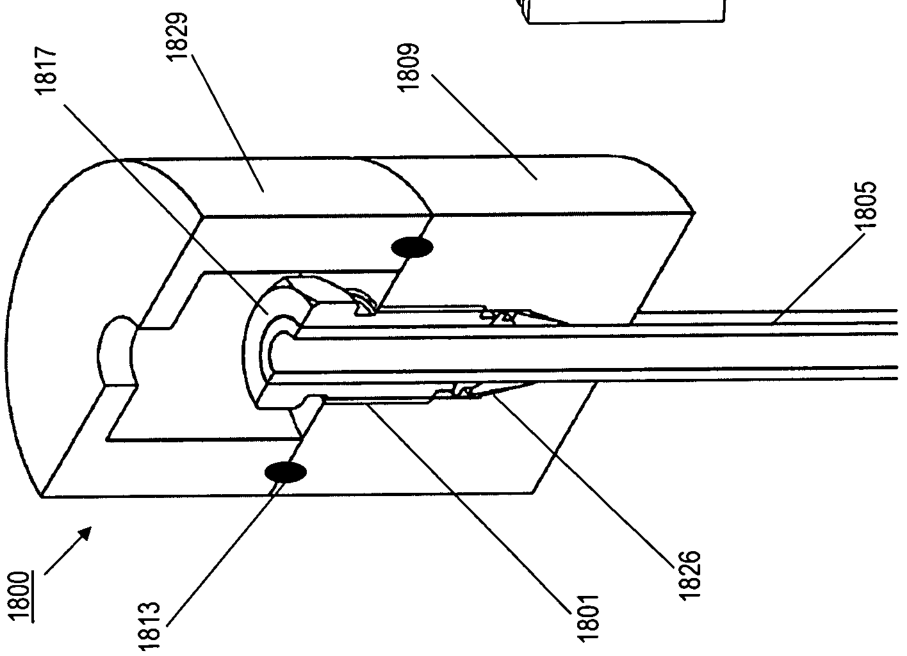

Fig. 19A

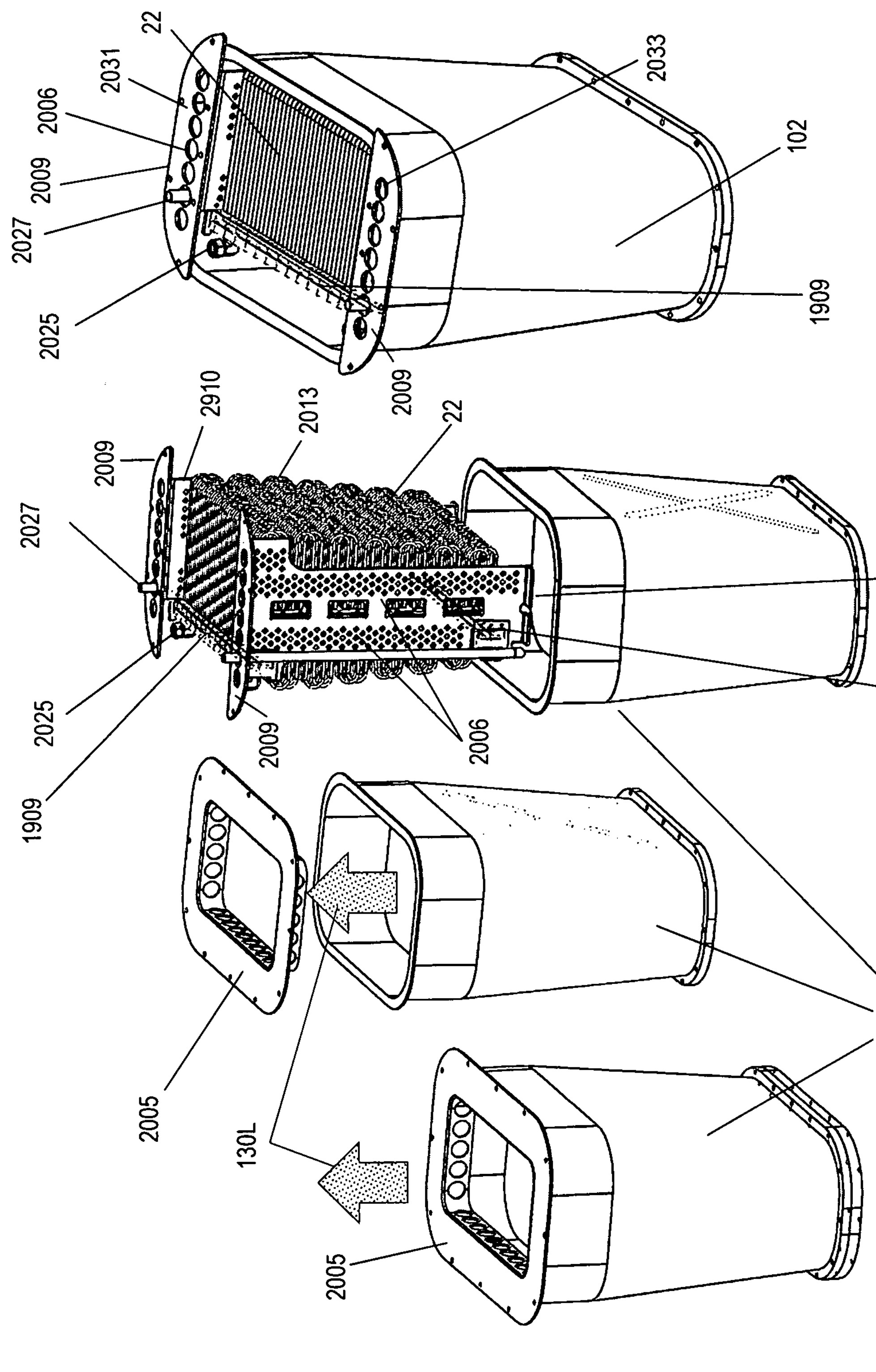
22
2031
2006
2009
2027
2025
2033
102
1909
2009
2910
2013
22
2009
2027
2025
1909
2009
2006
2011
1909
102
2005
130L
2005
102

Fig. 20A

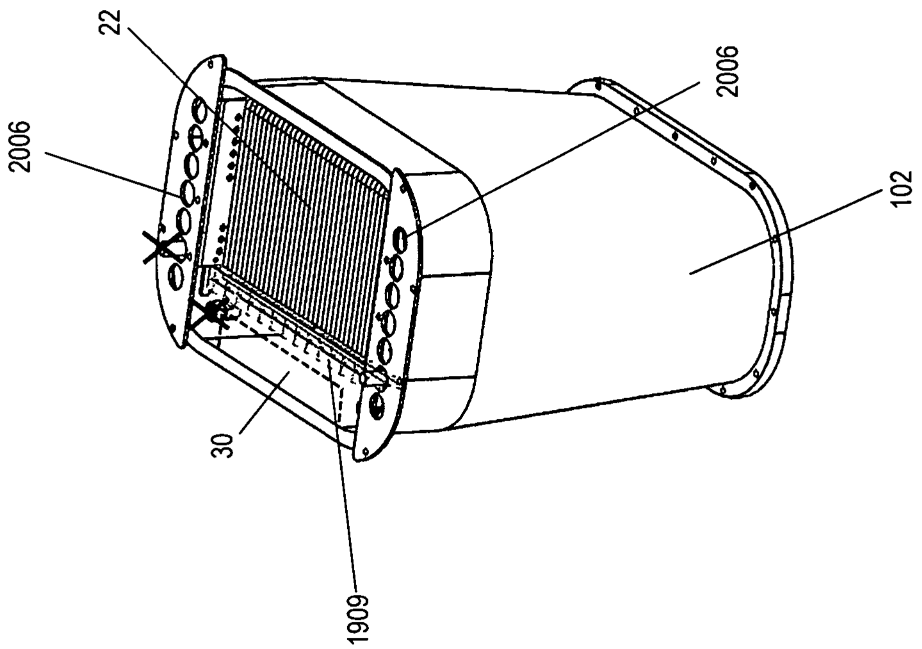

Fig. 20C

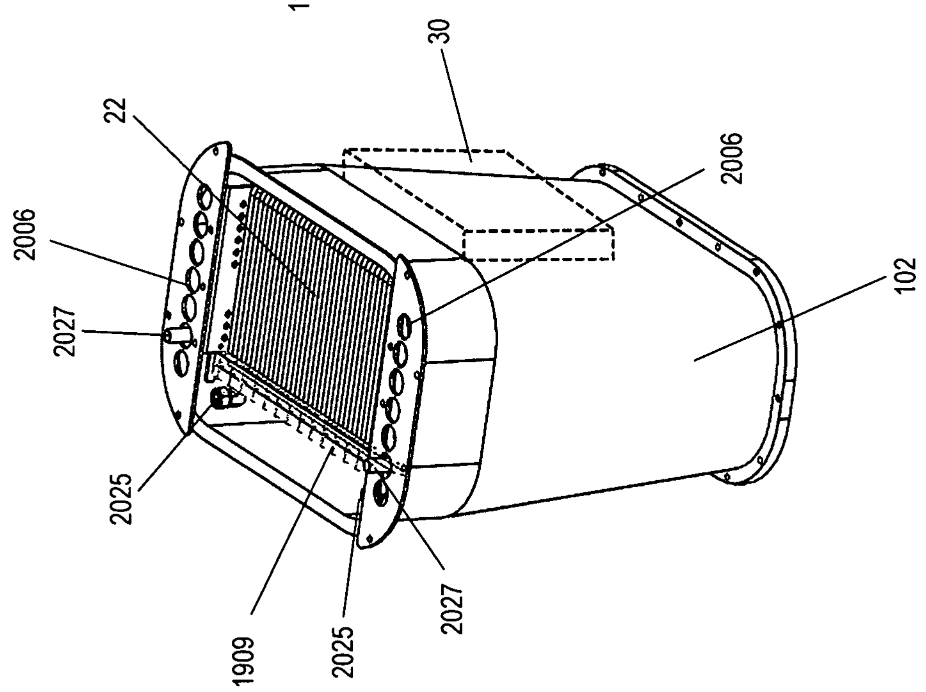

Fig. 20B

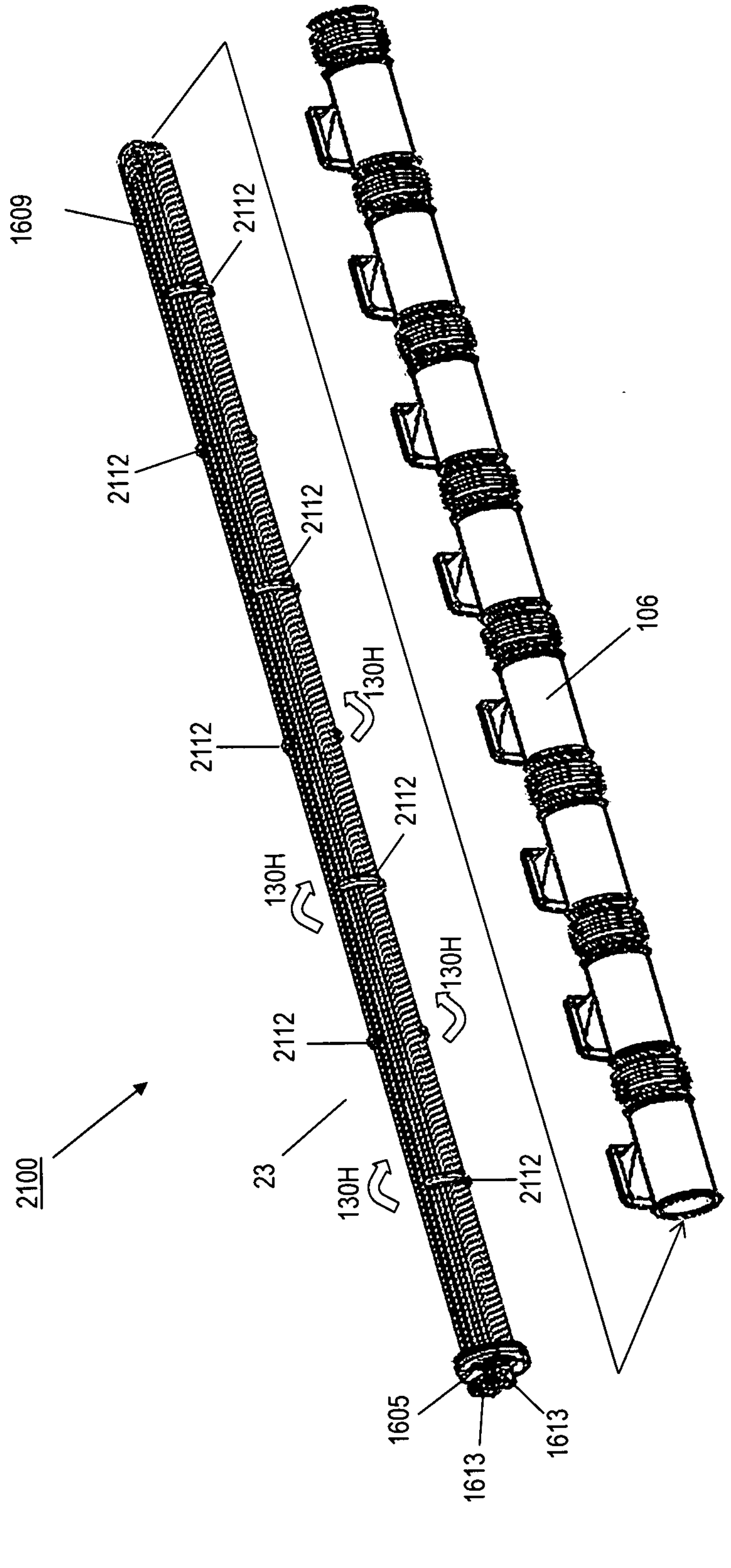
1609
2112
2112
2112
130H
2112
2112
130H
130H
2112
23
2100
130H
2112
1605
1613
1613
106

Fig. 21A

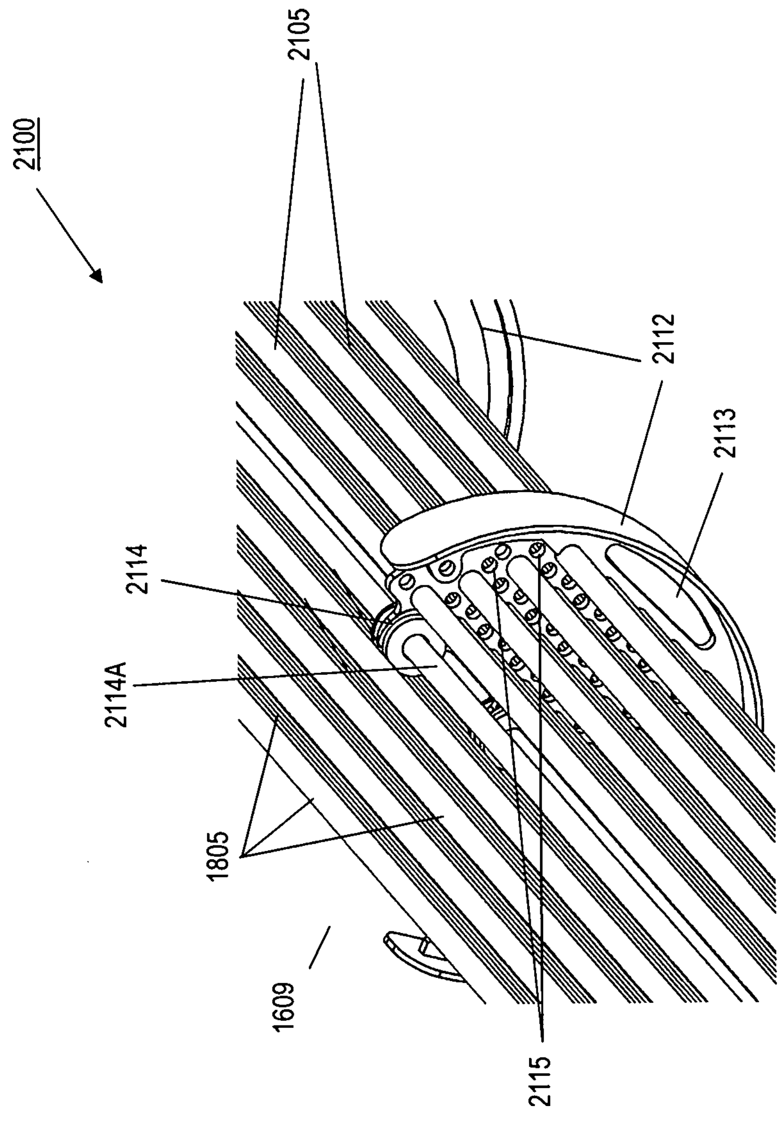

Fig. 21B

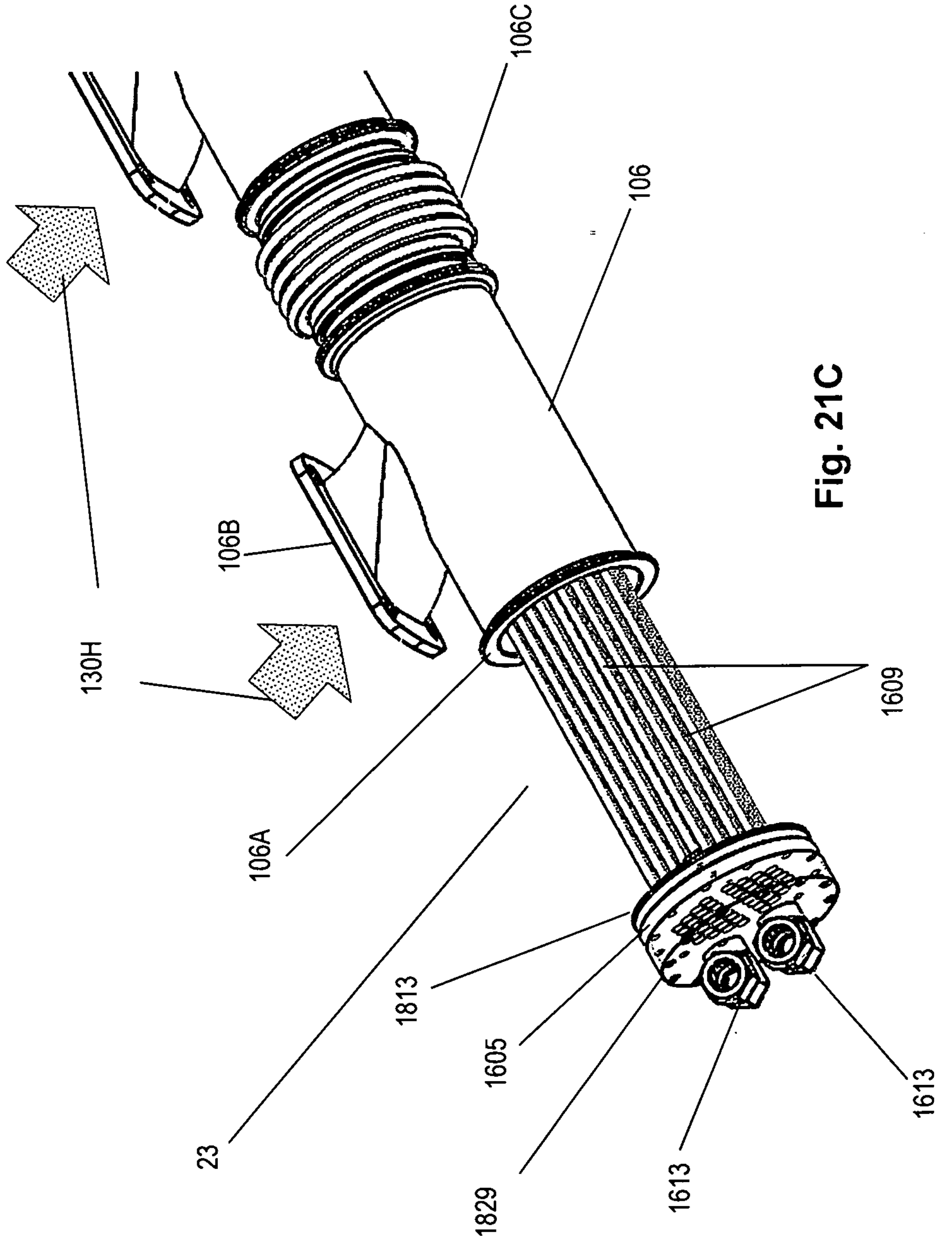

Fig. 21C

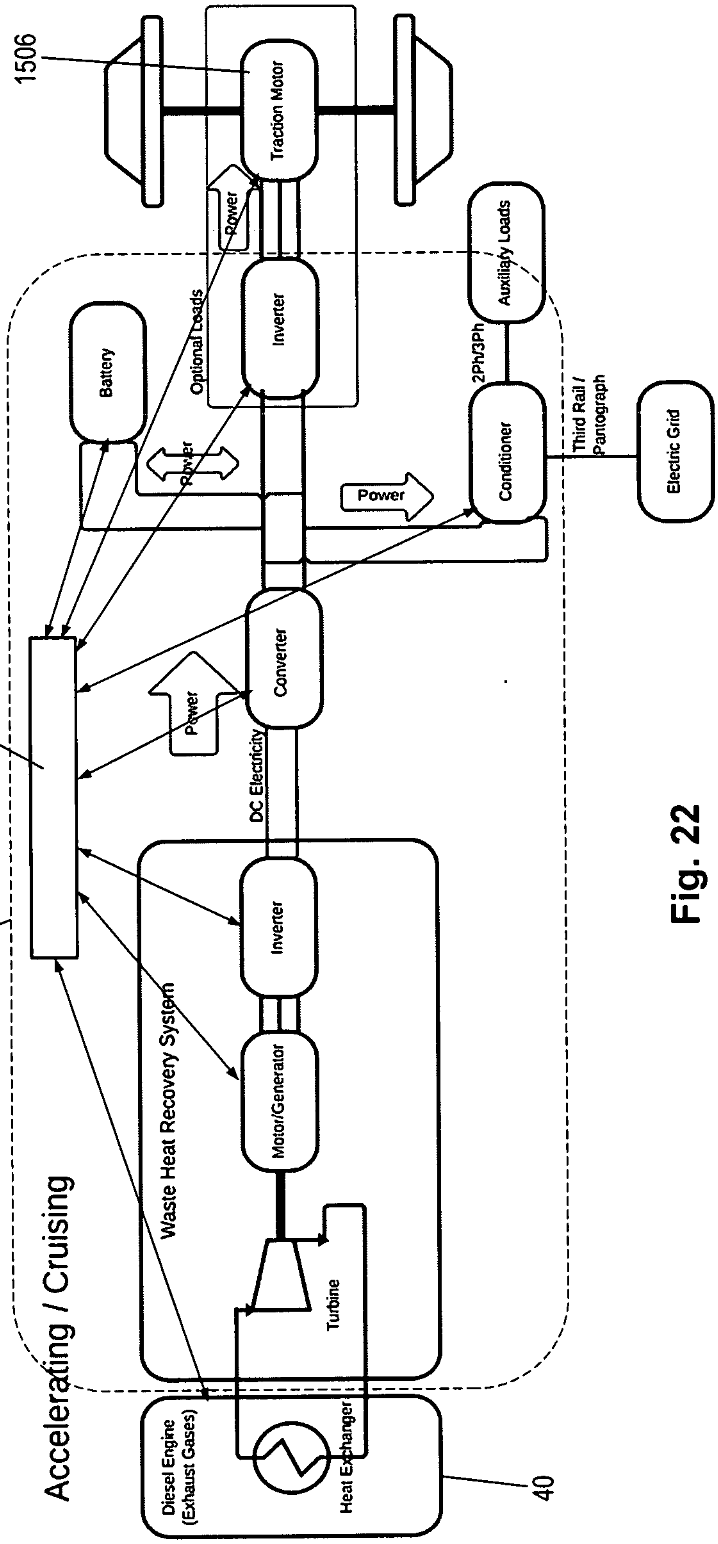
1506
Traction Motor
Power
Optional Loads
Inverter
Battery
Power
Auxiliary Loads
2Ph/3Ph
Power
Conditioner
Third Rail / Pantograph
Electric Grid
114
Converter
Power
DC Electricity
30
Inverter
Waste Heat Recovery System
Motor/Generator
Turbine
Accelerating / Cruising
Diesel Engine (Exhaust Gases)
Heat Exchanger
40

Fig. 22

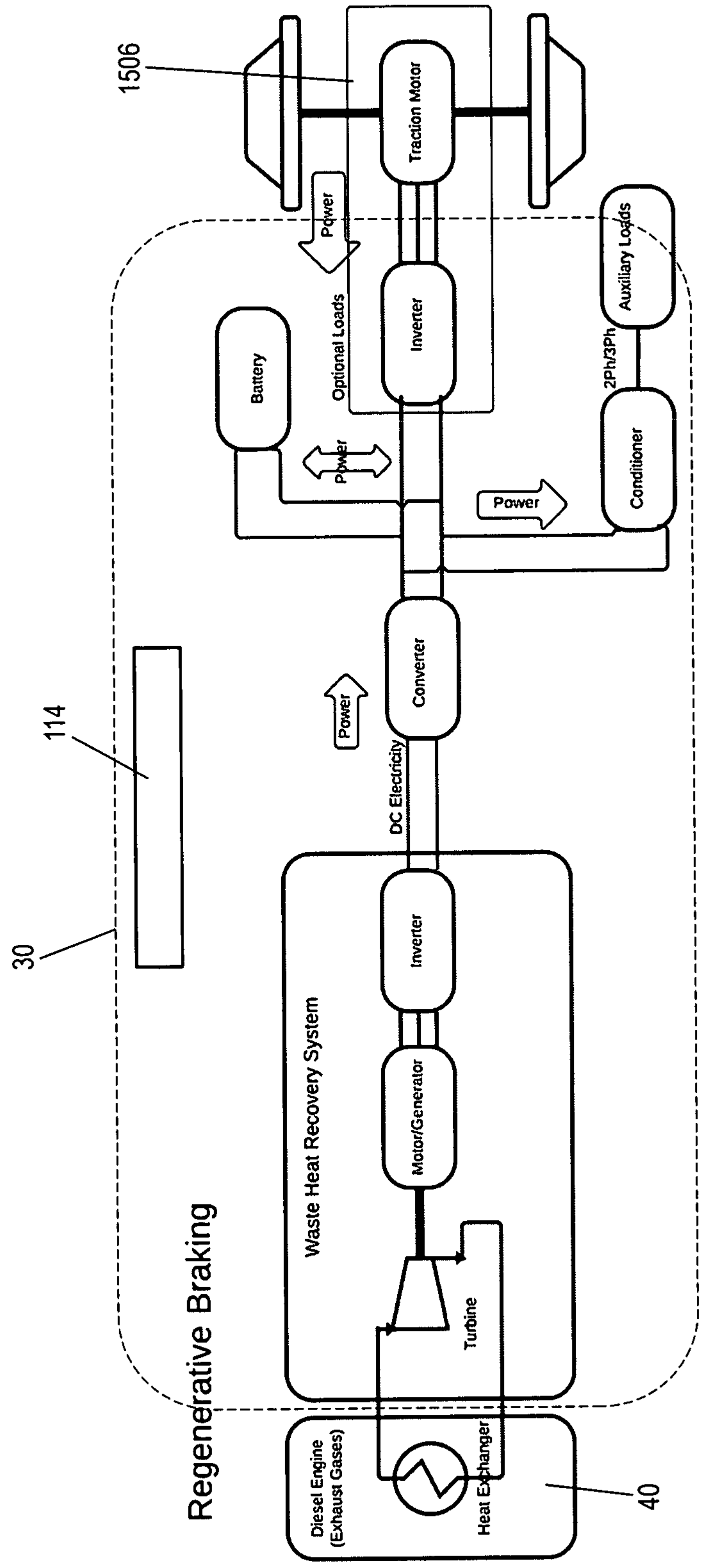
1506
Traction Motor
Power
Optional Loads
Inverter
Battery
Power
Power
Auxiliary Loads
2Ph/3Ph
Conditioner
Converter
Power
DC Electricity
114
30
Waste Heat Recovery System
Inverter
Motor/Generator
Turbine
Regenerative Braking
Diesel Engine
(Exhaust Gases)
Heat Exchanger
40

Fig. 23

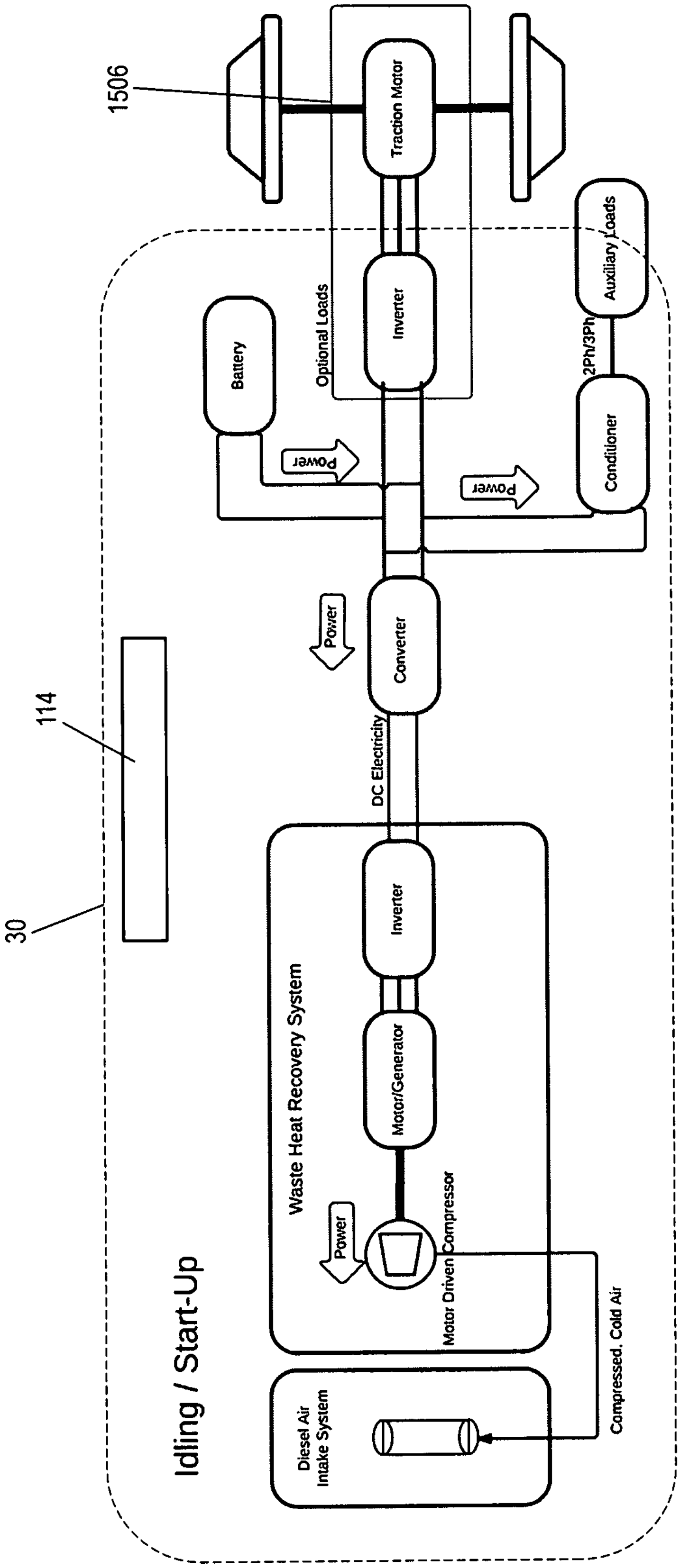
1506
Traction Motor
Optional Loads
Inverter
Battery
Power
Power
Auxiliary Loads
2Ph/3Ph
Conditioner
Power
Converter
DC Electricity
114
30
Waste Heat Recovery System
Inverter
Motor/Generator
Power
Motor Driven Compressor
Compressed, Cold Air
Idling / Start-Up
Diesel Air
Intake System

Fig. 24

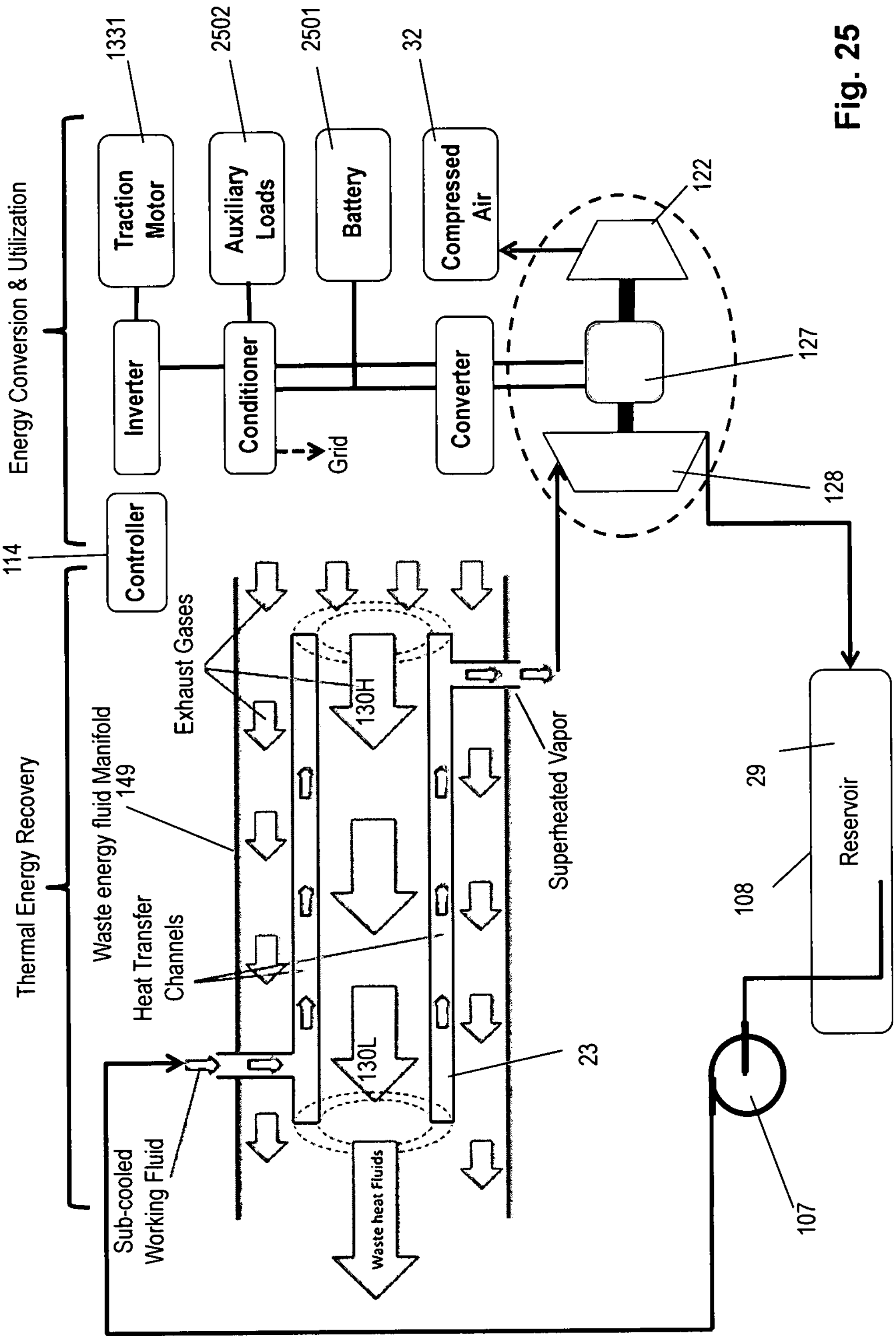
Energy Conversion & Utilization
Thermal Energy Recovery
1331
2502
2501
32
Traction Motor
Auxiliary Loads
Battery
Compressed Air
Inverter
Conditioner
Converter
Grid
Controller
114
122
127
128
Exhaust Gases
130H
130L
Waste energy fluid Manifold
149
Heat Transfer Channels
Superheated Vapor
Sub-cooled Working Fluid
Waste heat Fluids
23
29
108
Reservoir
107

Fig. 25

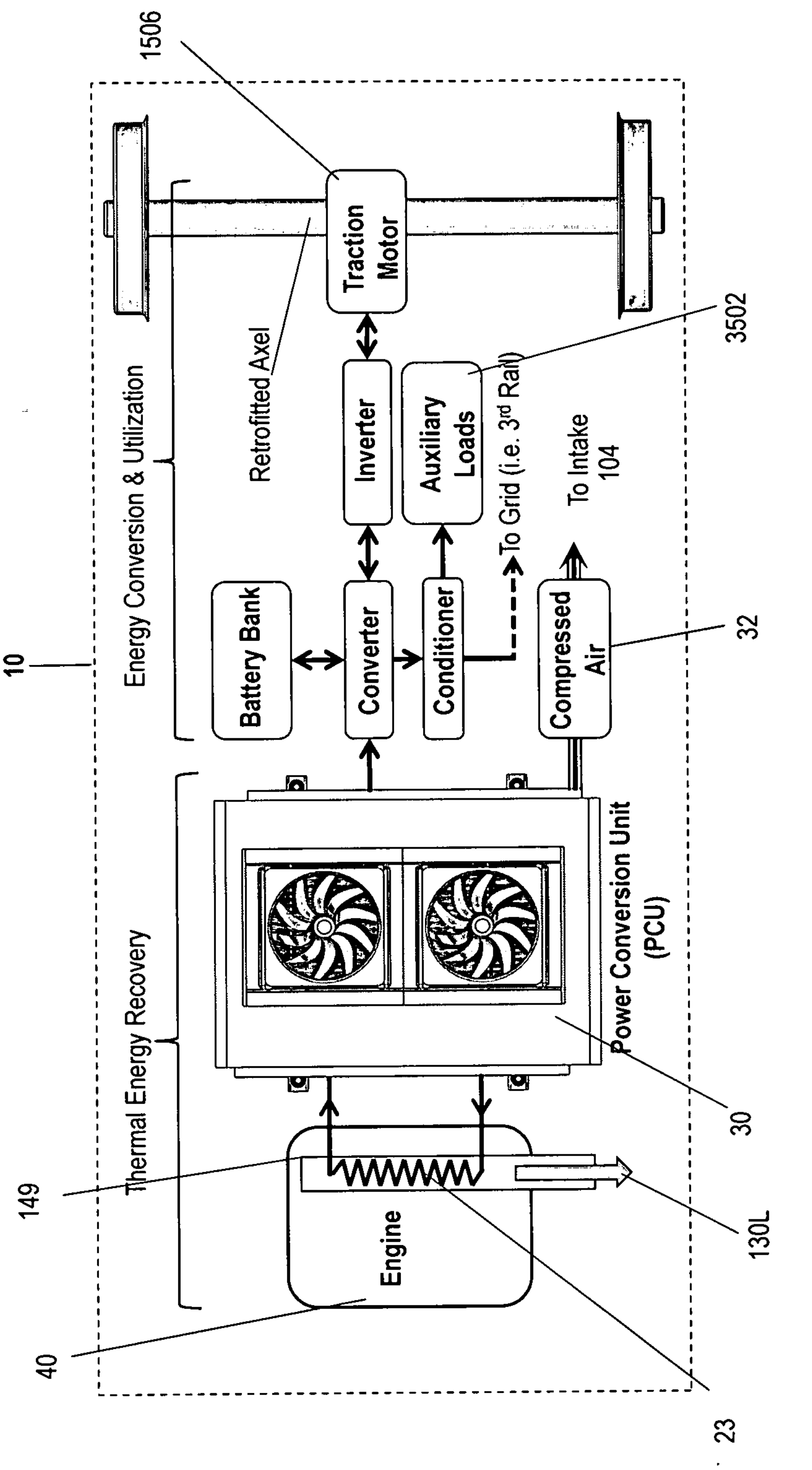
1506
Traction Motor
Retrofitted Axel
Energy Conversion & Utilization
10
Battery Bank
Converter
Inverter
Conditioner
Auxiliary Loads
3502
To Grid (i.e. 3rd Rail)
To Intake 104
Compressed Air
32
Thermal Energy Recovery
Power Conversion Unit (PCU)
30
149
Engine
40
130L
23

Fig. 26

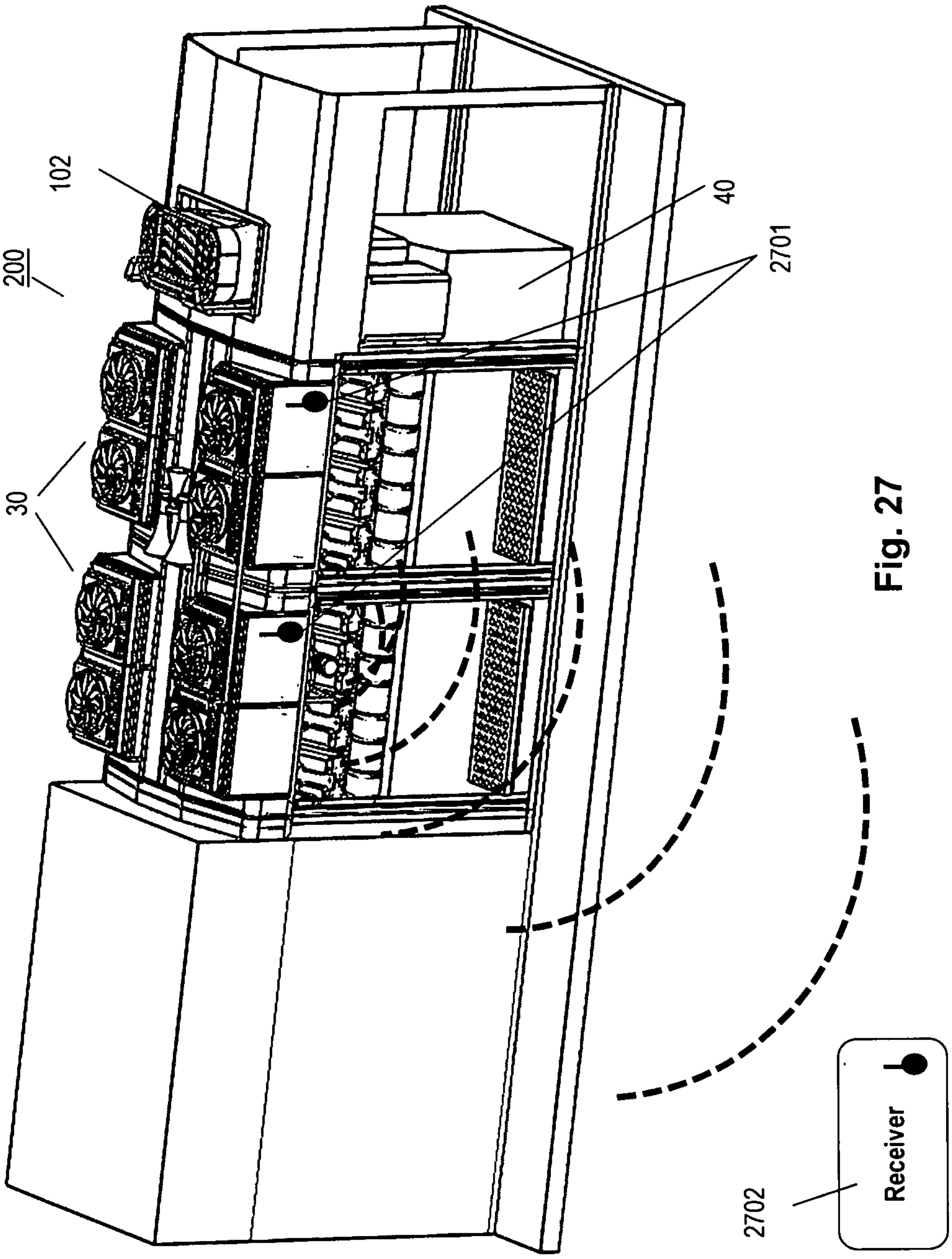

Fig. 27

INTERNATIONAL SEARCH REPORT

International application No. PCT/US 16/15963

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F01K 23/02, F01K 25/02, F01K 23/10, F02G 5/02 (2016.01)

CPC - F28D 7/10, F01K 23/065, F28F 1/42, F28D 7/16, F28D 7/06, F01N 5/02, F01K 25/00

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
CPC - F28D7/10, F01K23/065, F28F1/42, F28D7/16, F28D7/06, F01N5/02, F01K25/00
IPC(8) - F01K23/02, F01K25/02, F01K23/10, F02G5/02 (2016.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - F28D7/10, F01K23/065, F28F1/42, F28D7/16, F28D7/06, F01N5/02, F01K25/00
IPC(8) - F01K23/02, F01K25/02, F01K23/10, F02G5/02 (2016.01); USPC - 60/670, 60/616

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Patbase; Google Web, Freepatentsonline, Google Patent
Search terms used: heat recovery rankine loop heat exchangers expander condensor generator pump engine vibration isolation attach affix secure

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2013/019761 A1 (FILIPPONE) 07 February 2013 (07.02.2013); Fig 1, 10-12; para [0002], [0035], [0037], [0042]-[0047], [0056]	1-3
A	US 2015/0000274 A1 (ERNST et al.) 01 January 2015 (01.01.2015), entire document	1-3
A	US 7,272,932 B2 (WATSON et al.) 25 September 2007 (25.09.2007), entire document	1-3
A	US 4,517,799 A (HANAOKA et al.) 21 May 1985 (21.05.1985), entire document	1-3
A	US 2014/0137554 A1 (ERNST et al.) 22 May 2014 (22.05.2014), entire document	1-3
A	US 2005/0109031 A1 (INABA et al.) 26 May 2005 (26.05.2005), entire document	1-3

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 April 2016 (12.04.2016)	09 JUN 2016

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 16/15963

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

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

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 4-20
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.