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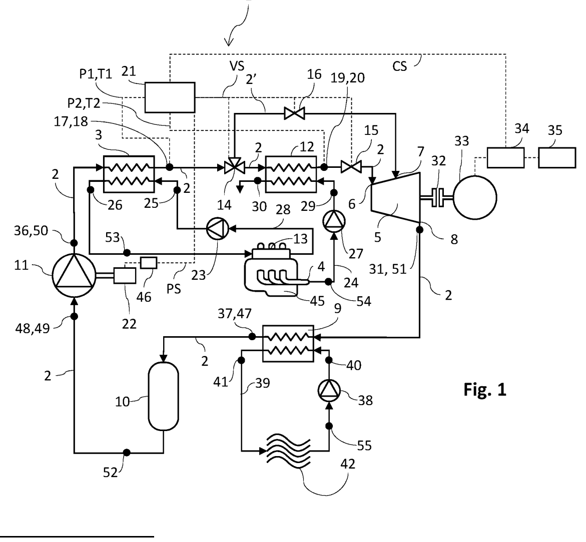
(54) **SYSTEM FOR CONVERTING HEAT ENERGY IN ELECTRIC ENERGY**

(57) System (1) for converting heat energy into electric energy comprising: a closed main circuit (2) in which flows an organic fluid; a first heat exchanger (3) thermally coupled to a first energy source (4) through a first circuit (28); said first heat exchanger (3) being positioned along the main circuit (2) for heating the organic fluid; an expander (5) comprising at least a first and second suction inlets (6,7) and one discharge outlet (8); an electric generator (33) mechanically coupled to an output shaft of the expander (5); a condenser (9) positioned along the main circuit (2) and fluidly connected to the discharge outlet (8) of the expander (5) and to a tank (10), said condenser (9) being configured to condense the organic fluid exiting from the expander (5); a first pump (11) positioned along the main circuit (2) between the tank (10) and the first heat exchanger (3); a second heat exchanger (12) thermally coupled to a second energy source (13) through a second circuit (24); said second heat exchanger (3) being positioned along the main circuit (2) between the first heat exchanger (3) and the first suction inlet (6) of the expander (5) for heating the organic fluid; a branch (2') of the main circuit (2) fluidly connecting a point of the main circuit (2) arranged between the first and second exchangers (3,12) to the second suction inlet (7) of the expander (2) so to bypass the second exchanger (12); at least a valve (14,15,16) configured to divert the organic fluid towards the first suction inlet (6) of the expander (5) or towards the second suction inlet (7) of the expander (5); a first temperature sensor (25) arranged along the first circuit (28) upstream the first heat exchanger (3) configured to output a first temperature signal (T1); a second temperature sensor (26) arranged along the first circuit (28) downstream the first heat exchanger (3) configured to output a second temperature signal (T2); a third temperature sensor (29) arranged along the second circuit (24) upstream the second heat exchanger (12) configured to output a third temperature signal (T3); a fourth temperature sensor (30) arranged along the second circuit (24) downstream the second heat exchanger (12) configured to output a fourth temperature signal (T4); a control unit (21) configured to receive said first, second, third and fourth temperature signals (T1,T2,T3,T4) to generate a first pump control signal (PS) and a first valve control signal (VS) based on said first, second, third and fourth temperature signals (T1,T2,T3,T4) to operate the first pump (11) and the at least a valve (14,15,16); wherein the expander (5) being configured to expand the organic fluid vaporized in said first heat exchanger (3) or in said first and second heat exchangers (3,12) to generate mechanical energy for driving the electric generator (33).

Vehicle (100) comprising said system (1) for converting heat energy in electric energy.

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## Description

TECHNICAL FIELD

**[0001]** The present invention relates to systems for converting heat energy in electric energy. In particular, it relates to ORC type systems, i.e., based on an organic Rankine cycle. Even more specifically, the present invention relates to a small size conversion system, installable within a vehicle or a residence.

BACKGROUND

**[0002]** In the background various solutions using organic Rankine cycles for converting heat in electric energy are known.

**[0003]** Several solutions using waste heat sources to produce mechanical energy, later converted in electric energy, are known.

**[0004]** An example in this sense is provided by patent document US8193659B2 which describes a system wherein the vapor heat coming from one or more steam turbines is used to heat an organic fluid used to operate several expanders. In this document, each heat source has its ORC heat recovery cycle and the heat sources are not used in a combined way with each other to optimize the operation of the system for generating electric energy.

**[0005]** A further example of a system for converting heat in electric energy is provided by patent document US20200191021A1 wherein an organic fluid in the form of vapor is expanded both in a first expander connected to a compressor and in a second expander connected to a power generator.

**[0006]** The need is felt to optimize the use of fuel on board small boats, recovering the heat output from the engine both in the form of exhaust fumes and engine cooling liquid, obtaining enough power to supply part of the utilities on board. In particular, the need is felt to provide small size systems, i.e., capable of generating electric power up to about 1.5 kWe for vehicles or for stationary applications for civil use. As a matter of fact, implants producing from 1 to 10 kW, therefore being closer to the size of an average domestic utility, are absent from the markets.

**[0007]** In the background there are no available solutions wherein a single expander is used differentially depending on the amount of heat available. In particular, there is no available system capable of optimizing the production of electric energy based on heat sources at low relative temperatures, i.e., lower than 120°C with an overall efficiency greater than 10%.

**[0008]** Furthermore, small size solutions, i.e., easy to transport and install within a vehicle or a residence are not available.

SUMMARY

**[0009]** The above-mentioned drawbacks of the prior art are now solved by a first scope of the present invention, i.e., a system for converting heat energy in electric energy comprising: a closed circuit in which flows an organic fluid and comprising a branch; a first heat exchanger; a second heat exchanger; an expander; an electric generator; a condenser; an organic fluid storage tank; a first pump; at least a circuit valve; a first, a second, a third and a fourth pressure sensor; and a control unit.

**[0010]** Said first heat exchanger being thermally coupled to a first energy source through a first circuit. Said second heat exchanger being thermally coupled to a second energy source through a second circuit. Said first heat exchanger and said second heat exchanger are positioned along the main circuit, i.e., present a side of the exchanger thermally connected to the main circuit to heat the organic fluid flowing in the main circuit. Said expander comprising at least a first and second suction inlets and one discharge outlet.

**[0011]** Said second heat exchanger being positioned between the first heat exchanger and the first suction inlet of the expander.

**[0012]** Said electric generator being mechanically coupled to an output shaft of the expander.

**[0013]** Said condenser being positioned along the circuit and fluidly connected to the discharge outlet of the expander and to the tank. Said condenser being configured to condense the organic fluid exiting from the expander.

**[0014]** Said first pump being positioned along the circuit between the tank and the first heat exchanger.

**[0015]** Said branch of the circuit fluidly connects a point of the circuit arranged between the first and second exchangers to the second suction inlet of the expander so to bypass the second exchanger.

**[0016]** Said at least a valve being configured to divert the organic fluid towards the first suction inlet of the expander or towards the second suction inlet of the expander.

**[0017]** Wherein the first temperature sensor is arranged along the first circuit upstream the first exchanger, the second temperature sensor is arranged along the first circuit downstream the first exchanger, the third temperature sensor is arranged along the second circuit upstream the second exchanger, the fourth temperature sensor is arranged along the second circuit downstream the second exchanger.

**[0018]** The first temperature sensor is configured to output a first temperature signal, which is indicative of the temperature of the fluid flowing in the first circuit entering in the first exchanger, the second temperature sensor is configured to output a second temperature signal, which is indicative of the temperature of the fluid flowing in the first circuit exiting from the first exchanger, the third temperature sensor is configured to output a third temperature signal, which is indicative of the temperature of the fluid flowing in the second circuit entering in the second exchanger and the fourth temperature sensor is configured to output a fourth temperature signal, which is indicative of the temperature of the fluid flowing in the second circuit exiting from the second exchanger.

**[0019]** Said one control unit being configured to receive said first, second, third and fourth temperature signals to generate a first pump control signal and a first valve control signal based on said first, second, third and fourth temperature signals to operate the first pump and the at least a valve.

**[0020]** Said expander being configured to expand the organic fluid vaporized in said first heat exchanger or in said first and second heat exchangers to generate mechanical energy for driving the electric generator.

**[0021]** The system thus devised allows to efficiently use the expander depending on the heat available in the first and second exchangers. The control unit is therefore optimized and allows to control the expander based on average pressure and temperature values or based on medium-high pressure and temperature values, maximizing the system efficiency.

**[0022]** The control unit may be configured to operate the first pump if the first temperature signal exceeds a first temperature threshold and the second temperature signal exceeds a second temperature threshold and/or if the third temperature signal exceeds a third temperature threshold and the fourth temperature signal exceeds a fourth temperature threshold. In this way, upon reaching a temperature threshold considered minimum, the first pump is operated and the expander is set in operation to generate electric energy. Preferably, said first temperature threshold is about 60 °C, said second temperature threshold is about 50 °C, said third temperature threshold is about 100 °C, said fourth temperature threshold is about 90 °C. These temperature values optimize the operation of the system.

**[0023]** The control unit may further be configured to operate the at least a valve so to divert at least in part the organic fluid towards the first suction inlet of the expander if the first temperature signal exceeds a first temperature threshold and the second temperature signal exceeds a second temperature threshold. In this way, the heat energy of the first heat exchanger allows to set the expander in operation.

**[0024]** The control unit may further be configured to operate the at least a valve so to divert at least in part the organic fluid towards the second suction inlet of the expander if the third temperature signal exceeds a third temperature threshold and the fourth temperature signal exceeds a fourth temperature threshold. In this way, the heat energy of the second heat exchanger allows to set the expander in operation or to supercharge it, depending on whether or not the first heat exchanger is capable of outputting a certain amount of heat energy.

**[0025]** Said at least a valve may comprise a switch valve and/or a first and second valves. A greater number of valves increases control on the system and improves the efficiency thereof. Vice versa, a lower number of valves electrically controlled by the control unit allows to obtain a less expensive system.

**[0026]** Said expander may be a scroll type expander comprising a fixed scroll element and an orbiting scroll element, wherein the first suction inlet is arranged substantially at a central portion of the fixed scroll element, the discharge outlet is arranged at a periphery portion of the fixed scroll element and the second suction inlet is arranged at an intermediate radial position of the fixed scroll element positioned between the central portion and the periphery portion. This type of expander allows to obtain a high performance with reduced overall dimensions, aimed at rendering the system usable in small size environments such as a vehicle or a residence.

**[0027]** The expander may be mechanically coupled to the electric generator via a magnetic clutch controlled by the control unit based on said first, second, third and fourth temperature signals. In this way, it is possible to actuate the magnetic clutch and drive the electric generator only when determined operative conditions are reached.

**[0028]** The electric generator may be a brushless generator. In this way, the performance of the system is maximized.

**[0029]** The system may comprise a contactor electrically connected to the electric generator and controlled by the control unit based on said first, second, third and fourth temperature signals. Said contactor allows to uncouple the system from the electric mains wherein the system gives up energy when the system is not operating. Preferably, the system may also comprise an automatic voltage regulator electrically connected to the contactor. The automatic voltage regulator allows to stabilize the current produced by the generator.

**[0030]** A second scope of the present invention is a vehicle comprising a system for converting heat energy in electric energy according to the first scope of the present invention, wherein the first heat source derives from a cooling system of an internal combustion engine of the vehicle and the second heat source derives from an exhaust gas of the internal combustion engine. In this way, the heat produced by the vehicle is used to generate reusable electric energy to drive an electric engine of the vehicle or for the internal utilities of the vehicle.

**[0031]** These and other advantages will be more detailed from the description below of an indicative and not limitative example of an embodiment with reference to the appended drawings.

## DESCRIPTION OF THE DRAWINGS

**[0032]** In the drawings:

Fig. 1 depicts a schematic view of the system according to the present invention;

Fig. 2 depicts a schematic view of a vehicle equipped with a system according to the present invention;

Fig. 3 depicts an operation diagram of the control unit according to the present invention;

Fig. 4 depicts a schematic view of an expander for a system according to the present invention.

## DETAILED DESCRIPTION

**[0033]** The following description of one or more embodiments of the invention refers to the appended drawings. The same reference numbers in the drawings identify identical or similar elements. The object of the invention is defined in the appended claims. Technical peculiarities, structures or features of the solutions described below may be combined with each other in any way.

**[0034]** With respect to Fig. 1 a system 1 for generating electric energy from heat energy sources is depicted. In particular, the system of Fig. 1 represents a circuit 2 along which a series of devices are arranged. Specifically, the system 1 comprises along the main circuit 2, which is closed on itself, clockwise: a tank 10, a first pump 11, a first heat exchanger 3, a valve 14,15,16, a second heat exchanger 12, an expander 5, a condenser 9.

**[0035]** Within the main circuit 2 flows an organic fluid. Preferably, the fluid is pentafluoropropane R245fa. This fluid is particularly suitable for the range of temperatures of system 1 in accordance with the present invention, it is further less problematic for the environment. Alternatively, the organic working fluid usable may be one among the following: R717, HFO-1234yf, HFO-1234ze, R141b, R123, R124, R142b, R22, R290, R601, R600, R600a, R32, R143a, R125, R227ea, R152a, R236fa.

**[0036]** With respect to Fig. 1, the organic fluid is initially stocked into the tank 10. Preferably the volume of the tank is comprised from 5 to 15 liters, even more preferably is of 10 liters. The organic fluid inside the tank 10 is in liquid phase, at a pressure close or slightly higher than atmospheric pressure, and at a temperature similar or lower than ambient temperature. The temperature of the organic liquid in the tank 10 is based on the condenser 9 arranged upstream the tank 10. The more the temperature at condenser 9 is low, the greater the performance of the system 1 is.

**[0037]** The organic fluid in liquid phase is thus collected and pumped from a first pump 11 arranged along the main circuit 2 downstream and adjacent to tank 10. The pump 11 is configured to circulate the organic fluid inside the main circuit 2.

**[0038]** The first pump 11 used may be made of stainless steel or brass. Preferably the first pump 11 is a rotating blading brass pump. In particular, the pumps normally used in refrigeration, water circulation or dispensing machines are particularly indicated. An example of pump usable in the system 1 is the pump commercialized by the company Fluid-o-Tech, in particular a model of the series PO 70-400. The first pump 11 has a maximum operating pressure of about 20 bar.

**[0039]** The first pump 11 is set in rotation by an electric engine 22 connected to an inverter 46 configured to manage the power of the electric engine 22 and thus the flow rate of the organic fluid exiting from the first pump 11. By using a first pump 11 as identified above, flow rates up to 500 liters/hour can be reached.

**[0040]** The system 1, may comprise one or more recirculation pumps besides the first pump 11, as better described below: a second pump 23, a third pump 27, and a fourth pump 38.

**[0041]** The organic fluid exiting from the first pump 11 has a higher pressure with respect to the fluid contained in the tank 10. This pressurized working fluid undergoes then an enthalpy jump in the following heat exchangers 3,12 as described below.

**[0042]** Depending on which and how many valves are open/closed along the main circuit 2, the organic fluid can pass through one or two heat exchangers 3,12 and be sent to at least one of the suction inlets 6,7 of the expander 5. The control unit 21 decides which valves 14,15,16 to open based on the control logic described below.

**[0043]** The organic working fluid is thus pumped from the first pump 11 towards the first heat exchanger 3. Preferably, the first heat exchanger 3 is a plate heat exchanger, with a heat exchange power comprised from 10 to 15 kWth (thermal kilowatt). If the operating conditions are sufficient, i.e., 5-6 bar and 60 °C for the R245fa fluid, the organic working fluid passing through the first heat exchanger 3 will completely change from a liquid to a gaseous state.

**[0044]** The first heat exchanger 3 is thermally connected to a first heat source 13 through a first circuit 28. This heat source 13 can be a thermal source with temperatures comprised from 60 °C to 100 °C. The heat needed to obtain this temperature can derive from renewable energy heat sources or from the cooling system of an endothermic engine, as depicted in Fig. 1. Practically, the internal combustion engine 45 may comprise a first engine 45 cooling circuit 28, as commonly occurs in engines with an engine capacity greater than 100 cc. The engine 45 cooling liquid circulates inside a first circuit 28, along which the first and second temperature sensors 25,26 are arranged. Said first and second temperature sensors 25,26 are respectively arranged upstream and downstream the first heat exchanger 3. The cooling fluid exiting from the engine 45, for example from its head 13, has a temperature around or higher than 90°C and enters in the first heat exchanger 3 to heat the organic working fluid.

**[0045]** The organic fluid, heated by the liquid circulating within the first circuit 28, when exiting from the first heat exchanger 3 is under saturated vapor conditions and, when the valves 14,15,16 are conveniently positioned, it can enter in the expander through a suction inlet 6,7 of the expander 5.

**[0046]** If the temperature of the first energy source 4 is sufficiently high, preferably higher than 100 °C, the control unit 21 switches the solenoid valves 14,15,16 so that the organic fluid passes inside the second heat exchanger 12 as well. This exchanger confers to the fluid greater heat energy and a greater available enthalpy jump once the fluid enters in the expander 5. Consequently, the expander 5 may operate under full load conditions.

**[0047]** When determined operating conditions of the first heat exchanger 3 and of the second heat exchanger 12 are satisfied, the organic fluid passes into the second high pressure heat exchanger 12. The heat power of the second heat exchanger 12 is comprised from 10 to 15 kWth. The second heat exchanger 12 is configured to bring the organic working fluid to high pressure saturated vapor conditions. The second heat exchanger 12 may be a plate heat exchanger, such as the first exchanger 3, or a tube bundle heat exchanger. The second heat exchanger 12 may be heated by recovering the heat of waste gases of the endothermic engine 45. Alternatively, the second heat source 4 may be any other heat source with a temperature comprised from 120 to 200 degrees.

**[0048]** The system 1 has an electric energy generation capacity lower than 10 kWe, preferably of about 1.5 kWe.

**[0049]** The expander 5 is preferably a scroll expander as depicted in Fig. 3. Notoriously, in snail-type expanders, otherwise referred to as scroll expanders, the fluid enters in a central portion of the fixed scroll element and expands outwardly in a radial direction, setting in rotation a scrolled element orbiting eccentrically in the fixed portion. The orbiting element sets a shaft in rotation. Figures 3A,3B,3C,3D show angular positions at 0°, 90°, 180°, 270° of the orbiting scroll element 44 with respect to the fixed element 43.

**[0050]** As depicted in Fig. 4, the scroll expander 5 may be configured to work under partial load or under full load. In particular, the expander 5 is composed by a fixed part and a rotoric part with scroll-type bladings. A fixed scroll element 43 comprises a periphery edge 43' which contains and surrounds an orbiting scroll element 44 which moves eccentrically inside the fixed scroll element 43. The involutes of the fixed and rotoric elements are conformed in such a way that the elements are always tangent to each other and their walls touch and brush against each other during the eccentric movement of the orbiting scroll element 44. The output shaft of the expander 5 is connected to the orbiting scroll element 44.

**[0051]** The output shaft of the expander 5 is mechanically connected to an electric generator 33. Preferably the electric generator 33 is an alternator which can be engaged by means of a magnetic clutch 32. When the magnetic clutch 32 is actuated, the output shaft of the expander 5 is rotorically connected to the alternator 33 and vice versa.

**[0052]** The current produced by the alternator 33 is based on the rotating speed of the orbiting scroll element. The power produced by the system 1 thus devised is an average of 1.5 kWe with peak points of 2 kWe. The electricity generated by the electric generator 33 is thus stabilized by the automatic voltage regulator 35 (AVR) at a predefined value, for example of 220V for single-phase current or 400V for a three-phase current.

**[0053]** When exiting from the expander 5 the organic fluid is still vaporized, but with lower temperature and pressure, preferably comprised from 1 to 3 bar. The output temperature is preferably comprised from 70 °C to 40 °C. The organic working fluid therefore passes into the condenser 9, so to completely condense and come out under saturated liquid conditions.

**[0054]** The condenser 9 can both be a plate condenser (liquid-liquid) and a liquid-air radiator. For stationary applications a radiator with such a radiant size to dissipate a power comprised from 10 to 20 kWth, preferably 15 kWth. Vice versa, in the case wherein the system 1 is installed on a vehicle, for example on a boat 100, the condenser 9 may be a plate liquid-liquid condenser, preferably made of steel and copper, and have a heat exchange power comprised from 10 to 20 kW.

**[0055]** Preferably, heat exchange can occur with a low temperature heat source. In the case wherein a liquid-air condenser is used, the exchange can occur with air at ambient temperature. When instead the condenser 9 is a counter-currant liquid-liquid plate heat exchanger, on one side of the exchanger flows the organic liquid of the circuit 2 and on the other the water suctioned by a fourth pump 38 through a third circuit 39. Preferably, in the case of boats, cooling water may be sea water and the fourth pump 38 may be a self-priming pump if the system 1 is arranged over the draft. Otherwise, it is sufficient that the fourth pump 38 is a low absorption water circulator. In the latter case, the overall performance of the system 1 as previously described is around 12% under full load conditions and condenser 9 operating at 20 degrees with 1 bar of pressure.

**[0056]** Once out of the condenser 9, the organic fluid is gathered inside the previously described storage tank 10 and the organic fluid can be recirculated again through the first pump 11.

**[0057]** The expander 5 is a scroll type expander and is configured to have an optimal efficiency for the R245fa fluid. In particular, the blading geometry of the fixed and orbiting scroll elements is conformed following the base equations which generate the involute of a circle, and the thickness of the walls and the height of the blading are optimized in accordance with the laws of refrigerant mass conservation and energy conservation, in particular in the transient phases.

**[0058]** The optimal values experimentally obtained for the two involutes of the fixed and orbiting scroll elements 43,44 are:

- diameter of the base circle [mm]: 10.2
- thickness of the walls [mm]: 4.0
- height of the scroll [mm]: 40
- number of circumferences: 2.9
- starting angle of the involute (rad): 0.8
- final angle of the involute (rad): 20.3

**[0059]** Since the output shaft is eccentrically connected to the orbiting scroll element, expansion chambers are created between the two orbiting and fixed scroll elements thanks to the tangency conditions of the fixed and rotoric walls 43,44. The eccentricity of the shaft is preferably of about 12.5 mm.

**[0060]** In particular, the expander 5 presents two suction inlets, a first suction inlet 6 and a second suction inlet 7.

**[0061]** The first suction inlet 6 is situated at the center of the fixed scroll element 43. The discharge outlet 8 is arranged at a periphery portion of the fixed scroll element, preferably on the periphery edge 43', whereas the second suction inlet 7 is situated in a radially intermediate position between the first suction inlet 6 and the discharge outlet 8.

**[0062]** The organic fluid vaporized under high pressure conditions, preferably comprised from 12 to 18 bar, and temperature comprised from 100 to 160 °C, enters the first suction inlet 6 of the expander 5 and comes out of the discharge outlet 8.

**[0063]** The organic fluid vaporized under medium pressure conditions, preferably comprised from 6 to 10 bar, and temperature comprised from 60 to 100 °C, enters the second suction inlet 7 of the expander 5 and comes out of the discharge outlet 8.

**[0064]** The suction inlets 6, 7 may be opened or closed by the solenoid valves 15,16. The solenoid valves 15,16 are respectively arranged close to the first and second suction inlets 6,7 of the expander 5 to prevent work losses and vibrations.

**[0065]** The opening and closing of the suction inlets 6,7 via the solenoid valves 15,16 is governed by the control unit 21 in order to optimize the performance of the system 1 in real time.

**[0066]** The control unit 21 which supervises the system 1 is managed by a programmable logical controller, commonly referred to as PLC. It is preferable to use Simatic controllers of the Siemens company, in particular S7 models. These allow remote controlling of the measured and calculated quantities.

**[0067]** The system 1 of Fig. 1, in order to operate correctly, needs a control unit capable of capturing signals coming from various temperature and pressure sensors, from a plurality of flow meters and from a plurality of sensors measuring the number of rounds of the rotating devices of system 1.

**[0068]** In particular, the temperature sensors of system 1 may be one or more of the following:

- a first temperature sensor 25 arranged upstream the first heat exchanger 3 along a first circuit 28 relative to the first heat source 13;
- a second temperature sensor 26 arranged downstream the first heat exchanger 3 along the first circuit 28 relative to the first heat source 13;
- a third temperature sensor 29 arranged upstream the second heat exchanger 12 along a second circuit 24 relative to the second heat source 4;
- a fourth temperature sensor 30 arranged downstream the second heat exchanger 12 along the second circuit 24 relative to the second heat source 4;
- a fifth temperature sensor 18 arranged along the main circuit 2 immediately downstream the first heat exchanger 3;
- a sixth temperature sensor 20 arranged along the main circuit 2 immediately downstream the second heat exchanger 12;
- a seventh temperature sensor 31 arranged along the main circuit 2 immediately downstream the discharge outlet 8 of the expander 5;
- an eighth temperature sensor 40 arranged upstream the heat 12 condenser 9 along a fourth circuit 39 relative to the third heat source 42;
- a ninth temperature sensor 41 arranged downstream the condenser 9 along the fourth circuit 39 relative to the third heat source 42;
- a tenth temperature sensor 37 arranged immediately downstream the condenser 9 along the main circuit 2;
- an eleventh temperature sensor 48 arranged immediately upstream the first pump 11 along the main circuit 2;
- a twelfth temperature sensor 36 arranged immediately downstream the first pump 11 along the main circuit 2.

Said first temperature sensor 25 is configured to output a first signal T1 representative of the temperature read by the sensor.

Said second temperature sensor 26 is configured to output a second signal T2 representative of the temperature read by the sensor.

Said third temperature sensor 29 is configured to output a third signal T3 representative of the temperature read by the sensor.

Said fourth temperature sensor 30 is configured to output a fourth signal T4 representative of the temperature read by the sensor.

Said fifth temperature sensor 18 is configured to output a fifth signal T5 representative of the temperature read by the sensor.

Said sixth temperature sensor 20 is configured to output a sixth signal T6 representative of the temperature read by the sensor.

Also the other temperature sensors 31,18,20,40,41,37,48,36 are configured to output a respective signal representative of the temperature read by the sensor.

**[0069]** In particular, the pressure sensors of system 1 may be one or more of the following:

- a first pressure sensor 17 arranged along the main circuit 2 immediately downstream the first heat exchanger 3;
- a second pressure sensor 19 arranged along the main circuit 2 immediately downstream the second

heat exchanger 12;

- a third pressure sensor 51 arranged along the main circuit 2 immediately downstream the discharge outlet 8 of the expander 5;
- a fourth pressure sensor 47 arranged along the main circuit 2 immediately downstream the condenser 9;
- a fifth pressure sensor 49 arranged along the main circuit 2 immediately upstream the first pump 11;
- a sixth pressure sensor 50 arranged along the main circuit 2 immediately downstream the first pump 11.

Said first pressure sensor 17 is configured to output a first pressure signal P1 representative of the pressure read by the sensor.
Said second temperature sensor 19 is configured to output a second pressure signal P2 representative of the pressure read by the sensor.
Also the other pressure sensors 51,47,49,50 are configured to output a respective signal representative of the pressure read by the sensor.

**[0070]** In particular, the control unit 21 may be configured to capture the signals relative to the number of rounds of the first pump 11 and of the expander 5. The signal of the number of rounds of the pump is referred to as NGP and that of the expander as NGE.

**[0071]** Furthermore, the control unit may be configured to capture the signals coming from one or more of the following flow meters:

- first flow meter 52 arranged along the main circuit 2 to measure the flow rate of the fluid therein;
- second flow meter 53 arranged along the first circuit 28 to measure the flow rate of the fluid therein;
- third flow meter 54 arranged along the second circuit 24 to measure the flow rate of the fluid therein;
- fourth flow meter 55 arranged along the third circuit 39 to measure the flow rate of the fluid therein.

Each of said flow meters 52,53,54,55 is configured to output a respective signal representative of the volumetric flow rate read by the meter.

**[0072]** The control unit 21 may further comprise an analogic output for controlling the inverter 46.

**[0073]** The control unit 21 may further comprise a plurality of digital type outputs to control the opening/closing of said solenoid valves 14,15,16 and the powering on/powering off of at least one of said pumps 11,23,27,38.

**[0074]** The control unit 21 is configured to collect the signals of all sensors, meters and devices of the system 1 and to elaborate them to generate said output signals so that the performance, calculated as the ratio between the heat used by the system 1 and the work obtained, is optimized instant by instant.

**[0075]** With respect to the flow chart of Fig. 3, once the control unit 21 captures at least said first, second, third and fourth temperature signals T1,T2,T3,T4, the control unit 21 itself is capable of distinguishing whether or not the solenoid valves 14,15,16 have to be actuated and whether or not the electric generator 33 has to be set in rotation by the expander 5 by activating the magnetic clutch 32.

**[0076]** In particular, the control unit 21 is mainly configured to operate according to the conditions schematized in the following table:

| | | | | |
|---|---|---|---|---|
| T1 | <TT1 | ≥TT1 | ≥TT1 | <TT1 |
| T2 | <TT2 | ≥TT2 | ≥TT2 | <TT2 |
| T3 | <TT3 | <TT3 | ≥TT3 | ≥TT3 |
| T4 | <TT4 | <TT4 | ≥TT4 | ≥TT4 |
| | ↓ | ↓ | ↓ | ↓ |
| valvola(16) | OFF | OFF | ON | ON |
| valvola(15) | ON | ON | OFF | OFF |
| valvola(14) | OFF | OFF | ON | ON |
| pompa(11) | OFF | ON | ON | ON |
| pompa(38) | ON | ON | ON | ON |
| pompa(23) | ON | ON | ON | ON |
| pompa(27) | ON | ON | ON | ON |
| CNT(34) | OFF | ON | ON | ON |

**[0077]** The table schematizes what is depicted in the flow chart of Fig. 3.

**[0078]** Essentially, when the temperature T1 exceeds the threshold TT1 and the temperature T2 exceeds the threshold TT2, the organic fluid passes through the opened solenoid valve 15, while the solenoid valve 16 remains closed, and continues along the main circuit 2 towards the second suction inlet 7 of the expander 5, whereas when the temperature T3 exceeds the threshold TT3 and the temperature T4 exceeds the threshold TT4, the organic fluid is entirely diverted towards the branch 2' and therefore towards the second heat exchanger 12 and the first suction inlet 6 of the expander 5, by opening the solenoid valve 16 and closing the solenoid valve 15. When instead all the temperatures T1,T2,T3,T4 are lower than the respective thresholds TT1,TT2,TT3,TT4, only the solenoid valve 15 remains open and the organic fluid circulates in the main circuit 2. Vice versa, when all the temperatures T1,T2,T3,T4 are higher than the respective thresholds TT1,TT2,TT3,TT4, the solenoid valve 16 is open whereas the solenoid valve 15 is closed, determining the passage of the organic fluid through the second heat exchanger 12 towards the first suction inlet 6 of the expander 5.

**[0079]** The solenoid valve 14 is a two way solenoid valve, which in rest position (OFF) does not divert the organic fluid on the branch 2', whereas in operating position (ON) diverts the organic fluid entirely on branch 2'. The two way solenoid valve 14 is normally in rest position, except when the temperature T3 exceeds the threshold TT3 and the temperature T4 exceeds the threshold TT4.

**[0080]** Practically, when the first exchanger 3 is under such conditions to heat the organic fluid of the main circuit 2 over a certain threshold determined by the temperatures T1,T2, the organic fluid heated and at pressure P1 enters the expander 5 through the second suction inlet 7. However, if the second exchanger 12 is under such conditions to heat the organic fluid of the main circuit 2 over a certain threshold determined by the temperatures T3,T4, the heated organic fluid also passes through the second exchanger 12 coming out at pressure P2 and then enters the expander 5 through the first suction inlet 6.

**[0081]** The control unit 21 is further configured to receive the pressure signals P1 and P2 and manage the opening of the valves 14,15,16 and the operation of the first pump 11 based on said first and second pressure signals P1,P2. In a particular version of the system 1, not depicted in Fig. 3, together with the temperature signals T1 and T2 exceeding the temperature thresholds TT1 and TT2, also the first pressure signal P1 must exceed a first pressure threshold PT1 so that the first pump 11 is operated and said valves 14,15,16 are actuated in order to divert the organic fluid heated from the first heat exchanger 3 towards the expander 5. Similarly, together with the temperature signals T3 and T4 exceeding the temperature thresholds TT3 and TT4, also the second pressure signal P2 must exceed a second pressure threshold PT2 so that the first pump 11 is operated and said valves 14,15,16 are actuated in order to divert the organic fluid towards the second heat exchanger 12 and therefore towards the expander 5. Preferably, said first pressure threshold PT1 is 5 bar and said second pressure threshold PT2 is 10 bar.

**[0082]** The control unit 21 is further configured to receive the temperature signals T5 and T6 and manage the opening of valves 14,15,16 and the operation of the first pump 11 based on said fifth and sixth temperature signals T5,T6 respectively measured by said fifth and sixth temperature sensors 18,20. In a particular version of the system 1, not depicted in Fig.3, together with the temperature signals T1 and T2 exceeding the temperature thresholds TT1 and TT2, also the fifth temperature signal T5 must exceed a fifth temperature threshold TT5 so that the first pump 11 is operated and said valves 14,15,16 are actuated in order to divert the organic fluid heated from the first heat exchanger 3 towards the expander 5. Similarly, together with the temperature signals T3 and T4 exceeding the temperature thresholds TT3 and TT4, also the sixth temperature signal T6 must exceed a sixth temperature threshold TT6 so that the first pump 11 is operated and said valves 14,15,16 are actuated in order to divert the organic fluid towards the second heat exchanger 12 and therefore towards the expander 5. Preferably, said fifth temperature threshold TT5 is 60°C and said sixth temperature threshold TT6 is 100°C,

**[0083]** The control unit 21 is further configured to control the magnetic clutch 32 so to mechanically connect the expander 5 to the alternator 33 in order to generate electric energy when the expander 5 is set in rotation. In particular, the magnetic clutch 32 is configured to be closed, i.e., to connect the expander 5 to the alternator 33, when the signal of the number of rounds of the NGE expander exceeds a predetermined round threshold.

**[0084]** In this case, the control unit 21 controls the closing of the contactor 34 and the electric energy is transferred from the alternator 33 to the automatic voltage regulator 35 and thus to the electric mains or to the electrical implant of the vehicle 100. The contactor 34 instead remains disconnected from the electric mains or implant when the system 1 does not generate electric energy.

**[0085]** The control unit 21 is configured to calculate the heat available on the heat exchangers 3,12 and derive the electric power obtainable on the instantaneous conditions of the system 1. Consequently, the control unit 21 is configured to calculate the performance of the implant as the ratio between the used heat and the work obtained instant by instant. The control unit 21 is configured to optimize said performance.

**[0086]** As described above, the system 1 may provide electric energy to an electrical implant of a vehicle 100. In particular, as depicted in Fig. 2, the vehicle 100 may be a boat equipped with an internal combustion engine 45.

**[0087]** In conclusion, it is clear that the invention thus devised is susceptible to several modifications or variations, all within the invention; all details are further substitutable by technically equivalent elements. In practice, the quantities may vary according to technical requirements.

## Claims

1. System (1) for converting heat energy in electric energy comprising:

   - a closed main circuit (2) in which flows an organic fluid;
   - a first heat exchanger (3) thermally coupled to a first energy source (4) through a first circuit (28); said first heat exchanger (3) being positioned along the main circuit (2) for heating the organic fluid;
   - an expander (5) comprising at least a first and second suction inlets (6,7) and one discharge outlet (8);
   - an electric generator (33) mechanically coupled to an output shaft of the expander (5);
   - a condenser (9) positioned along the main circuit (2) and fluidly connected to the discharge outlet (8) of the expander (5) and to a tank (10), said condenser (9) being configured to condense the organic fluid exiting from the expander (5);

- a first pump (11) positioned along the main circuit (2) between the tank (10) and the first heat exchanger (3);
- a second heat exchanger (12) thermally coupled to a second energy source (13) through a second circuit (24); said second heat exchanger (3) being positioned along the main circuit (2) between the first heat exchanger (3) and the first suction inlet (6) of the expander (5) for heating the organic fluid;
- a branch (2') of the main circuit (2) fluidly connecting a point of the main circuit (2) arranged between the first and second exchangers (3,12) to the second suction inlet (7) of the expander (2) so to bypass the second exchanger (12);
- at least a valve (14,15,16) configured to divert the organic fluid towards the first suction inlet (6) of the expander (5) or towards the second suction inlet (7) of the expander (5);
- a first temperature sensor (25) arranged along the first circuit (28) upstream the first heat exchanger (3) configured to output a first temperature signal (T1);
- a second temperature sensor (26) arranged along the first circuit (28) downstream the first heat exchanger (3) configured to output a second temperature signal (T2);
- a third temperature sensor (29) arranged along the second circuit (24) upstream the second heat exchanger (12) configured to output a third temperature signal (T3);
- a fourth temperature sensor (30) arranged along the second circuit (24) downstream the second heat exchanger (12) configured to output a fourth temperature signal (T4);
- a control unit (21) configured to receive said first, second, third and fourth temperature signals (T1,T2,T3,T4) to generate a first pump control signal (PS) and a first valve control signal (VS) based on said first, second, third and fourth temperature signals (T1,T2,T3,T4) to operate the first pump (11) and the at least a valve (14,15,16);

wherein the expander (5) being configured to expand the organic fluid vaporized in said first heat exchanger (3) or in said first and second heat exchangers (3,12) to generate mechanical energy for driving the electric generator (33).

**2.** System (1) according to claim 1, wherein the control unit (21) is configured to operate the first pump (11) if the first temperature signal (T1) exceeds a first temperature threshold (TT1) and the second temperature signal (T2) exceeds a second temperature threshold (TT2) and/or if the third temperature signal (T3) exceeds a third temperature threshold (TT3) and the fourth temperature signal (T4) exceeds a fourth temperature threshold (TT4), preferably said first temperature threshold (TT1) is about 60°C, said second temperature threshold (TT2) is about 50°C, said third temperature threshold (TT3) is about 100°C, said fourth temperature threshold (TT4) is about 90°C.

**3.** System (1) according to claim 2, wherein the control unit (21) is also configured to operate the at least a valve (14,15,16) so to divert at least in part the organic fluid towards the first suction inlet (6) of the expander (5) if the first temperature signal (T1) exceeds a first temperature threshold (TT1) and the second temperature signal (T2) exceeds a second temperature threshold (TT2).

**4.** System (1) according to claim 3, wherein the control unit (21) is configured to operate the at least a valve (14,15,16) so to divert at least in part the organic fluid towards the second suction inlet (7) of the expander (5) if the third temperature signal (T3) exceeds a third temperature threshold (TT3) and the fourth temperature signal (T4) exceeds a fourth temperature threshold (TT4).

**5.** System (1) according to any one of preceding claims, wherein said at least a valve comprises a switch valve (14) and/or a first and second valves (15,16).

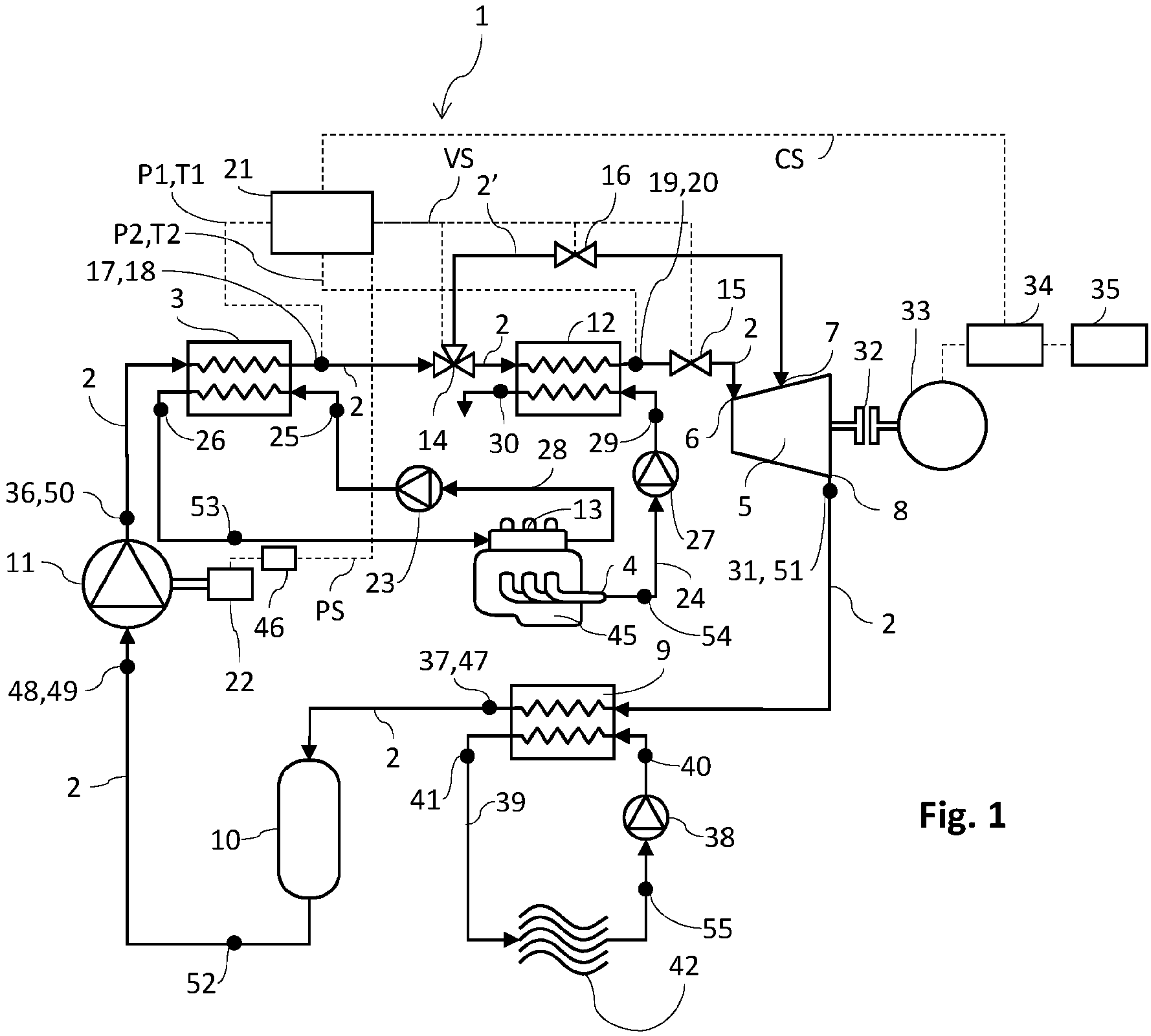
**6.** System (1) according to any one of preceding claims, wherein the expander (5) is a scroll type expander comprising a fixed scroll element (43) and an orbiting scroll element (44), wherein the first suction inlet (6) is arranged substantially at a central portion of the fixed scroll element (43), the discharge outlet (8) is arranged at a periphery portion of the fixed scroll element (43) and the second suction inlet (7) is arranged at an intermediate radial position of the fixed scroll element (43) positioned between the central portion and the periphery portion.

**7.** System (1) according to any one of preceding claims, wherein the expander (5) is mechanically coupled to the electric generator (33) via a magnetic clutch (32) controlled by the control unit (21) based on said first, second, third and fourth temperature signals (T1,T2,T3,T4).

**8.** System (1) according to any one of preceding claims, wherein the electric generator (33) is a brushless type generator.

**9.** System (1) according to any one of preceding claims, comprising a contactor (44) electrically connected to the electric generator (33) and controlled by the control unit (21) based on said first, second, third and fourth temperature signals (T1,T2,T3,T4), preferably the system (1) also comprises an automatic voltage regulator (35) electrically connected to the contactor (44).

**10.** Vehicle (100) comprising a system (1) for converting heat energy in electric energy according to any one of preceding claims, wherein the first heat source (13) derives from a cooling system of an internal combustion engine (45) of the vehicle (100) and the second heat source (4) derives from an exhaust gas of the internal combustion engine (45).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VS
2'
16
19,20
CS
P1,T1
21
P2,T2
17,18
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12
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7
32
33
34
35
2
26
25
2
14
30
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6
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36,50
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8
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23
4
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46
PS
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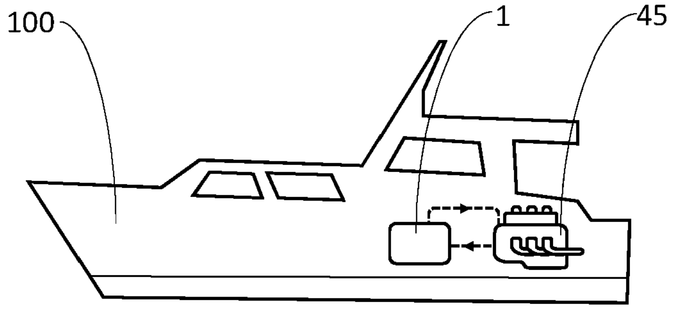
42

Fig. 1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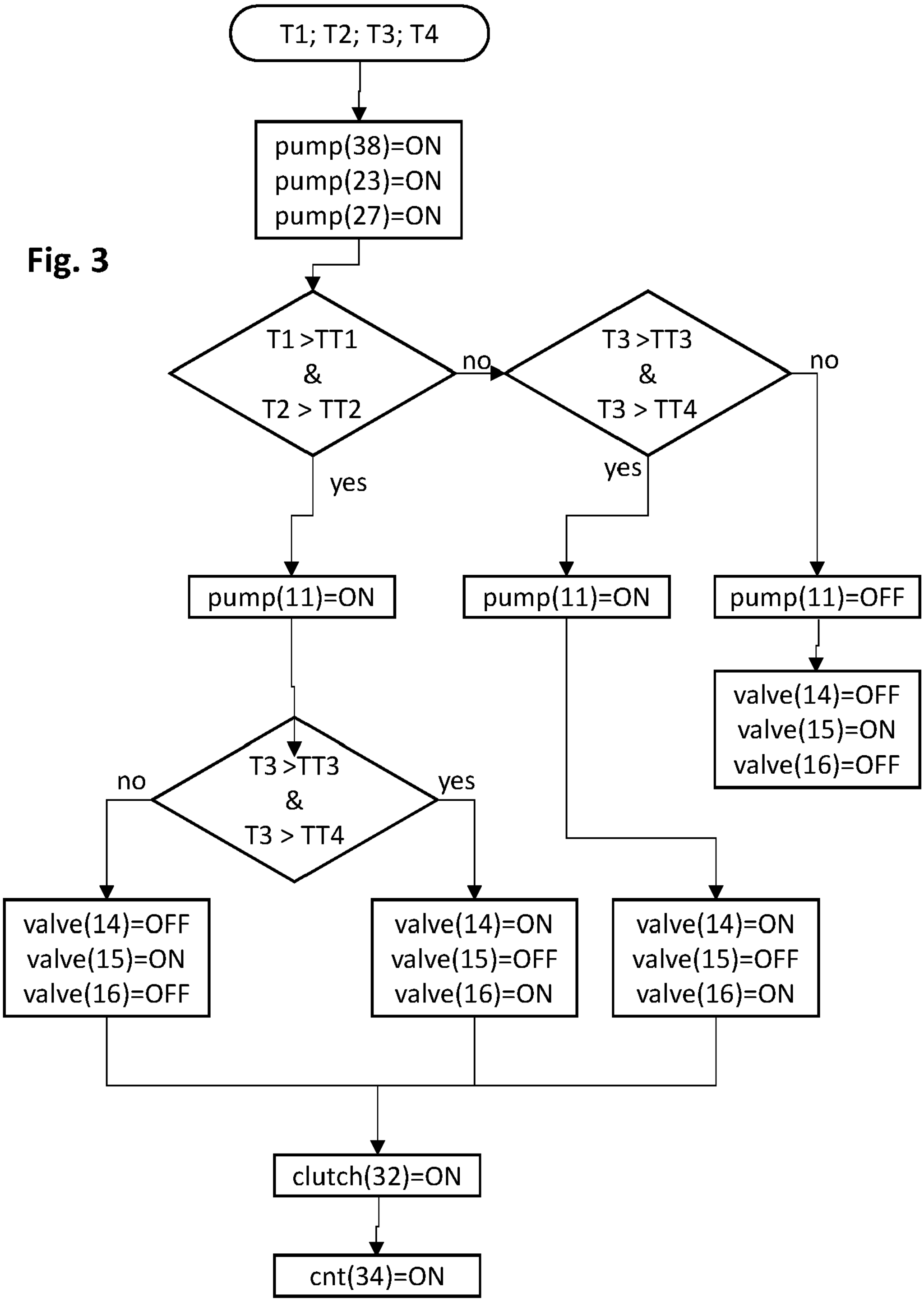
1
45

Fig. 2

Fig. 3


T1; T2; T3; T4
pump(38)=ON
pump(23)=ON
pump(27)=ON
T1 >TT1
&
T2 > TT2
no
T3 >TT3
&
T3 > TT4
no
yes
yes
pump(11)=ON
pump(11)=ON
pump(11)=OFF
valve(14)=OFF
valve(15)=ON
valve(16)=OFF
no
T3 >TT3
&
T3 > TT4
yes
valve(14)=OFF
valve(15)=ON
valve(16)=OFF
valve(14)=ON
valve(15)=OFF
valve(16)=ON
valve(14)=ON
valve(15)=OFF
valve(16)=ON
clutch(32)=ON
cnt(34)=ON

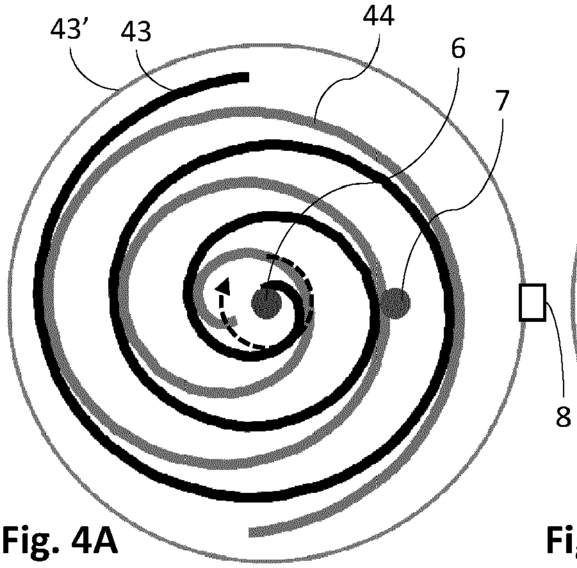



Fig. 4A

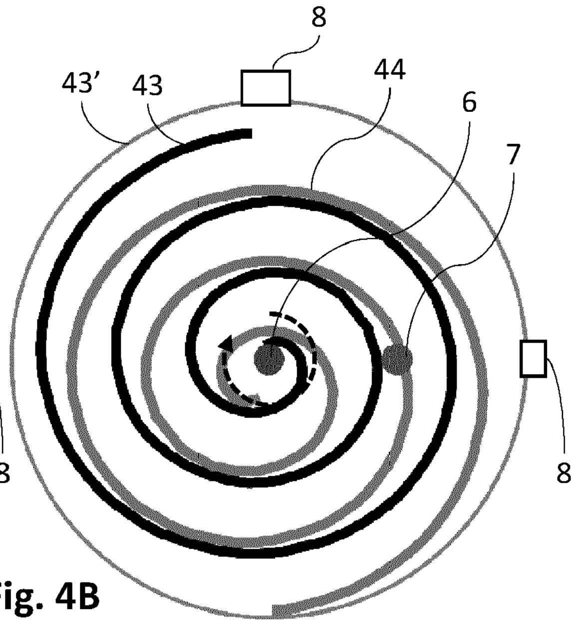



Fig. 4B

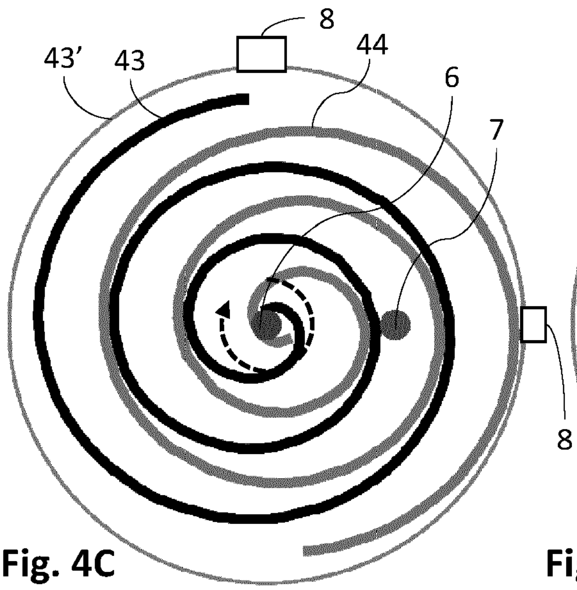



Fig. 4C

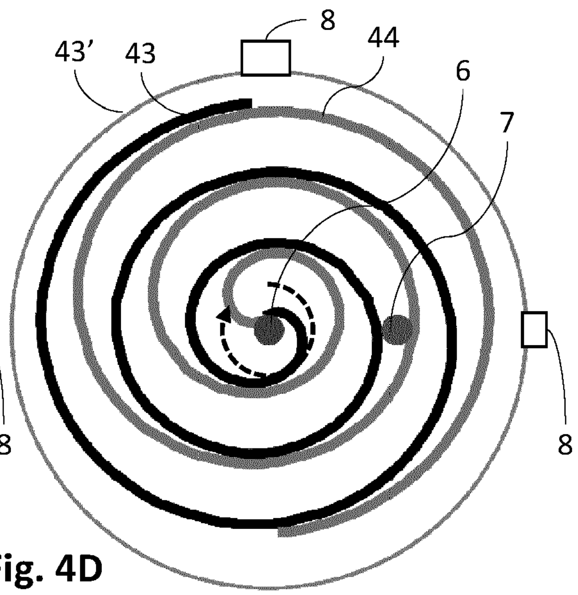



Fig. 4D

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# EUROPEAN SEARCH REPORT

Application Number
EP 21 17 2609

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| | | | F01K |

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| Munich | 4 May 2022 | Varelas, Dimitrios |

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CATEGORY OF CITED DOCUMENTS

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