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(54) COMPRESSION AND ENERGY-RECOVERY UNIT

VERDICHTUNG UND ENERGIE RÜCKGEWINNUNGSEINHEIT

UNITÉ DE COMPRESSION ET RÉCUPERATION D'ENERGIE

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Description

TECHNICAL FIELD

[0001] The present invention relates to a recuperator for recovery of thermal energy from the lubricating/cooling oil of a compressor and for conversion of said energy into mechanical energy, as well as to a compression and energy-recovery unit comprising said recuperator.

BACKGROUND ART

[0002] During compression of the air performed with a volumetric rotary machine (bladed compressor, screw compressor, lobed compressor, etc.) it is necessary to inject into the machine considerable amounts of oil, which have the function of:

a) reducing the coefficients of friction between the rotating parts in relative motion;
b) extracting thermal energy during the transformation of compression so as to reduce the work of compression; this extraction of heat, in fact, modifies the transformation of compression from adiabatic (not isoentropic, as is typical of turbosuperchargers) to polytropic, with considerable absorption of heat; on the ideal hypothesis of complete absorption of heat, the transformation of compression would be isothermal and the work necessary would be the least possible; and
c) carrying out an effective fluid tightness thanks to the film of oil that is created between components in relative motion: in bladed compressors, for example, on the inner surface of the stator, along which the blades pushed outwards by the centrifugal force slide, a film of oil is created that seals the spaces between adjacent cells preventing leaks of compressed air; this occurs also on the axial seals (heads) of the compressor itself.

[0003] The oil thus absorbs from the air the thermal energy that is generated during compression and the thermal energy that is generated by friction. Said thermal energy is usually dissipated in a radiator cooled by air in a forced way via a fan. In certain applications, the radiator can be cooled also by another fluid.

[0004] US2005103016 A1 discloses a reciprocating engine that is cooled by a plurality of heat exchangers. The extracted heat is supplied to an ORC turbine to generate power.

DISCLOSURE OF INVENTION

[0005] The aim of the present invention is to recover the thermal power generated in the compressor in a recuperator that converts it into mechanical or electrical power.

[0006] The aforesaid aim is achieved by a compressor and energy-recovery unit according to Claim 1.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] For a better understanding of the present invention some preferred embodiments are described in what follows, with reference to the attached drawings, wherein:

Figure 1 is a cross-sectional view of a bladed expander used in the compression and energy-recovery unit of the present invention;
Figure 2 is a schematic axial cross-sectional view of the expander of Figure 1;
Figure 3 is a graph of the thermodynamic behaviour of the expander of Figures 1 and 2;
Figure 4 is a circuit diagram of a compression and recovery unit according to the present invention, which uses the bladed expander of Figure 1;
Figures 5 and 6 are perspective views from opposite sides of the unit represented in the diagram of Figure 4;
Figure 7 is a circuit diagram of a thermal-energy recuperator interfaceable with an external compressor to obtain the unit of the invention;
Figure 8 is a perspective view of the recuperator represented in the diagram of Figure 7; and
Figures 9 and 10 are schematic illustrations of two different possibilities of use of the recuperator of Figure 8.

BEST MODE FOR CARRYING OUT THE INVENTION

[0008] With reference to Figures 1 and 2, designated as a whole by 1 is a bladed expander according to the present invention.

[0009] The expander 1 basically comprises an external casing 2, an annular stator 3 with axis A housed in the casing 2 and provided with a cylindrical cavity 4 with axis B parallel to and distinct from the axis A, and a substantially cylindrical rotor 5 with axis A housed in the cavity 4.

[0010] As a result of the eccentricity of the cavity 4 with respect to the rotor 5, formed between the rotor 5 and the stator 3 is an annular chamber 6 of variable width in a radial direction.

[0011] The rotor 5 carries a plurality of blades 7, which extend in a radial direction in the annular chamber 6 and slide radially so as to co-operate substantially in a sealed way with an inner surface 8 of the stator 3. The blades 7 are spaced at equal distances apart circumferentially around the rotor 5, and divide the annular chamber 6 into a plurality of compartments 9 with variable volume.

[0012] The stator 3 has an inlet port 10 in the area of minimum radial width of the compartment 6 and an outlet port 11 in the area of maximum radial width of the compartment 6 in such a way that each chamber 9 increases progressively in volume from the inlet port 10 to the outlet port 11.

[0013] The casing 2 is conveniently provided in two pieces 13, 14, of which one (13) is a cup-shaped body defining integrally a head 15 and an outer annular wall 16, and the other (14) constitutes the other head of the casing.

[0014] The casing 2 defines an annular chamber 17 surrounding the stator 3, which has an inlet 18 and an outlet 19 for connection to an external hydraulic circuit, as will be described more fully in what follows. The annular chamber 17 is delimited axially by the heads 14, 15 and radially by the stator 3 on the inside and by the wall 16 on the outside. Conveniently, the stator 3 is provided with radial fins 20 extending within the annular chamber 17 (Figure 1), which have the purpose of increasing the surface of heat exchange with the fluid contained therein.

[0015] The expander 1 is provided with an output shaft 12, which, in the example illustrated, is integral with the rotor 5. The output shaft 12 is supported in respective through seats 22, 23 of the heads 14, 15, and exits radially from the heads 14 with an axial end 24 of its own, which constitutes a power take off designed to be connected to a current generator or a motor functioning as generator or other mechanical load, as will be described more fully in what follows.

[0016] The seat 23 of the heads 15 is closed axially by a lid 25.

[0017] The shaft 12 is conveniently provided with a blind axial hole 26, which extends substantially throughout its length except for the end 24. The hole 26 gives out axially into a chamber 27, which is made in the lid 25 and communicates with a first area of the annular chamber 17 through a channel 28 made in the head 15. An opposite end of the hole 26 is connected by radial holes 29 with a portion 30 of the seat 22 and delimited axially in a sealed way by a pair of gaskets 34, 35. The hole 26 could present devices (not represented) designed to increase the coefficient of heat exchange. The portion 30 communicates with a second area of the annular chamber 17 opposite to the first area via a channel 36 made in the head 14.

[0018] In use, the expander 1 is used for carrying out the step of expansion of a thermodynamic cycle of the ORC (Organic Rankine Cycle) or Hirn type, during which it is possible to recover mechanical energy at the shaft 12 by subtracting thermal energy from a working fluid, generally an organic fluid or mixture, such as a chlorofluorocarbon in pure form or in mixture or a fluorocarbon, or the like.

[0019] The inlet port 10 and the outlet port 11 of the expander are consequently connected, respectively, to a high-pressure branch and to a low-pressure branch of a closed circuit traversed by the working fluid.

[0020] The annular chamber 17, the hole 26 of the shaft 12, and the corresponding connection channels and ports define as a whole a heating line 37 designed to be connected to a fluid source at a temperature at least equal to the inlet temperature of the working fluid. In this way, the expansion is carried out in conditions such as to be able to receive thermal energy from outside, instead of being substantially adiabatic, as occurs in expanders of a conventional type.

[0021] The ideal configuration would be to carry out an isothermal expansion or even an expansion at an increasing temperature if the fluid that laps the chamber 17 were so to allow.

[0022] The calculation of the work of expansion of a gas that expands following upon a variation of the volume that contains it can be made applying the equation of conservation of energy written for closed systems. For ideal processes (absence of losses), the work can be expressed as

$$L = \int_{Vin}^{Vfin} pdV \qquad (1)$$

where:

Vin is the initial volume of the compartment; and
Vfin is the final volume of the compartment.

[0023] Since Vfin > Vin, the work of expansion is positive and is consequently exchanged with the outside world (from

the fluid that expands to the mobile members of the machine).

[0024] The integral (1) can be calculated once the evolution of the pressure during the variation of volume (thermodynamic transformation) is known. In other words, Eq. (1) becomes

$$L = \int_{Vin}^{Vfin} p(V)dV \qquad (2)$$

[0025] The work exchanged thus depends upon the thermodynamic transformation that the gas undergoes during the transformation of expansion within the compartments.

[0026] Figure 3 represents the cases of an adiabatic transformation (curve a) and of an isothermal transformation (curve i).

[0027] The equation of the transformation will be

$$p(V) = p_{in}V_{in}^{k}V^{-k} \qquad (3)$$

in the case of the adiabatic transformation and

$$p(V) = p_{in}V_{in}\ V^{-1} \qquad (4)$$

in the case of the isothermal transformation.

[0028] In the case of thermostatting of the expansion volume such as to approximate an isothermal transformation, the increase of the work of expansion that derives therefrom is represented by the hatched area in Figure 3. If the transformation of expansion were at an increasing temperature (by virtue of the heat exchange that takes place between the fluid in the chamber 17 and the working fluid in the compartments), a trace thereof in the plane pV would be the curve S of Figure 3, and the benefit of said invention would be still greater.

[0029] The advantage of the stator and rotor heating proves even greater in the case where the fluid that expands in the compartment can present a transition of state from vapour to liquid: this is the case of water vapour or of any other substance, whether pure or in mixture.

[0030] During expansion the pressure decreases within the compartment and along with it the temperature: if the pressure during expansion reaches the value of the saturation pressure (at the temperature of the fluid), part of the vapour (which is by now saturated and dry) starts to condense so that a given fraction becomes liquid.

[0031] Obviously, if the fluid during expansion receives thermal energy from outside (from the annular chamber 17), the condensation of the fluid is delayed if not prevented altogether.

[0032] The fraction of fluid that condenses represents a loss of work of expansion in so far as the liquid no longer undergoes variations of volume during the process of expansion.

[0033] The thermostatting of the expander 1 consequently produces a dual advantage:

a) it causes the work of expansion to increase if the working fluid is a gas or a vapour when it is in the aeriform state;
b) it prevents condensation of the working fluid in contact with the surfaces of the machine if the working fluid is a vapour, thus eliminating the consequent loss of work; in fact, in the case where the working fluid is a vapour of pure substance or of mixtures, keeping the rotor and the stator at a level of temperature that is as high as possible produces the further benefit of preventing local condensation of the vapour, with generation of a film of liquid in contact with the inner surfaces of the expander and consequent loss of power.

[0034] Figure 4 is a diagram of a compression unit 40 provided according to the present invention and equipped with an ORC recuperator 41 for recovery of the thermal energy from the lubricating/cooling oil of the compressor.

[0035] The compression unit 40 basically comprises a compressor 42, for example a bladed volumetric compressor, driven by an electric motor 43 via a shaft 44. Connected in series on the output line of the compressed air 45 of the compressor 42 is a stage 46 of an air/working fluid heat exchanger 47 or economizer, described more fully in what follows.

[0036] Connected to the shaft 44 of the compressor 42 via an electromagnetic clutch 48, or other coupling device, is the output shaft 12 of a bladed expander 1 of the type previously described, forming part of the recuperator 41.

[0037] The compressor 42 comprises a lubricating/cooling line 49, which is connected to the heating line 37 of the expander 1 to form a closed oil circuit 50 therewith. The oil circuit further comprises a three-way by-pass valve 51, with three open-centre positions and continuous positioning, via which an oil outlet 52 of the compressor can be connected

to the inlet 18 of the expander 1 or else to a line 53 of return to the compressor 42, thus bypassing the expander. The valve 51 is normally in a bypass position and is driven into the position of connection to the expander 1 by a thermal actuator 54 controlled by the temperature of the oil at output from the compressor 40. In this way, the recuperator 41 is activated only when the compressor reaches the steady-state temperature. The electromagnetic clutch 48 is controlled accordingly; i.e., it is closed until the steady-state temperature is reached.

[0038] Connected in series on the line 53 of return to the compressor are a stage 55 of an oil/working-fluid heat exchanger 56, described more fully in what follows and, downstream of this, a filter 57.

[0039] The recuperator 41 comprises a closed circuit traversed by the working fluid and operating according to a Rankine cycle (if the organic fluid is brought into saturation conditions) or, preferably, a Hirn cycle (if the organic fluid is brought into superheating conditions).

[0040] More in particular, the recuperator 41 comprises a pump 58 driven by an electric motor 59 or other device and designed to bring the working fluid to a pre-set pressure level. At the end of the compression stage, the fluid is in the liquid state.

[0041] Set in series to one another downstream of the pump 58 are the other stage 60 of the heat exchanger (economizer) 47, in which the fluid is pre-heated by the heat exchange with the compressed air generated by the compressor 42, and the other stage 61 of the heat exchanger 56, in which the working fluid is further heated and undergoes a change of state (vaporization). Preferably, at output from the heat exchanger 56 the working fluid is in the state of saturated or superheated vapour, as mentioned previously.

[0042] Downstream of the heat exchanger 56 the working fluid reaches the expander 1 and, then, a two-position three-way solenoid valve 62, which can deliver the flow selectively, and two circuit branches 63, 64, set in parallel to one another and both connected to the inlet of the pump 58. Set on the first branch 63 is a radiator 65 in heat exchange with a forced air flow generated by an electric fan 66; set on the second branch 64 is a stage 67 of a heat exchanger 68, the other stage 69 of which is designed to be connected to a source of cold fluid, for example water, which may be available. In the case where it is not necessary to have available this alternative, the solenoid valve 62 can be omitted, and just one between the radiator 65 and the heat exchanger 68 can be used.

[0043] The radiator 65 or the heat exchanger 68 constitutes a condenser in which the working fluid undergoes a change of state and returns into the liquid state, subsequently reaching the pump 58 (start of cycle).

[0044] The compression unit 40 and the recuperator 41, in this embodiment, are integrated together to form an integrated compression and energy-recovery unit 70, assembled on a single load-bearing structure 71 (Figure 5). In Figures 5 and 6, which are perspective views of the unit 70, the main components are clearly visible: the compressor 42, the electric motor 43, the expander 1 (all on a common axis), the heat exchangers 47 (air/ORC fluid), 56 (oil/ORC fluid), 68 (ORC fluid/water), the radiator 65 with the corresponding electric fan 66, and the oil filter 57.

[0045] Figures 7 and 8 illustrate, instead, an embodiment of the present invention in which the recuperator 41 constitutes an autonomous unit, interfaceable with an external compressor of any type or with another machine or system generating a recoverable thermal power (for example, a static internal-combustion engine or an internal-combustion engine for vehicle applications, or else a system for exploitation of the geothermal energy or of the energy produced by biomasses).

[0046] The circuit diagram of the recuperator 41 is similar to the one described with reference to the integrated unit. In this case, however, the recuperator comprises an electric generator 72 driven by the bladed expander. Consequently, energy recovery occurs through generation of electrical energy, instead of mechanical energy. The economizer 47 can be omitted.

[0047] The recuperator 41 has a pair of connections 73 for inlet/outlet of a hot fluid (oil, water, burnt gases, etc.) and a pair of connections 74 for inlet/outlet of a cold fluid (typically water of the water mains), whenever available.

[0048] Figure 8 illustrates an embodiment of the recuperator 41. The components described with reference to the integrated solution of Figures 4 and 5 are designated by the same reference numbers, and clearly visible is the electric generator 72 coupled to the bladed expander 1.

[0049] In the case where the recuperator 41 is used in combination with an external compressor of a conventional type, two situations may basically arise.

[0050] If the compressor 42 is provided with a radiator 75 for cooling the oil with forced ventilation (Figure 9), the hot fluid can be constituted directly by the lubricating/cooling oil of the compressor. In this case, it is sufficient to connect the connections 73 of the recuperator 41 to a pair of bypass valves 76 set upstream and downstream of the radiator 75. The recuperator is consequently set in parallel with respect to the radiator 75, which can be excluded via the bypass valves 76 (and possibly used as emergency solution to prevent machine stoppages of the compressor 42 in the case of breakdown or maintenance of the recuperator).

[0051] If, instead, the compressor 42 is provided with cooling of the oil with water via a water/oil heat exchanger 77 (Figure 10), the hot fluid used by the recuperator 41 can be constituted by the cooling water.

[0052] In a way similar to what has been described for the previous case, the recuperator 41 is connected in parallel to the water stage of the water/oil heat exchanger 77 via bypass valves 76 set upstream and downstream of the heat exchanger itself along a water line 78.

[0053] By switching the bypass valves 76, it is possible to select whether to use the recuperator 41 for the production of electrical energy or else use the cooling water for other purposes (for example, for heating environments in winter).

[0054] The compression unit 40 basically comprises a compressor 42, for example a bladed volumetric compressor, driven by an electric motor 43 via a shaft 44. Connected in series on the output line for the compressed air 45 of the compressor 42 is a stage 46 of an air/working-fluid heat exchanger 47 or economizer, described more fully in what follows.

[0055] Connected to the shaft 44 of the compressor 42, via an electromagnetic clutch 48, or other coupling device, is the output shaft 12 of a bladed expander 1 of the type previously described, forming part of the recuperator 41.

[0056] The compressor 42 comprises a lubricating/cooling line 49, which is connected to the heating line 37 of the expander 1 to form a closed oil circuit 50 therewith. The oil circuit further comprises a three-way by-pass valve 51, with three open-centre positions and continuous positioning, via which an oil outlet 52 of the compressor can be connected to the inlet 18 of the expander 1 or else to a line 53 of return to the compressor 42, thus bypassing the expander. The valve 51 is normally in the bypass position and is driven into the position of connection to the expander 1 by a thermal actuator 54 controlled by the temperature of the oil at output from the compressor 40. In this way, the recuperator 41 is activated only when the compressor reaches the steady-state temperature. The electromagnetic clutch 48 is controlled accordingly; i.e., it is closed until the steady-state temperature is reached.

[0057] Connected in series on the line 53 of return to the compressor are a stage 55 of an oil/working-fluid heat exchanger 56, described more fully in what follows and, downstream of this, a filter 57.

[0058] The recuperator 41 comprises a closed circuit traversed by the working fluid and operating according to a Rankine cycle (if the organic fluid is brought into saturation conditions) or, preferably, a Hirn cycle (if the organic fluid is brought into superheating conditions).

[0059] More in particular, the recuperator 41 comprises a pump 58 driven by an electric motor 59 or some other device and designed to bring the working fluid to a pre-set pressure level. At the end of the compression stage, the fluid is in the liquid state.

[0060] Set in series with respect to one another downstream of the pump 58 are the other stage 60 of the heat exchanger (economizer) 47, in which the fluid is pre-heated by the heat exchange with the compressed air generated by the compressor 42, and the other stage 61 of the heat exchanger 56, in which the working fluid is further heated and undergoes a change of state (vaporization). Preferably, at output from the heat exchanger 56 the working fluid is in the state of saturated or superheated vapour, as mentioned previously.

[0061] Downstream of the heat exchanger 56 the working fluid reaches the expander 1 and, then, a two-position three-way solenoid valve 62, which can deliver the flow selectively, and two circuit branches 63, 64, set in parallel to one another and both connected to the inlet of the pump 58. Set on the first branch 63 is a radiator 65 in heat exchange with a forced air flow generated by an electric fan 66. Set on the second branch 64 is a stage 67 of a heat exchanger 68, the other stage 69 of which is designed to be connected to a source of cold fluid, for example water, which may be available. In the case where it is not necessary to have available this alternative, the solenoid valve 62 can be omitted, and just one between the radiator 65 and the heat exchanger 68 can be used.

[0062] The radiator 65 or the heat exchanger 68 constitutes a condenser in which the working fluid undergoes a change of state and returns into the liquid state, subsequently reaching the pump 58 (start of cycle).

[0063] The compression unit 40 and the recuperator 41, in this embodiment, are integrated together to form an integrated compression and energy-recovery unit 70, assembled on a single load-bearing structure 71 (Figure 5). In Figures 5 and 6, which are perspective views of the unit 70, the main components are clearly visible: the compressor 42, the electric motor 43, the expander 1 (all on a common axis), the heat exchangers 47 (air/ORC fluid), 56 (oil/ORC fluid), 68 (ORC fluid/water), the radiator 65 with the corresponding electric fan 66, and the oil filter 57.

[0064] Figures 7 and 8 illustrate, instead, an embodiment of the present invention in which the ORC recuperator 41 constitutes an autonomous unit, interfaceable with an external compressor of a rotary volumetric type to form a unit according to the present invention.

[0065] The circuit diagram of the ORC recuperator 41 is similar to the one described with reference to the integrated unit. In this case, however, the recuperator comprises an electric generator 72 driven by the bladed expander. Consequently, energy recovery occurs through generation of electrical energy, instead of mechanical energy. The economizer 47 can be omitted.

[0066] The ORC recuperator 41 has a pair of connections 73 for inlet/outlet of a hot fluid (oil, water, burnt gases, etc.) and a pair of connections 74 for inlet/outlet of a cold fluid (typically water of the water mains), whenever available.

[0067] Figure 8 illustrates one embodiment of the ORC recuperator 41. The components described with reference to the integrated solution of Figures 4 and 5 are designated by the same reference numbers, and clearly visible is the electric generator 72 coupled to the bladed expander 1

[0068] In the case where the ORC recuperator 41 is used in combination with an external compressor of a conventional type, two situations may basically arise.

[0069] If the compressor 42 is provided with a radiator 75 for cooling the oil with forced ventilation (Figure 9), the hot fluid can be constituted directly by the lubricating/cooling oil of the compressor. In this case, it is sufficient to connect

the connections 73 of the recuperator 41 to a pair of bypass valves 76 set upstream and downstream of the radiator 75. The recuperator is consequently set in parallel with respect to the radiator 75, which can be excluded via the bypass valves 76 (and possibly used as emergency solution to prevent machine stoppages of the compressor 42 in the case of breakdown or maintenance of the recuperator).

[0070] If, instead, the compressor 42 is provided with cooling of the oil with water via a water/oil heat exchanger 77 (Figure 10), the hot fluid used by the ORC recuperator 41 can be constituted by the cooling water; consequently, the heat exchange between the lubricating/cooling oil of the compressor 42 and the working fluid in this case is indirect.

[0071] In a way similar to what has been described for the previous case, the ORC recuperator 41 is connected to the water stage of the water/oil heat exchanger 77 via bypass valves 76 set along the water line 78 upstream and downstream of the heat exchanger 77.

[0072] By switching the bypass valves 76 it is possible to select whether to use the ORC recuperator 41 for the production of electrical energy or else use the cooling water for other purposes (for example, for heating environments in winter).

[0073] Use of a recuperator 41 provided according to the invention affords a considerable energy saving.

[0074] The thermal power that is exchanged by the lubricating/cooling oil of a compressor is slightly lower than the electric power absorbed and is characterized by a medium-to-low thermal level. The oil, in fact, does not generally exceed 100°C and cannot be cooled to temperatures lower than 55-60°C.

[0075] From assessments made, the efficiency of the recuperator 41 can be approximately 15%.

[0076] Assuming that it is applied to a compression unit with a compressor having an absorption of electric power of 50 kW, the thermal power exchanged with the lubricating/cooling oil of the compressor is approximately 40 kW.

[0077] With an average conversion efficiency of 15%, the mechanical/electrical power recovered is 6 kW. A value of 6 kW represents more than 10% of the absorbed electric power, which in the specific sector is very significant.

[0078] In the case of Figures 5 and 6, the power produced by the system is used in mechanical form. Once the recovery system is brought to steady-state conditions, the mechanical power is supplied to the compressor 42 via the electromagnetic clutch 48, enabling reduction by more than 10% of the absorption of electric power of the electric motor 43.

[0079] In the cases of Figures 7 to 10, the power produced by the system is used in electrical form. The same power is reintroduced into the power mains, representing for the person running the compression unit an additional income (sale of electrical energy).

[0080] Finally, it is clear that modifications and variations may be made to the present invention, without thereby departing from the sphere of protection of the claims.

For example, thermostatting of the expander may be absent, or else limited to the stator or to the rotor, and may be provided in a way different from what has been described herein.

[0081] Thermostatting can be carried out with the oil of the compressor or with another fluid, preferably in heat exchange therewith.

[0082] The compressor 42 may be a volumetric rotary compressor of any type.

[0083] The working fluid used may be an organic fluid such as a chlorofluorocarbon or any other fluid suited to the thermal levels involved.

Claims

1. A compressor and energy-recovery unit, comprising a compressor (42) driven by an electric motor (43) and provided with a lubricating/cooling oil system, **characterized by** comprising a Rankine-cycle or Hirn-cycle recuperator (41), which comprises a bladed expander (1) and uses a working fluid in at least indirect heat exchange with the lubricating/cooling oil of the compressor (42), the bladed expander comprising a stator (3) provided with an inlet port (10) and an outlet port (11) for the working fluid, a rotor (5) housed within the stator (3) and a plurality of blades (7) set between the rotor (5) and the stator (3) so as to delimit between them a plurality of compartments (9) with variable volume that increases between the inlet port (10) and the outlet port (11), and a heating line (37) traversed by a hot fluid and configured so as to subject at least one between the stator (3) and the rotor (5) to a heat exchange with the hot fluid and to carry out on the working fluid a substantially isothermal expansion transformation.

2. The unit according to Claim 1, **characterized in that** said bladed expander (1) is mechanically connectable to said compressor (42) so as to supply mechanical power to the compressor (42) itself.

3. The unit according to Claim 1, **characterized in that** said bladed expander is connected to an electric generator (72).

4. The unit according to any of the preceding claims, **characterized in that** the heating line (37) comprises a chamber (17) at least partially surrounding the stator (3).

5. The unit according to Claim 4, **characterized in that** the heating line (37) comprises at least one cavity (26) inside the rotor (5).

6. The unit according to any one of the preceding claims, **characterized in that** said hot fluid is the lubricating/cooling oil of the compressor (42).

7. The unit according to any one of the preceding claims, **characterized in that** said hot fluid is a fluid in heat exchange with the lubricating/cooling oil of the compressor (42).

8. The unit according to any one of the preceding claims, **characterized in that** the recuperator comprises a pump (58), at least one heat exchanger (56) for heating and vaporizing said working fluid using heat subtracted from the lubricating/cooling oil of the compressor (42), the heat exchanger (56) being connected to a delivery of the pump (58) and to an inlet of the bladed expander (1), and a condenser (65; 68) connected to an outlet of the expander (1) and to an inlet of the pump (58).

9. The unit according to Claim 8, **characterized in that** it comprises a closed oil circuit (50) comprising a lubricating/cooling line (49) of the compressor (42), the heating line (37) of the evaporator (1), and a stage (56) of the exchanger for heating and vaporization of the working fluid.

10. The unit according to Claim 9, **characterized in that** it comprises an economizer (47), in which the working fluid is pre-heated by means of heat exchange with the compressed air produced by the compressor (42), the economizer (47) being set upstream of the heat exchanger (56) for heating and vaporization of the working fluid.

11. The unit according to Claim 9 or Claim 10, **characterized in that** the oil circuit (50) comprises a bypass valve (51) for selectively connecting an outlet (52) of the compressor (42) to the expander (3) or to a line (53) of return to the compressor itself.

12. The unit according to Claim 2, **characterized in that** it comprises an electromagnetic clutch for mechanically connecting the expander (3) to the compressor (42) in a selective way.

13. The unit according to Claim 3, **characterized in that** said recuperator (41) is provided as autonomous unit interfaceable with said compressor (42) and purposely provided with connections for a hot fluid constituted by the lubricating/cooling oil of the compressor (42) or by a fluid in heat exchange therewith.

14. A method for recovery of thermal energy from the lubricating/cooling oil of a compressor (42), **characterized in that** it uses a Rankine-cycle or Hirn-cycle recuperator (41) comprising a bladed expander (1) and functioning with a working fluid in at least indirect heat exchange with the lubricating/cooling oil of the compressor (42), the bladed expander comprising a stator (3) provided with an inlet port (10) and an outlet port (11) for the working fluid, a rotor (5) housed within the stator (3) and a plurality of blades (7) set between the rotor (5) and the stator (3) so as to delimit between them a plurality of compartments (9) with variable volume that increases between the inlet port (10) and the outlet port (11), and a heating line (37) traversed by a hot fluid and configured so as to subject at least one between the stator (3) and the rotor (5) to a heat exchange with the hot fluid and to carry out on the working fluid a substantially isothermal expansion transformation.

15. The method according to Claim 14, **characterized in that** said bladed expander (1) is thermostatted by means of said oil.

16. The method according to Claim 14, **characterized in that** said bladed expander (1) is thermostatted by means of a fluid in heat exchange with said oil.

Patentansprüche

1. Verdichter- und Energierückgewinnungseinheit, umfassend einen Verdichter (42), der durch einen Elektromotor (43) angetrieben und mit einem Schmier-/Kühlölsystem versehen ist, **dadurch gekennzeichnet, dass** sie einen mit einem Rankine-Kreisprozess oder Hirn-Kreisprozess arbeitenden Rekuperator (41) umfasst, der eine Flügel-Expansionsmaschine (1) umfasst und ein Arbeitsfluid verwendet, das in zumindest indirektem Wärmeaustausch mit dem Schmier-/Kühlöl des Verdichters (42) steht, wobei die Flügel-Expansionsmaschine einen mit einem Ein-

lassanschluss (10) und einem Auslassanschluss (11) für das Arbeitsfluid versehenen Stator (3), einen innerhalb des Stators (3) aufgenommenen Rotor (5) und eine Vielzahl von Flügeln (7), die so zwischen den Rotor (5) und den Stator (3) gesetzt sind, dass sie zwischen sich eine Vielzahl von Abteilen (9) mit veränderlichem Volumen begrenzen, welches zwischen dem Einlassanschluss (10) und dem Auslassanschluss (11) zunimmt, und eine Heizleitung (37) umfasst, die von einem heißen Fluid durchströmt und so ausgelegt ist, dass sie den Stator (3) und/oder den Rotor (5) einem Wärmeaustausch mit dem heißen Fluid unterzieht und an dem Arbeitsfluid eine im Wesentlichen isotherme Expansionsumwandlung durchführt.

2. Einheit nach Anspruch 1, **dadurch gekennzeichnet, dass** die Flügel-Expansionsmaschine (1) mechanisch mit dem Verdichter (42) so verbindbar ist, dass sie dem Verdichter (42) selbst mechanische Leistung zuführt.

3. Einheit nach Anspruch 1, **dadurch gekennzeichnet, dass** die Flügel-Expansionsmaschine mit einem Stromerzeuger (72) verbunden ist.

4. Einheit nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die Heizleitung (37) eine den Stator (3) zumindest teilweise umgebende Kammer (17) umfasst.

5. Einheit nach Anspruch 4, **dadurch gekennzeichnet, dass** die Heizleitung (37) mindestens einen Hohlraum (26) im Inneren des Rotors (5) umfasst.

6. Einheit nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** es sich bei dem heißen Fluid um das Schmier-/Kühlöl des Verdichters (42) handelt.

7. Einheit nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** es sich bei dem heißen Fluid um ein Fluid handelt, das mit dem Schmier-/Kühlöl des Verdichters (42) in Wärmeaustausch steht.

8. Einheit nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** der Rekuperator eine Pumpe (58), mindestens einen Wärmetauscher (56) zum Erwärmen und Verdampfen des Arbeitsfluids unter Verwendung von dem Schmier-/Kühlöl des Verdichters (42) entzogener Wärme, wobei der Wärmetauscher (56) mit einem Förderstrom der Pumpe (58) und einem Einlass der Flügel-Expansionsmaschine (1) verbunden ist, und einen mit einem Auslass der Expansionsmaschine (1) und einem Einlass der Pumpe (58) verbundenen Kondensator (65; 68) umfasst.

9. Einheit nach Anspruch 8, **dadurch gekennzeichnet, dass** sie einen geschlossenen Ölkreislauf (50) umfasst, der eine Schmier-/Kühlleitung (49) des Verdichters (42), die Heizleitung (37) des Verdampfers (1) und eine Stufe (56) des Tauschers zum Erwärmen und Verdampfen des Arbeitsfluids umfasst.

10. Einheit nach Anspruch 9, **dadurch gekennzeichnet, dass** sie einen Vorwärmer (47) umfasst, in welchem das Arbeitsfluid mittels Wärmeaustauschs mit der von dem Verdichter (42) produzierten Druckluft vorgewärmt wird, wobei der Vorwärmer (47) dem Wärmetauscher (56) zum Erwärmen und Verdampfen des Arbeitsfluids vorgeschaltet ist.

11. Einheit nach Anspruch 9 oder Anspruch 10, **dadurch gekennzeichnet, dass** der Ölkreislauf (50) ein Umgehungsventil (51) zum selektiven Verbinden eines Auslasses (52) des Verdichters (42) mit der Expansionsmaschine (3) oder einer Rücklaufleitung (53) zu dem Verdichter selbst umfasst.

12. Einheit nach Anspruch 2, **dadurch gekennzeichnet, dass** sie eine elektromagnetische Kupplung zum selektiven mechanischen Verbinden der Expansionsmaschine (3) mit dem Verdichter (42) umfasst.

13. Einheit nach Anspruch 3, **dadurch gekennzeichnet, dass** der Rekuperator (41) als eigenständige Einheit vorhanden ist, die mit dem Verdichter (42) koppelbar und zweckmäßig mit Verbindungen für ein heißes Fluid versehen ist, welches in dem Schmier-/Kühlöl des Verdichters (42) oder einem mit diesem in Wärmeaustausch stehenden Fluid besteht.

14. Verfahren zur Rückgewinnung von Wärmeenergie aus dem Schmier-/Kühlöl eines Verdichters (42), **dadurch gekennzeichnet, dass** es einen mit einem Rankine-Kreisprozess oder Hirn-Kreisprozess arbeitenden Rekuperator (41) verwendet, der eine Flügel-Expansionsmaschine (1) umfasst und mit einem Arbeitsfluid arbeitet, das in zumindest indirektem Wärmeaustausch mit dem Schmier-/Kühlöl des Verdichters (42) steht, wobei die Flügel-Expansionsmaschine einen mit einem Einlassanschluss (10) und einem Auslassanschluss (11) für das Arbeitsfluid verse-

henen Stator (3), einen innerhalb des Stators (3) aufgenommenen Rotor (5) und eine Vielzahl von Flügeln (7), die so zwischen den Rotor (5) und den Stator (3) gesetzt sind, dass sie zwischen sich eine Vielzahl von Abteilen (9) mit veränderlichem Volumen begrenzen, welches zwischen dem Einlassanschluss (10) und dem Auslassanschluss (11) zunimmt, und eine Heizleitung (37) umfasst, die von einem heißen Fluid durchströmt und so ausgelegt ist, dass sie den Stator (3) und/oder den Rotor (5) einem Wärmeaustausch mit dem heißen Fluid unterzieht und an dem Arbeitsfluid eine im Wesentlichen isotherme Expansionsumwandlung durchführt.

15. Verfahren nach Anspruch 14, **dadurch gekennzeichnet, dass** eine Temperaturregelung der Flügel-Expansionsmaschine (1) mittels des Öls erfolgt.

16. Verfahren nach Anspruch 14, **dadurch gekennzeichnet, dass** eine Temperaturregelung der Flügel-Expansionsmaschine (1) mittels eines mit dem Öl in Wärmeaustausch stehenden Fluids erfolgt.

Revendications

1. Unité de compression et de récupération d'énergie, comprenant un compresseur (42) entraîné par un moteur électrique (43) et équipé d'un système d'huile de lubrification/refroidissement, **caractérisée en ce qu'**elle comprend un récupérateur à cycle de Rankine ou à cycle de Hirn (41), qui comprend un détendeur à aubes (1) et qui utilise un fluide de travail en échange de chaleur au moins indirect avec l'huile de lubrification/refroidissement du compresseur (42), le détendeur à aubes comprenant un stator (3) comportant un port d'entrée (10) et un port de sortie (11) pour le fluide de travail, un rotor (5) logé à l'intérieur du stator (3) et une pluralité d'aubes (7) placées entre le rotor (5) et le stator (3) de manière à délimiter entre elles une pluralité de compartiments (9) de volume variable qui augmente entre le port d'entrée (10) et le port de sortie (11), et une ligne de chauffage (37) traversée par un fluide chaud et configurée de manière à soumettre au moins un parmi le stator (3) et le rotor (5) à un échange de chaleur avec le fluide chaud et à exécuter sur le fluide de travail une transformation par détente sensiblement isotherme.

2. Unité selon la revendication 1, **caractérisée en ce que** ledit détendeur à aubes (1) est connecté de façon mécanique audit compresseur (42) de manière à fournir une puissance mécanique au compresseur (42) lui-même.

3. Unité selon la revendication 1, **caractérisée en ce que** ledit détendeur à aubes est connecté à un générateur électrique (72).

4. Unité selon l'une quelconque des revendications précédentes, **caractérisée en ce que** la ligne de chauffage (37) comprend une chambre (17) qui entoure au moins partiellement le stator (3).

5. Unité selon la revendication 4, **caractérisée en ce que** la ligne de chauffage (37) comporte au moins une cavité (26) à l'intérieur du rotor (5).

6. Unité selon l'une quelconque des revendications précédentes, **caractérisée en ce que** ledit fluide chaud est l'huile de lubrification/refroidissement du compresseur (42).

7. Unité selon l'une quelconque des revendications précédentes, **caractérisée en ce que** ledit fluide chaud est un fluide en échange de chaleur avec l'huile de lubrification/refroidissement du compresseur (42).

8. Unité selon l'une quelconque des revendications précédentes, **caractérisée en ce que** le récupérateur comprend une pompe (58), au moins un échangeur de chaleur (56) pour chauffer et vaporiser ledit fluide de travail en utilisant la chaleur prélevée auprès de l'huile de lubrification/refroidissement du compresseur (42), l'échangeur de chaleur (56) étant connecté à une décharge de la pompe (58) et à une entrée du détendeur à aubes (1), et un condenseur (65; 68) connecté à une sortie du détendeur (1) et à une entrée de la pompe (58) .

9. Unité selon la revendication 8, **caractérisée en ce qu'**elle comprend un circuit d'huile fermé (50) comprenant une ligne de lubrification/refroidissement (49) du compresseur (42), la ligne de chauffage (37) de l'évaporateur (1), et un étage (56) de l'échangeur pour chauffer et vaporiser le fluide de travail.

10. Unité selon la revendication 9, **caractérisée en ce qu'**elle comprend un économiseur (47), dans lequel le fluide de travail est préchauffé au moyen d'un échange de chaleur avec l'air comprimé produit par le compresseur (42), l'économiseur (47) étant installé en amont de l'échangeur de chaleur (56) afin de chauffer et de vaporiser le fluide

de travail.

11. Unité selon la revendication 9 ou la revendication 10, **caractérisée en ce que** le circuit d'huile (50) comprend une soupape de contournement (51) pour connecter de façon sélective une sortie (52) du compresseur (42) au détendeur (3) ou à une ligne (53) de retour vers le compresseur lui-même.

12. Unité selon la revendication 2, **caractérisée en ce qu'**elle comprend un embrayage électromagnétique pour connecter mécaniquement le détendeur (3) au compresseur (42) d'une façon sélective.

13. Unité selon la revendication 3, **caractérisée en ce que** ledit récupérateur (41) est prévu comme une unité autonome capable d'interfacer avec ledit compresseur (42) et équipée délibérément de connexions pour un fluide chaud constitué par l'huile de lubrification/refroidissement du compresseur (42) ou par un fluide en échange de chaleur avec celle-ci.

14. Procédé pour récupérer de l'énergie thermique à partir de l'huile de lubrification/refroidissement d'un compresseur (42), **caractérisé en ce qu'**il utilise un récupérateur à cycle de Rankine ou à cycle de Hirn (41), comprenant un détendeur à aubes (1) et fonctionnant avec un fluide de travail en échange de chaleur au moins indirect avec l'huile de lubrification/refroidissement du compresseur (42), le détendeur à aubes comprend un stator (3) comportant un port d'entrée (10) et un port de sortie (11) pour le fluide de travail, un rotor (5) logé à l'intérieur du stator (3) et une pluralité d'aubes (7) placées entre le rotor (5) et le stator (3) de manière à délimiter entre elles une pluralité de compartiments (9) de volume variable qui augmente entre le port d'entrée (10) et le port de sortie (11), et une ligne de chauffage (37) traversée par un fluide chaud et configurée de manière à soumettre au moins un parmi le stator (3) et le rotor (5) à un échange de chaleur avec le fluide chaud et à exécuter sur le fluide de travail une transformation par détente sensiblement isotherme.

15. Procédé selon la revendication 14, **caractérisé en ce que** ledit détendeur à aubes (1) est thermostaté au moyen de ladite huile.

16. Procédé selon la revendication 14, **caractérisé en ce que** ledit détendeur à aubes (1) est thermostaté au moyen d'un fluide en échange de chaleur avec ladite huile.

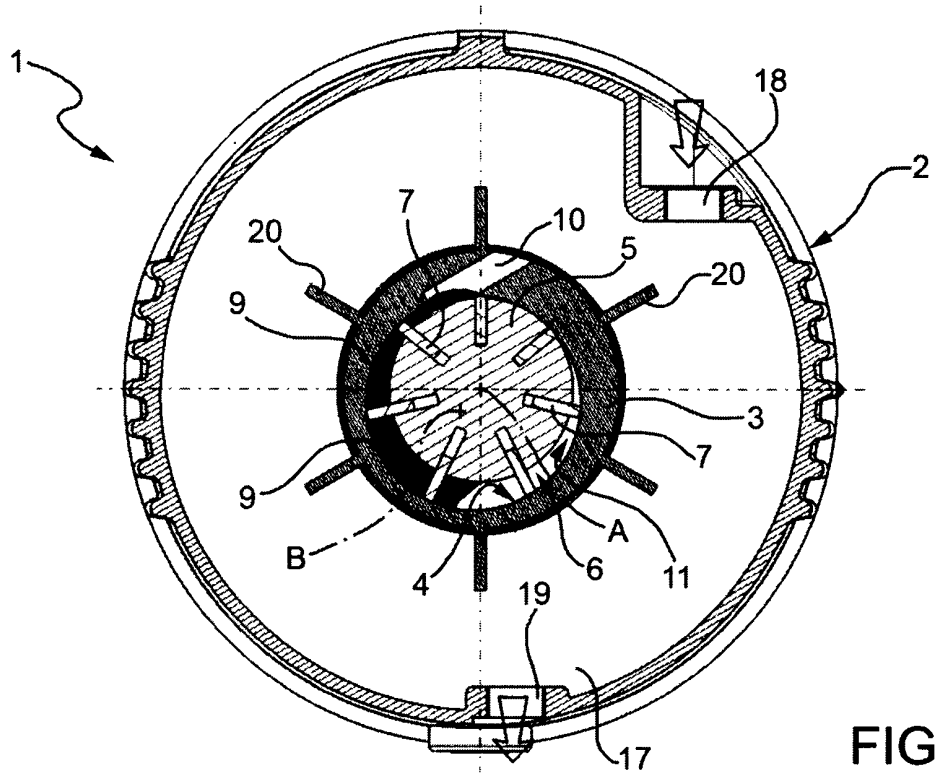

1
18
2
7
10
20
5
20
9
3
7
9
A
B
6
11
4
19
17

FIG. 1

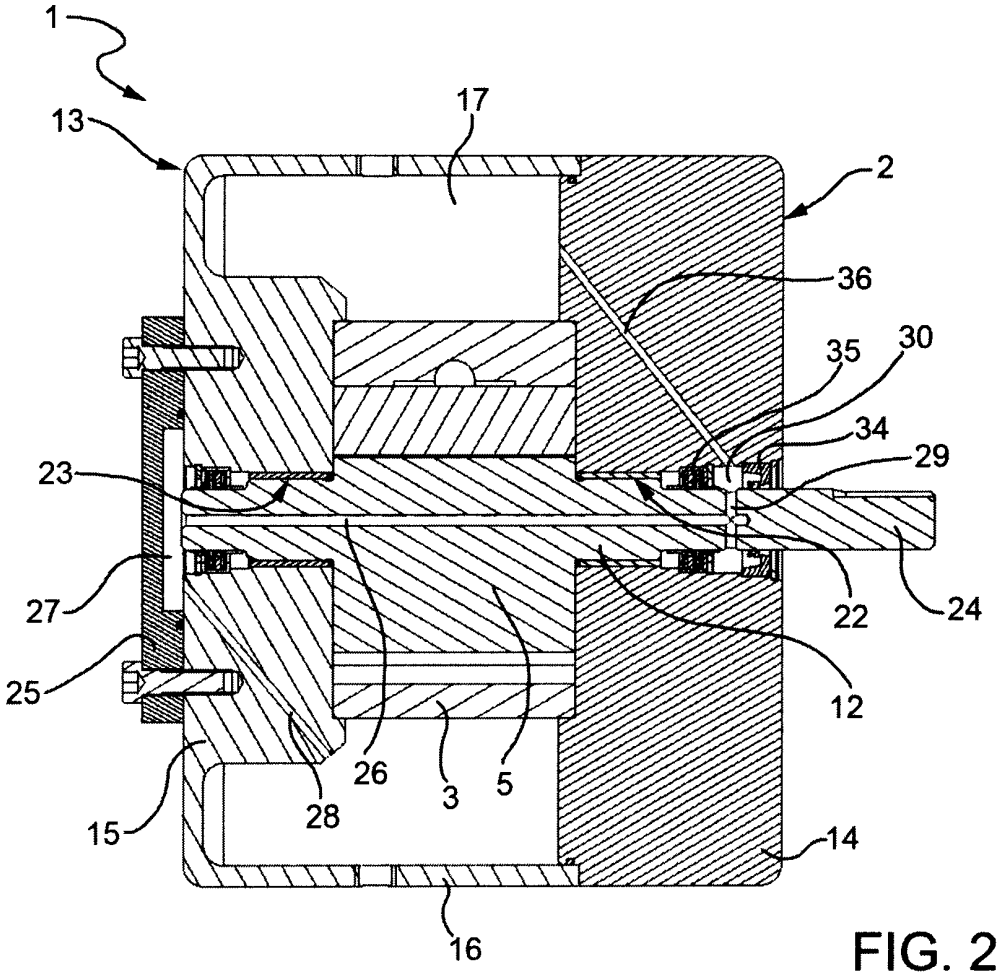

1
17
13
2
36
35
30
34
29
23
27
22
24
25
12
26
3
5
28
15
14
16

FIG. 2

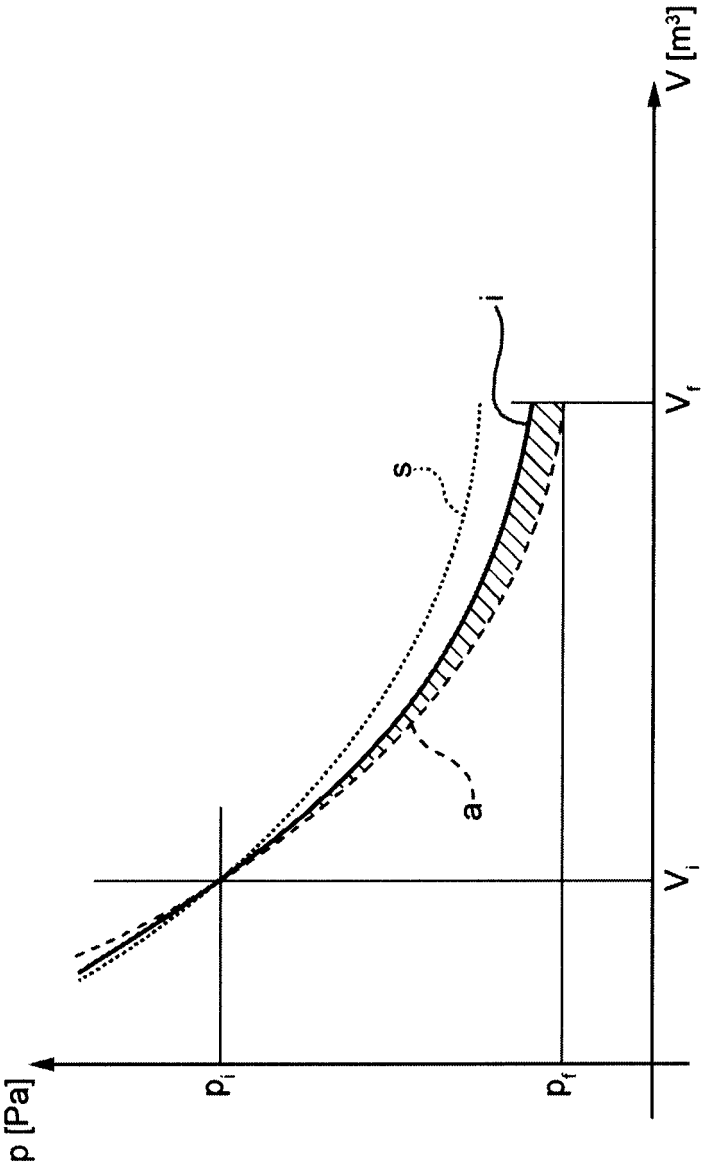


FIG. 3

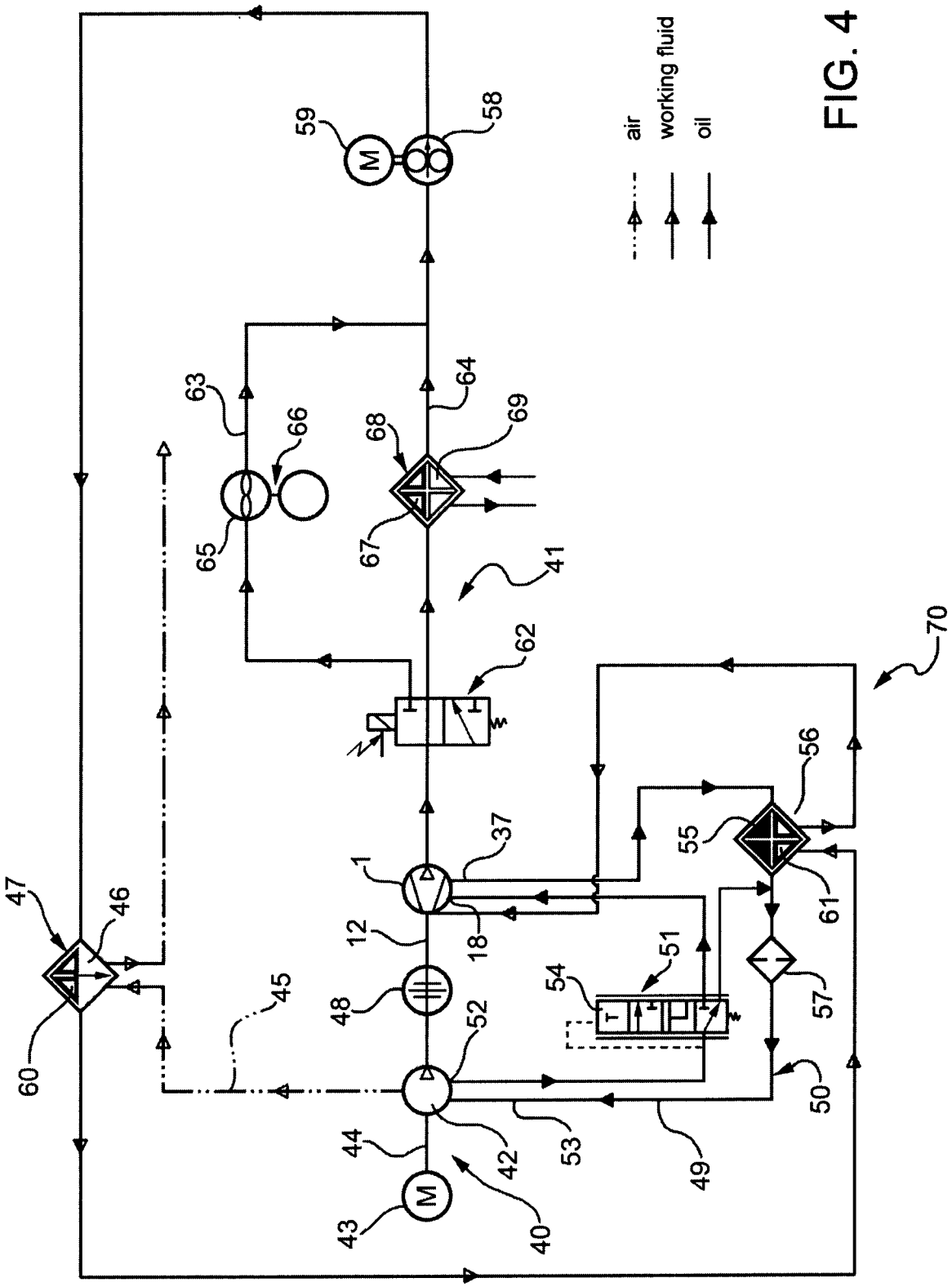

air
working fluid
oil
M
M
1
12
18
37
40
41
42
43
44
45
46
47
48
49
50
51
52
53
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60
61
62
63
64
65
66
67
68
69
70

FIG. 4

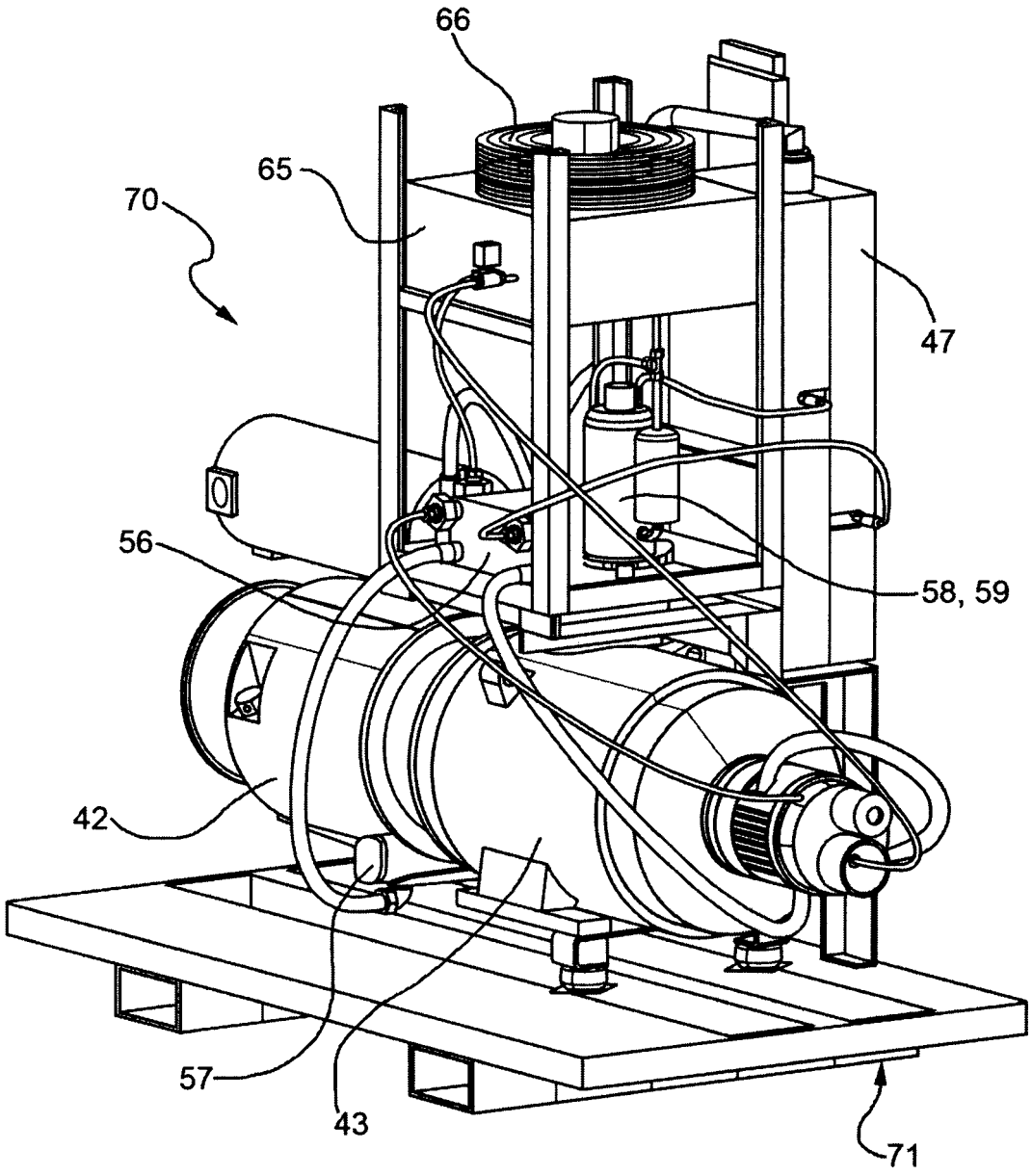


FIG. 5

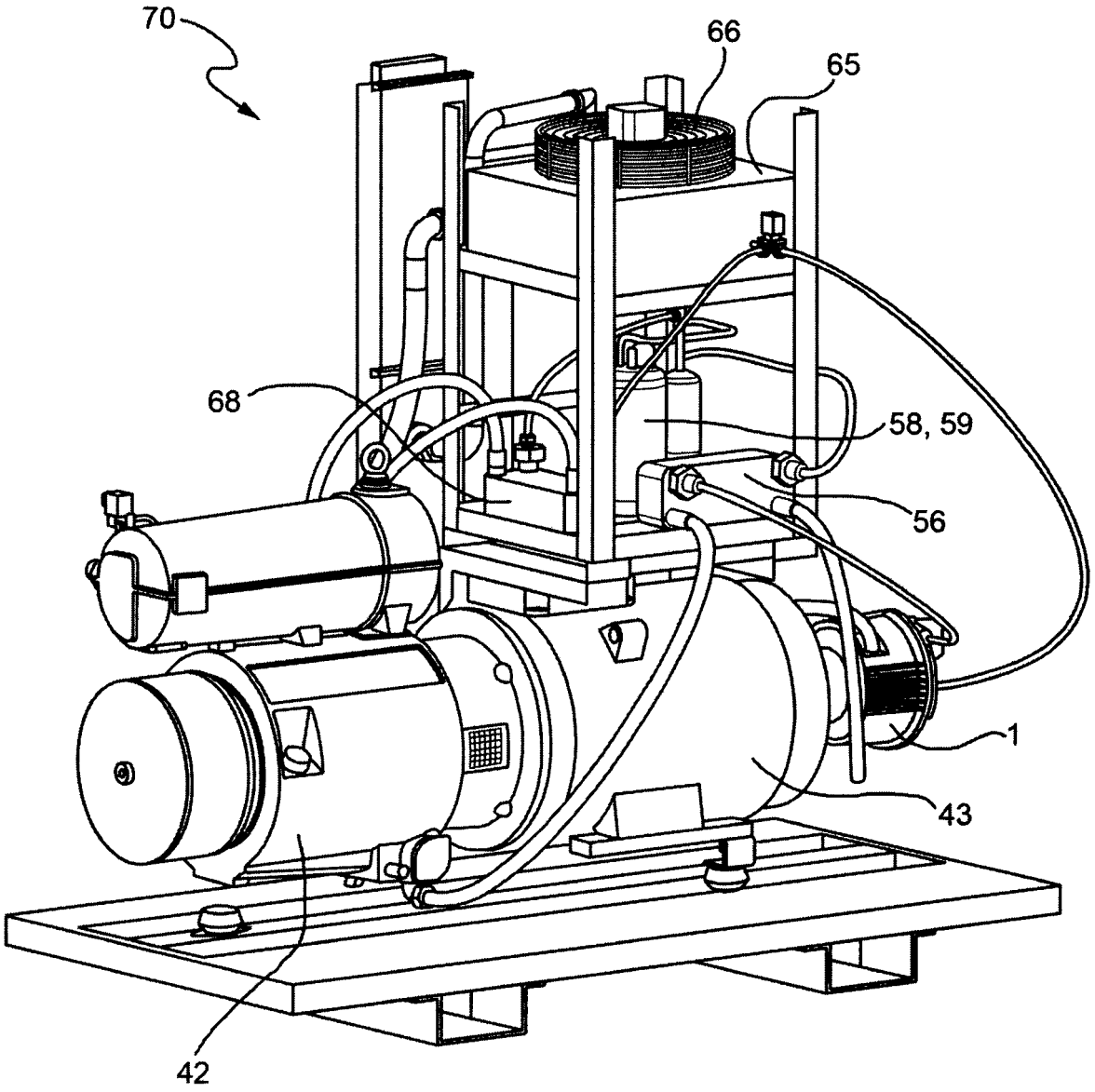


FIG. 6

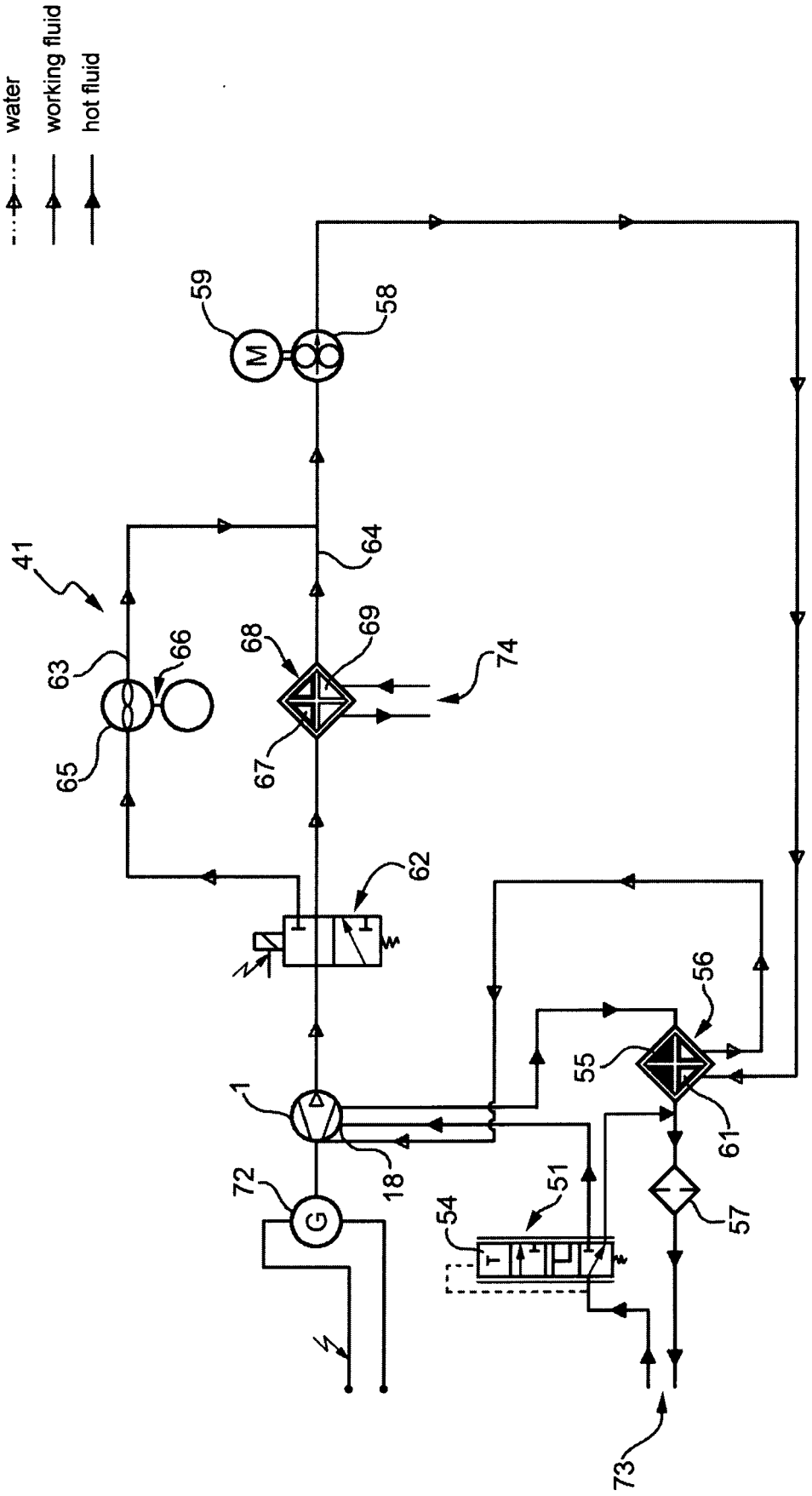

water
working fluid
hot fluid
59
58
M
41
64
63
66
68
69
74
65
67
62
56
55
1
61
18
72
51
54
57
G
73

FIG. 7

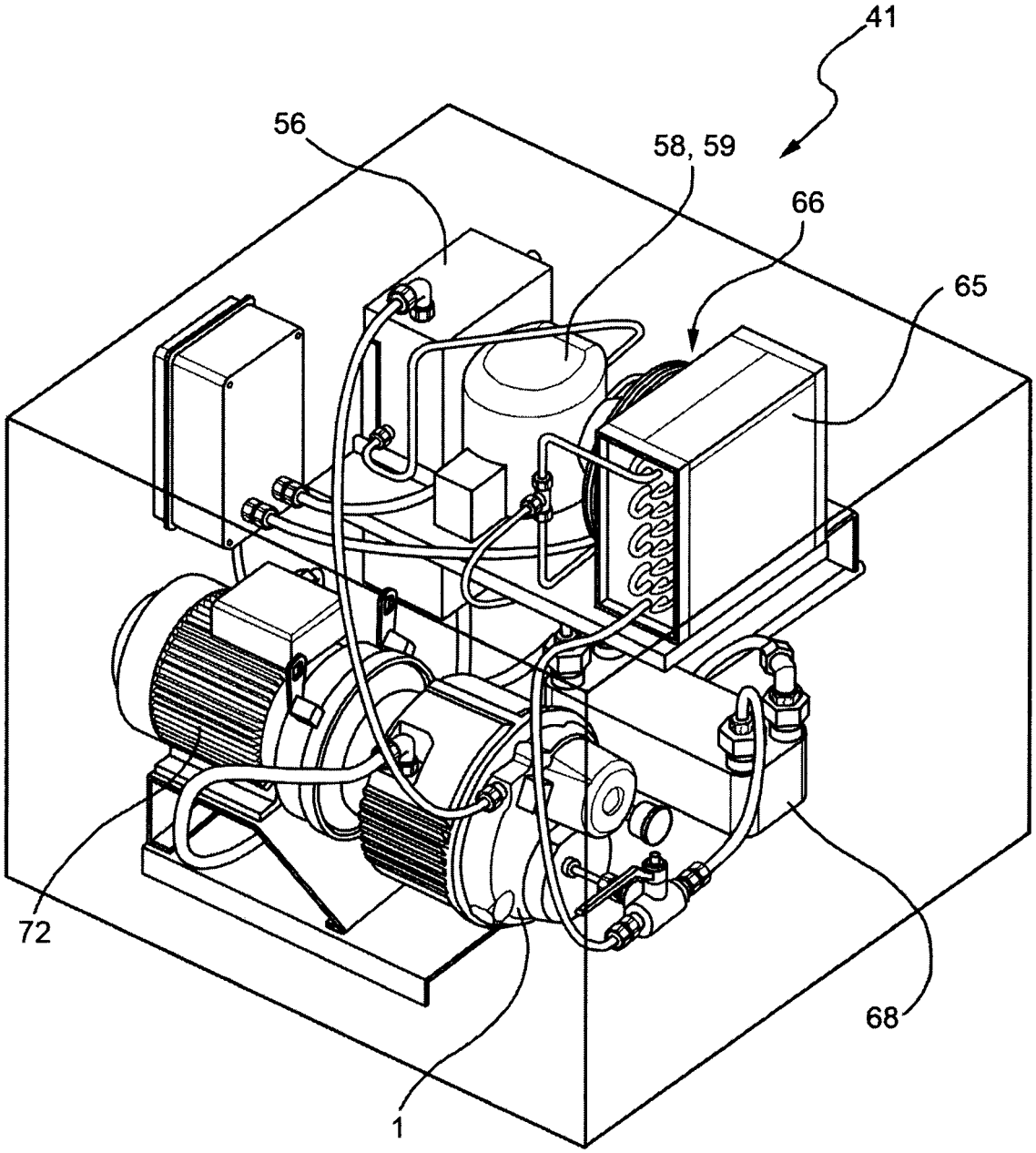


FIG. 8

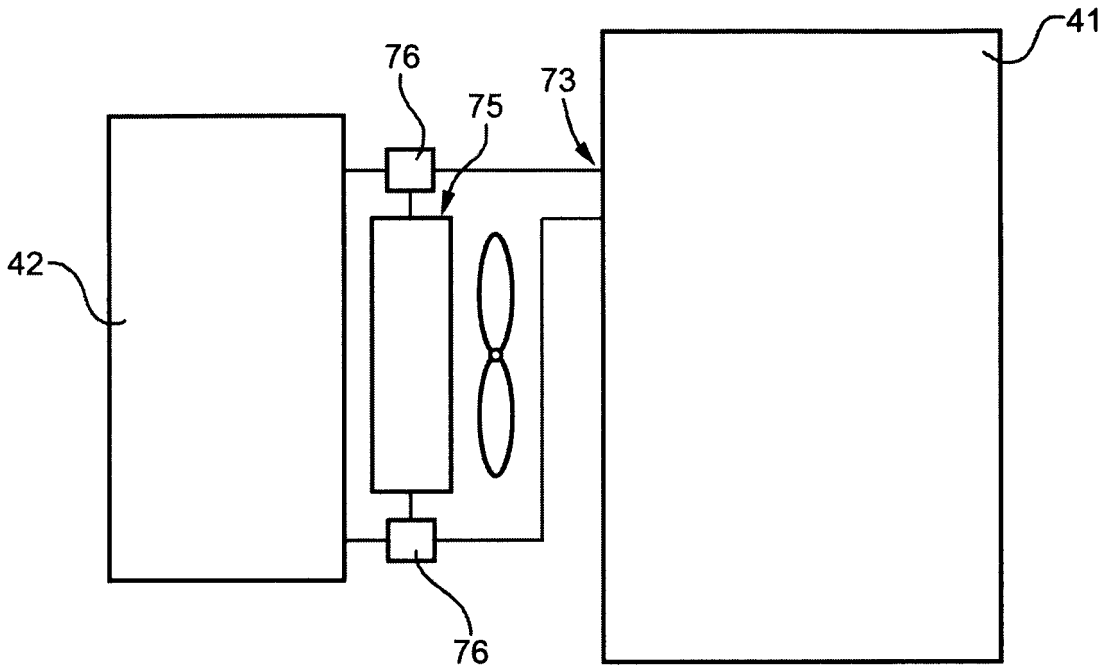


FIG. 9

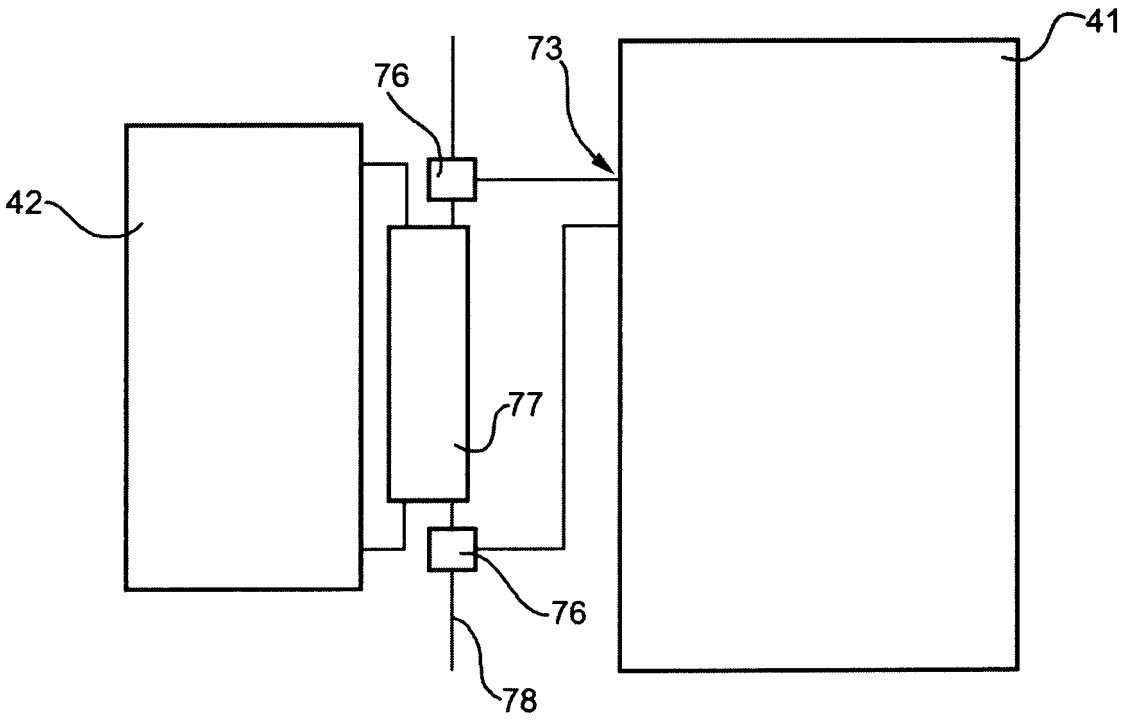


FIG. 10

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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