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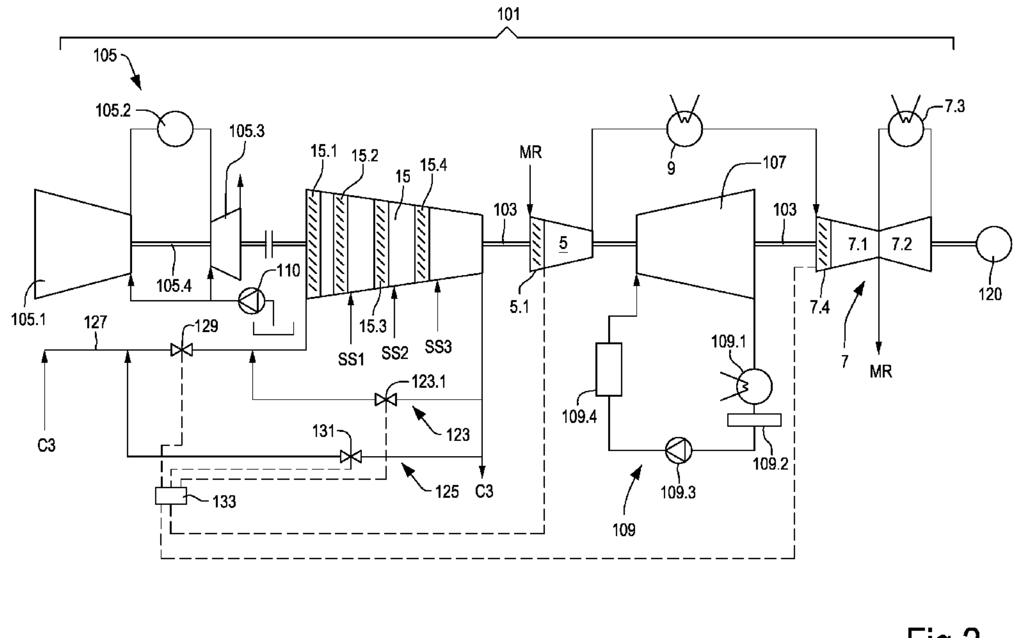

Fig.2

(57) **Abstract:** The compressor train comprises a plurality of turbomachines in combination along a same shaft line. Specifically, the compressor train comprises a gas turbine engine, a refrigerant compressor of a first refrigerant, as well as first and second refrigerant compressors of a second refrigerant fluidly coupled in series. Supplemental power and power at start-up are provided by a steam or vapor turbine.

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COMPRESSOR TRAIN WITH COMBINED GAS TURBINE AND STEAM TURBINE CYCLE

DESCRIPTION

TECHNICAL FIELD

[0001] The present disclosure relates to systems for liquefying natural gas. More specifically, the present disclosure concerns compressor trains for liquefying natural gas using a multi-refrigerant system, comprised of a first refrigerant circuit and a second refrigerant circuit.

BACKGROUND ART

[0002] Natural gas is becoming an increasingly important source of energy. In order to allow a cost-efficient and safe transportation of the natural gas from the source of supply to the place of use, it is beneficial to reduce the volume of the gas. Cryogenic liquefaction has become a routinely practiced process for converting the natural gas into a liquid, which is more convenient, less expensive and safer to store and transport. Transportation by pipeline or ship vessels of liquefied natural gas (LNG) becomes possible at ambient pressure, by keeping the chilled and liquefied gas at a temperature lower than liquefaction temperature at ambient pressure.

[0003] In order to store and transport natural gas in the liquid state, the natural gas is preferably cooled down for instance to around -150 to -170°C, where the gas possesses a nearly atmospheric vapor pressure.

[0004] Several processes and systems are known for the liquefaction of natural gas, which provide for sequentially passing the natural gas at an elevated pressure through a plurality of cooling stages, where the gas is cooled to successively lower temperatures by sequential refrigeration cycles until the liquefaction temperature is achieved.

[0005] Prior to passing the natural gas through the cooling stages, the natural gas is typically pretreated to remove impurities that can interfere the processing, damage the machinery or are undesired in the final product. Impurities include acid gases, sulfur compounds, carbon dioxide, mercaptans, water and mercury. The pre-treated gas from which impurities have been removed is then typically cooled by refrigerant streams to separate heavier hydrocarbons. The remaining gas mainly consists of methane and usually contains less than 0.1% hydrocarbons of higher molecular weight, such as propane or heavier hydrocarbons. The cleaned and purified natural gas is cooled down to the final temperature in a cryogenic section. The resulting LNG can be stored and transported at nearly atmospheric pressure.

[0006] Cryogenic liquefaction is usually performed by means of a multi-cycle process, i.e. a process using two or more refrigeration cycles. Depending upon the kind of process, each cycle can use a different refrigerant, or alternatively the same refrigerant can be used in two or more cycles. In a typical cryogenic liquefaction system, e.g. in the so-called APCI® process, the natural gas is first cooled by a first refrigerant which circulates in a pre-cooling loop or circuit and is subsequently cooled by a second refrigerant which circulates in a cooling loop or circuit. The pre-cooling circuit also pre-cools the second refrigerant.

[0007] In the pre-cooling circuit, the circulating first refrigerant can be compressed, condensed, and expanded, in order to subsequently remove heat from the natural gas and from the second refrigerant. In the cooling circuit, the circulating second refrigerant can be compressed and cooled, in order to subsequently remove heat from the natural gas. Driving two cooling circuit (pre-cooling circuit and cooling circuit) is energy-intensive, cost-intensive and space-consuming. Two compressor trains are usually used, to drive compressors of the pre-cooling circuit and compressors of the cooling circuit.

[0008] Large natural gas liquefaction systems, which have a large liquefaction capacity, usually require a plurality of compressor trains for each circuit. Each compressor train includes at least one driver.

[0009] Provisions of several compressor trains adds to the cost, complexity and total footprint of the system.

[0010] Accordingly, it would be beneficial to design and provide systems for liquefying natural gas that provide a high output capacity and consume less space.

SUMMARY

[0011] According to embodiments disclosed herein a compressor train for a natural gas liquefaction system is provided. Along the same shaft line a plurality of rotary turbomachines are arranged. In particular, a gas turbine engine provides the majority of the power to rotate the shaft line. A first refrigerant compressor for a first refrigerant is arranged along the shaft line. For processing a second refrigerant, first and second refrigerant compressors for a second refrigerant are arranged along the same shaft line. The first and second refrigerant compressors for the second refrigerant are coupled in series, such that the delivery side of the first refrigerant compressor is fluidly coupled to the suction side of the second refrigerant compressor, possibly with an intercooler there-between. A steam or vapor turbine provides supplemental power to rotate the compressor train.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] A more complete appreciation of the disclosed embodiments of the invention and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

Fig. 1 is a schematic diagram of a typical APCI® process for liquefying natural gas;

Fig.2 is a more detailed diagram of the compressor train of the system of Fig.1; and

Fig.3 is a schematic diagram of a further embodiment of a process according to the present disclosure.

DETAILED DESCRIPTION

[0013] Reference will now be made in detail to embodiments, one or more examples of which are illustrated in the figures. Each example is provided by way of explanation and is not meant as a limitation.

[0014] Within the following description of the drawings, the same reference numbers refer to corresponding or to similar components. Unless specified otherwise, the description of a part or aspect in one embodiment applies to a corresponding part or aspect in another embodiment as well.

[0015] In brief, a new and useful compressor train for LNG applications and an LNG system including such compressor train are disclosed. In order to achieve high production rates, a large heavy duty gas turbine engine, preferably a single-shaft gas turbine engine, is drivingly coupled to a shaft line. Along the shaft line, refrigerant compressors of at least two refrigeration circuits or loops are arranged. In some embodiments, the compressors belong to a pre-cooling circuit and a cooling circuit. A steam or vapor turbine is further arranged along the shaft line, to provide auxiliary driving power and to drive the compressor train at start-up. In embodiments described herein, at least one refrigerant compressor of the compressor train belongs to the pre-cooling circuit and is adapted to compress a first refrigerant in the pre-cooling circuit. At least one, and preferably two refrigerant compressors belong to the cooling circuit are further arranged along the shaft line and are adapted to process the second refrigerant circulating in the cooling circuit. Thus, all compressors of the two refrigerant circuits are grouped along the same shaft line and are driven by the same drivers.

[0016] Turning now to the drawings, Fig.1 shows a schematic diagram of a typical natural gas liquefaction system (briefly LNG system) using the so-called APCI® process. The shown process uses two refrigeration cycles. The LNG system, labeled 1 as a whole, includes a pre-cooling cycle, or pre-cooling circuit 12, which uses a first refrigerant, and a cooling cycle, or cooling circuit 2, which uses a second refrigerant. In some embodiments, the first refrigerant includes propane (C3) and the second refrigerant includes a mixed refrigerant (MR).

[0017] In the exemplary embodiment of Fig.1 cooling circuit 2 includes a first refrigerant compressor 5 and a second refrigerant compressor 7 in series for compressing the second refrigerant. An inter-stage cooler (also referred as intercooler) 9 can be provided to cool the second refrigerant delivered by the first refrigerant compressor 5 to reduce the temperature and the volume of the second refrigerant before entering the second refrigerant compressor 7. The compressed second refrigerant delivered by the second refrigerant compressor 7 can be cooled and at least partly condensed, for instance against air or water, in a condenser 11. The second refrigerant from the condenser 11 is further cooled and liquefied by heat exchange against the first refrigerant, which circulates in the pre-cooling circuit 12. In the schematic of Fig.1 a refrigerant accumulator is provided downstream of the condenser 11.

[0018] In the exemplary embodiment of Fig.1, the pre-cooling circuit 12 includes a refrigerant compressor 15. The compressed first refrigerant delivered by the refrigerant compressor 15 is cooled and condensed in a condenser 17, for instance against water or air. The condensed first refrigerant is used to pre-cool the natural gas (NG) flowing in a main natural gas line, down to -40°C, for instance, and to cool and partially liquefy the second refrigerant. The pre-cooling of the natural gas and the partial liquefaction of the second refrigerant are performed in a multi-pressure process, e.g. a four pressure process in the example shown in Fig. 1.

[0019] The stream of the condensed first refrigerant from condenser 17 can be collected in an accumulator 18 and therefrom is delivered to a first set of four, serially arranged auxiliary heat exchangers, to cool and partly liquefy the second refrigerant, and to a second set of four, serially arranged, pre-cooling heat exchangers, to pro-cool the natural gas NG. A first portion of the compressed first refrigerant streaming from the first condenser 17 is delivered through a pipe 19 to the first set of heat exchangers and is sequentially expanded in serially arranged expanders or valves (e.g. Joule-Thomson valves) 21, 23, 25 and 27 to four different, gradually decreasing pressure levels. Downstream from each expander or valve, a portion of the expanded first refrigerant is diverted to a respective heat exchanger 29, 31, 33 and 35.

[0020] The compressed second refrigerant delivered from the condenser 11can flow in a pipe 37 toward a main cryogenic heat exchanger 38. The pipe 37 sequentially passes through the heat exchangers 29, 31, 33 and 35, such that the second refrigerant is gradually cooled and partly liquefied against the expanded first refrigerant.

[0021] A second fraction of the condensed first refrigerant from the condenser 17 is delivered to a second pipe 39 and expanded sequentially in four serially arranged expanders or valves (e.g. Joule-Thomson valves) 41, 43, 45 and 47. A portion of the first refrigerant expanded in each expander or valve 41, 43, 45 and 47 is diverted towards a corresponding pre-cooling heat exchanger 49, 51, 53 and 55, respectively. A main natural gas line 61 flows sequentially through said pre-cooling heat exchangers 49, 51, 53 and 55, such that the natural gas is pre-cooled before entering the main cryogenic heat exchanger 38. The heated first refrigerant exiting the pre-cooling heat exchangers 49, 51, 53 and 55 is collected with the first refrigerant exiting the heat exchangers 29, 31, 33 and 35, and is fed again to the refrigerant compressor 15, which recovers the four evaporated streams of first refrigerant and re-compresses the vapor.

[0022] More specifically, the exhaust first refrigerant exiting the pre-cooling heat exchanger 55 and the heat exchanger 35 is collected and delivered at the suction side of the refrigerant compressor 15. The exhaust refrigerant exiting the pre-cooling heat exchanger 53 and the heat exchanger 33 is collected and forms a first side stream delivered to a first side stream inlet of the refrigerant compressor 15. The exhaust refrigerant exiting the pre-cooling heat exchanger 51 and the heat exchanger 31 is collected and forms a second side stream delivered to a second side stream inlet of the refrigerant compressor 15. The exhaust refrigerant exiting the pre-cooling heat exchanger 49 and the heat exchanger 29 is collected and forms a third side stream delivered to a third side stream inlet of the refrigerant compressor 15.

[0023] According to embodiments disclosed herein, the LNG system 1 comprises a single compressor train 101. With continued reference to Fig.1, in Fig.2 a more detailed diagram of the compressor train 101 is shown.

[0024] The compressor train 101 comprises the refrigerant compressor 15 of the first refrigerant circulating in the pre-cooling circuit 12, as well as the first and second refrigerant compressors 5 and 7 of the second refrigerant circulating in the cooling circuit 2.

[0025] More specifically, the compressor train 101 comprises a single shaft line 103. At a first end of the shaft line 103 a driver 105 is arranged. The driver 105 comprises a gas turbine engine. In some embodiments, the gas turbine engine 105 comprises a heavy duty gas turbine. In preferred embodiments, the gas turbine engine 105 is a single-shaft gas turbine engine. In order to provide sufficient refrigerant flowrate, the gas turbine engine 105 can have a rated power higher than 150 MW, preferably equal to or higher than 200 MW, more preferably equal to or higher than about 250 MW, in particular comprised between about 230 MW and about 350 MW, for instance. In some embodiments the gas turbine engine 105 can include a main frame gas turbine FR9F.03, available from General Electric, USA.

[0026] The gas turbine engine 105 comprises an air compressor section 105.1, including for instance an axial compressor, a combustor section 105.2, a power turbine section 105.3 and a single shaft 105.4 drivingly coupling the air compressor section 105.1 and the power turbine section 105.3.

[0027] The refrigerant compressor 15 is located along the shaft line 103 next to the gas turbine engine 105. In the schematic of Fig.2, the three side stream inlets of the refrigerant compressor 15 are shown at SS1, SS2 and SS3.

[0028] According to some embodiments, the refrigerant compressor 15 of the first refrigerant can include a multi-stage, horizontally split, centrifugal compressor, for instance a 3MCL1605 centrifugal compressor. As used herein, the term horizontally split indicates a compressor having a casing including two casing portions which are coupled to one another along an approximately horizontal plane, parallel to the shaft-line 103.

[0029] The refrigerant compressor 15 can include a plurality of compressor stages, each of which can include one or more impellers. For instance, the refrigerant compressor 15 can include three or four stages. In some embodiments, the last stage can include one or two impellers, and the upstream stages can include one impeller each. The compressor can further include upwards or downwards compressor nozzles.

[0030] Next to the first refrigerant compressor 15 of the first refrigerant circulating in the pre-cooling circuit 12, the first refrigerant compressor 5 of the second refrigerant circulating in the cooling circuit 2 is located along the shaft line 103. The first refrigerant compressor 5 of the second refrigerant can include a horizontally split multi-stage centrifugal compressor. In some embodiments, the first refrigerant compressor 5 can include five stages. Each stage can include one or more impellers as well as upwards or downwards compressor nozzles. For instance the first refrigerant compressor 5 of the second refrigerant can be a MCL1604 multi-stage centrifugal compressor.

[0031] Next to the refrigerant compressor 5, along the shaft line 103 an auxiliary driver is positioned. In some embodiments, the auxiliary driver comprises a steam turbine or a vapor turbine, labeled 107. The steam or vapor turbine 107 has a through shaft, such that power can be transmitted on the shaft line 103 at both sides of the steam or vapor turbine 107, i.e. to the refrigerant compressor 15 of the first refrigerant and to the first refrigerant compressor 5 of the second refrigerant, as well as to the second refrigerant compressor 7 of the second refrigerant, which is positioned at the second end of the shaft line 103, opposite the first refrigerant compressor 5 of the second refrigerant, with respect to the steam or vapor turbine 107.

[0032] The closed steam or vapor circuit of steam or vapor turbine 107 is shown schematically at 109. The steam or vapor circuit comprises a condenser 109.1, a liquid tank 109.2, a pump 109.3 and a heating section 109.4. This latter may include, in a manner known to those skilled in the art and not shown, a heater, a vaporizer and a super-heater. In some embodiments the steam or vapor turbine 107 may operate according to a regenerative Rankine cycle.

[0033] The second refrigerant compressor 7 of the second refrigerant can be a multistage centrifugal compressor. The second refrigerant compressor 7 can be a vertically split compressor, comprised of an external barrel in which compressor rotor and the stationary diaphragms and return channels of the compressor are arranged. At least one end cover closes the barrel at the side of the compressor opposite the steam or vapor turbine 107. A vertically split compressor is particularly useful in view of the high pressure achieved by the second refrigerant across the second refrigerant compressor 7. Since the second refrigerant compressor 7 is arranged at the end of the shaft line 103, access to the components of the compressor is easy even in case of a vertically split compressor.

[0034] In some embodiments, the second refrigerant compressor 7 of the second refrigerant can be a multi-phase centrifugal compressor, which can further include upwards or downwards compressor nozzles. In the exemplary embodiment of Fig. 2, the second refrigerant compressor 7 includes a first compressor phase or section 7.1 and a second compressor phase or section 7.2. An intercooler 7.3 can be provided between the first compressor phase 7.1 and the second compressor phase 7.2, to remove heat and reduce the volume and temperature of the refrigerant delivered by the first compressor phase 7.1 prior to further compressing said second refrigerant in the second compressor phase 7.2.

[0035] A barring system or slow-turning system 120 can be attached to the shaft line 103, for instance at the second end thereof, where the vertically split compressor 7 is located. The barring system could alternatively be coupled to the steam or vapor turbine 107. The barring system 120 can be activated at shut down, during the cooling phase of the turbomachines, to prevent or reduce temperature-induced bending of the rotors thereof.

[0036] Start-up of the compressor train 101 is performed using the steam or vapor turbine 107, which gradually increases the rotational speed of the shaft line 103 from zero to a minimum operation speed, at which the gas turbine engine 105 can be ignited. To facilitate start-up of the compressor train 101, the loads of one, some or preferably all the refrigerant compressors of the compressor train 101 should possibly be reduced. This is particularly beneficial if the steam or vapor turbine 107 has a rated power which is lower or substantially lower than the rated power of the gas turbine engine 105. According to some embodiments, the steam or vapor turbine 107 can provide approximately 1/5 or more of the total power required to drive the compressor train 101, while the remaining 4/5 of the power is provided by the gas turbine engine 105. If a single-shaft turbine is used, the gas turbine engine 105 will not be able of generating mechanical power until a minimum operational speed of the shaft has been achieved. The entire power at start-up shall be therefore generated by the steam or vapor turbine 107, until the minimum operational speed has been achieved.

[0037] To facilitate the start-up of the compressor train 101, one, some or all compressors can advantageously be provided with load-reducing devices. For instance, in some embodiments, one, some or all the compressors 15, 5, 7 may be provided with variable inlet guide vanes (IGVs), to reduce the flowrate therethrough and thus the load at start-up. In currently preferred embodiments, variable IGVs are provided for the first and second refrigerant compressors 5, 7 of the second refrigerant. The variable IGVs of the first refrigerant compressor 5 of the second refrigerant are schematically shown at 5.1 and the variable IGVs of the second refrigerant compressor 7 of the second refrigerant are schematically shown at 7.4.

[0038] In some embodiments variable IGVs can be provided also at the refrigerant compressor 15 of the first refrigerant, as schematically shown at 15.1, 15.2, 15.3, 15.4. Preferably variable IGVs are arranged at the suction side of the refrigerant compressor 15 as well upstream of each side stream inlet, as shown in Fig. 2.

[0039] At start-up the variable IGVs are maintained in a closed position, such as to reduce or prevent gas flow through the relevant compressor and thus reduce the load. The variable IGVs can be gradually opened once a minimum operational speed has been achieved, e.g. when the gas turbine engine 105 can be turned on.

[0040] In other embodiments, an anti-surge loop, usually provided for each compressor section of the compressor train 101, can be used to reduce the load of the compressor by presetting the opening position so as to reduce the recycled flow and still ensuring surge prevention.

[0041] In some embodiments, a recycle duct connecting the compressor discharge side and the compressor suction side can be provided, in combination with a throttling valve. In the schematic of Fig.2, the refrigerant compressor 15 is provided with an anti-surge loop 123 and a recycle duct 125 in combination. The anti-surge loop 123 includes an anti-surge valve 123.1 and connects the discharge end of the refrigerant compressor 15 with the suction end thereof. The recycle duct 125 connects the discharge end of the refrigerant compressor 15 with an inlet duct 127 fluidly coupled with the suction end of the refrigerant compressor 15. A throttling valve 129 is arranged along the inlet duct 127, between the outlet of the recycle duct 125 and the outlet of the anti-surge loop 123. A recycle valve 131 is arranged along the recycle duct 125.

[0042] In other embodiments, the recycle duct 125 can be used as the anti-surge loop and the recycle valve 131 can be replaced by an anti-surge valve.

[0043] In the schematic arrangement of Fig.2, the anti-surge valve 123.1, the throttling valve 129 and the recycle valve 131 can be selectively opened, choked and closed by valve actuators (not shown) under the control of a control unit 133. The control unit 133 can further control the variable inlet guide vanes 5.1, 7.4, 15.1, 15.2, 15.3 and 15.4, through suitable actuators, not shown.

[0044] During normal operation of the compressor train 101 the recycle valve 131 is closed and the throttling valve 129 is fully opened. The anti-surge valve 123.1 is opened usually only if the operation point of the refrigerant compressor 15 approaches the surge line.

[0045] The flowrate of the first refrigerant through the refrigerant compressor 15 can be modulated, if so required by the operating conditions of the refrigerant circuits, acting upon the recycle duct 125 and/or the throttling valve 129. The flowrate of the second refrigerant through the first refrigerant compressor 5 and the second refrigerant compressor 7 can be modulated acting upon the variable IGVs 5.1 and the variable IGVs 7.4, respectively. It is thus possible to operate all refrigerant compressors 15, 5, 7 at the same speed.

[0046] At start-up the recycle valve 131 can be open and the throttling valve 129 can be closed or partly closed (choked), so as to reduce the load of the refrigerant compressor 15. Similarly, the variable IGVs 5.1 and the variable IGVs 7.4 can be closed or partly closed, to reduce the load of the first refrigerant compressor 5 and the second refrigerant compressor 7.

[0047] The flowrate through the refrigerant compressors 5, 7, 15 can be increased as the rotational speed of the shaft line 103 increases from zero towards a minimum operational speed under the control of the steam or vapor turbine 107.

[0048] Once the minimum operational speed has been reached, the gas turbine engine 105 starts providing additional power to the shaft line 103, such that the compressor loads can be further increased until the steady-state operational conditions are achieved.

[0049] In some embodiments, the rotary machines arranged along the shaft line 103 are provided with a jacking oil system. In the schematic of Fig.2 a jacking oil system 108 and relevant jacking oil pump 110 is shown for the gas turbine engine 105. The jacking oil system provides high pressure oil to the base of the bearings and floats the rotors on a film of oil to reduce the breakaway torque. In preferred embodiments, the jacking oil system can be designed to supply jacking oil to all bearings of the train.

[0050] Fig.3 illustrates a diagram of a further embodiment of a natural gas liquefaction system (briefly LNG system) using a APCI® process including a compressor train according to the present disclosure. The system is similar to the one shown in Fig.1 described above. The same or equivalent parts are labeled with the same reference numbers used in Fig.1 and will not be described again.

[0051] The main difference between the system of Fig.1 and the system of Fig.3 is that the latter comprises a combined gas turbine and steam or vapor turbine configuration. More specifically, a waste heat recovery exchanger 201 is provided between the gas turbine engine 105 and a combustion gas stack 203.

[0052] When the gas turbine engine 105 is in operation, waste heat contained in the combustion gas thereof can be used to generate steam or vapor for the steam or vapor turbine 107. Heat from the combustion gas is exchanged against pressurized working fluid, e.g. water, circulating in a closed circuit 205 of the steam or vapor turbine 107 (the closed circuit is not shown in Fig.1 and schematically illustrated in Fig.3).

[0053] In Fig.3 only the main components of the closed circuit 205 are shown for the sake of better understanding of the present disclosure. However, those skilled in the art will understand that the closed circuit 205 can be much more complex than shown in Fig.3. The closed circuit 205 can include a pre-heater, a heater, a vaporizer, a super-heater and a regeneration section, for instance, depending upon the cycle used by the steam or vapor turbine 107. In the schematic of Fig. 3 only a condenser 207, a pump 209 and a heating section 211 are shown, as main components of the closed circuit 205.

[0054] The heating section 211 includes the waste heat recovery exchanger 201, such that when sufficient waste heat is available from the gas turbine engine 105, a substantial improvement in the overall thermal efficiency of the system can be obtained by converting low-temperature heat, discharged from the gas turbine engine 105, into mechanical power through the low-temperature thermodynamic cycle of the steam or vapor turbine 107.

[0055] As mentioned above, the steam or vapor turbine 107 can be used to start rotation of the shaft line 103 when the gas turbine engine 105 is non-operative. In this case, no waste heat is available from the gas turbine engine 105 to generate steam or vapor for the steam or vapor turbine 107.

[0056] The thermal power required to start operation of the steam or vapor turbine 107 can be provided by any source of steam or vapor, which may be part of the LNG system, through a steam supply duct 213. Pressurized hot steam or vapor available through duct 213 can expand through the steam or vapor turbine 107 to generate mechanical power. The spent steam or vapor can be collected through a discharge duct 213.

[0057] In addition or as an alternative to the external supply of pressurized hot steam or vapor through duct 213, the heating section 211 may include a heater 217, which may be supplied with a fuel F, for instance natural gas from the main natural gas line 61. The heater 217 can be arranged in parallel to the waste heat recovery exchanger

201.

[0058] Valves 221, 223, 225 can be provided to selectively use the waste heat exchanger 201, the heater 217, or the duct 213 individually or in combination. For instance, if the waste heat from the gas turbine engine 105 is insufficient to power the steam or vapor turbine 107, additional heat can be provided by the heater 217 and/or a supplemental flow of pressurized steam or vapor can be supplied through duct 213.

[0059] It shall be understood that the waste heat recovery exchanger 201 and the heater 217 can be arranged differently than in Fig.3. Moreover, each of the waste heat recovery exchanger 201 and the heater 217 can in turn include one or more sections, which can be arranged in parallel and/or in series.

[0060] For instance, waste heat from the gas turbine engine 105 can be used in a steam generator arranged in series with a superheater, which may be powered by fuel F and include heater 217, or vice-versa. Also, the waste heat recovery exchanger 201 may be divided into sections, for heating and/or vaporizing and/or superheating and/or re-generating the steam or vapor, and one or more heater sections can be arranged upstream, downstream or intermediate one or more said sections of the waste heat recovery exchanger 201.

[0061] What matters is that at least a portion of the thermal energy contained in the combustion gas from the gas turbine engine 105 can be converted into useful mechanical power through the steam or vapor expanding in the steam or vapor turbine 107.

[0062] Moreover, in order to use the steam or vapor turbine as a starter to initiate rotation of the shaft line 103, in currently preferred embodiments a supplemental source of heat (schematically represented by heater 217) and/or a supplemental source of hot and pressurized steam or vapor (schematically represented by duct 213) can be combined with the waste heat recover exchanger 201, to supply the steam or vapor turbine 107 when no or insufficient waste heat is available from the gas turbine engine 105.

[0063] In other embodiments, an electric starter motor (not shown) can be envisaged, to start rotation of the shaft line 103.

[0064] While the invention has been described in terms of various specific embodiments, it will be apparent to those of ordinary skill in the art that many modifications, changes, and omissions are possible without departing form the spirit and scope of the claims. In addition, unless specified otherwise herein, the order or sequence of any process or method steps may be varied or re-sequenced according to alternative embodiments.

COMPRESSOR TRAIN WITH COMBINED GAS TURBINE AND STEAM TURBINE CYCLE

CLAIMS

1. A compressor train for a natural gas liquefaction system comprising in combination and along a same shaft line:

a gas turbine engine;

a refrigerant compressor of a first refrigerant;

a first refrigerant compressor of a second refrigerant;

a second refrigerant compressor of the second refrigerant, wherein the first refrigerant compressor of the second refrigerant and the second refrigerant compressor of the second refrigerant are fluidly coupled in series; and

a steam or vapor turbine.

2. The compressor train of claim 1, wherein the gas turbine engine, the refrigerant compressor of the first refrigerant, the first refrigerant compressor of the second refrigerant, the second refrigerant compressor of the second refrigerant and the steam or vapor turbine are adapted for rotation at substantially the same rotational speed.

3. The compressor train of claim 1 or 2, wherein the gas turbine engine is arranged at a first end of the shaft line and the second refrigerant compressor of the second refrigerant is arranged at a second end of the shaft line.

4. The compressor train of claim 3, wherein the refrigerant compressor of the first refrigerant and the first refrigerant compressor of the second refrigerant are arranged between the gas turbine engine and the steam or vapor turbine.

5. The compressor train of claim 4, wherein the refrigerant compressor of the first refrigerant is arranged next to the gas turbine engine and the first refrigerant compressor for the second refrigerant is arranged next to the steam or vapor turbine.

6. The compressor train of any one of the preceding claims, wherein the refrigerant compressor of the first refrigerant comprises a gas inlet, a gas outlet and at least one side stream inlet between the gas inlet and the gas outlet.

7. The compressor train of any one of the preceding claims, wherein the refrigerant compressor of the first refrigerant is a horizontally split, multi-stage centrifugal compressor.

8. The compressor train of any one of the preceding claims, wherein the first refrigerant compressor of the second refrigerant is a horizontally split centrifugal compressor, preferably a multi-stage compressor.

9. The compressor train of any one of the preceding claims, wherein the second refrigerant compressor of the second refrigerant is a vertically split centrifugal compressor.

10. The compressor train of claim 9, wherein the second refrigerant compressor of the second refrigerant is a multi-phase, inter-refrigerated centrifugal compressor, comprising at least two phases in series.

11. The compressor train of any one of the preceding claims, wherein the gas turbine engine is a single-shaft, heavy duty gas turbine engine, with a rated power preferably higher than 150MW, more preferably higher than 200 MW, still more preferably higher than 250 MW, in particular comprised between 230 MW and 350 MW.

12. The compressor train of any one of the preceding claims, wherein under steady state conditions the gas turbine engine provides at least twice the power provided by the steam or vapor turbine, and preferably wherein the gas turbine engine provides from about 2/3 to about 4/5 of the total power required to drive the compressor train.

13. The compressor train of any one of the preceding claims, wherein at least one, and preferably all of said refrigerant compressor of the first refrigerant, said first refrigerant compressor of the second refrigerant and said second refrigerant compressor of the second refrigerant comprise a flowrate reduction device, adapted to reduce compressor load at start-up.

14. The compressor train of any one of the preceding claims, wherein at least one of said refrigerant compressor of the first refrigerant, said first refrigerant compressor of the second refrigerant and said second refrigerant compressor of the

second refrigerant comprises a recycle duct, having a first end fluidly coupled to the discharge side of the compressor and a second end fluidly coupled to a suction duct of the compressor; wherein a control valve is arranged along the recycle duct; and wherein a throttling valve is arranged along the suction duct, between the second end of the recycle duct and the suction side of the compressor.

15. The compressor train of claim 14, wherein said recycle duct is provided at the refrigerant compressor of the first refrigerant.

16. The compressor train of any one of the preceding claims, wherein at least one of said refrigerant compressor of the first refrigerant, said first refrigerant compressor of the second refrigerant and said second refrigerant compressor of the second refrigerant comprises variable inlet guide vanes.

17. The compressor train of any one of the preceding claims, further comprising at least one of a jacking oil system and a slow-turning system.

18. The compressor train of any one of the preceding claims, including a waste heat recovery exchanger adapted to recover waste heat from the gas turbine engine to generate steam or vapor for the steam or vapor turbine.

19. The compressor train of claim 18, further comprising at least one of; a supplemental source of heat, and a supplemental source of pressurized hot steam or vapor, to provide expandable steam or vapor to the steam or vapor turbine.

20. A natural gas liquefaction system comprising:
a pre-cooling circuit adapted to circulate a first refrigerant therein;
a cooling circuit adapted to circulate a second refrigerant therein; and
a compressor train according to any one of the preceding claims.

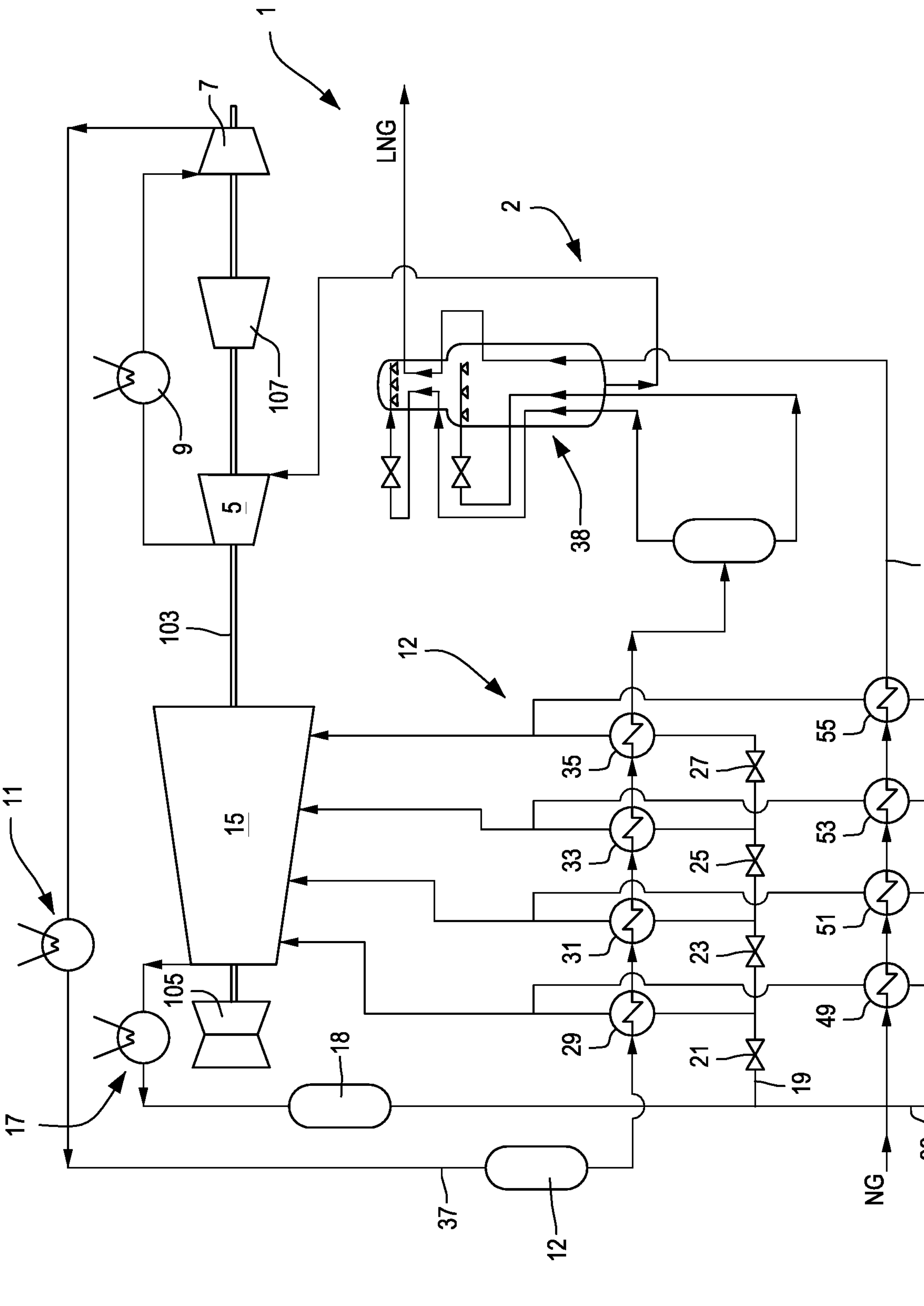
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Fig.1

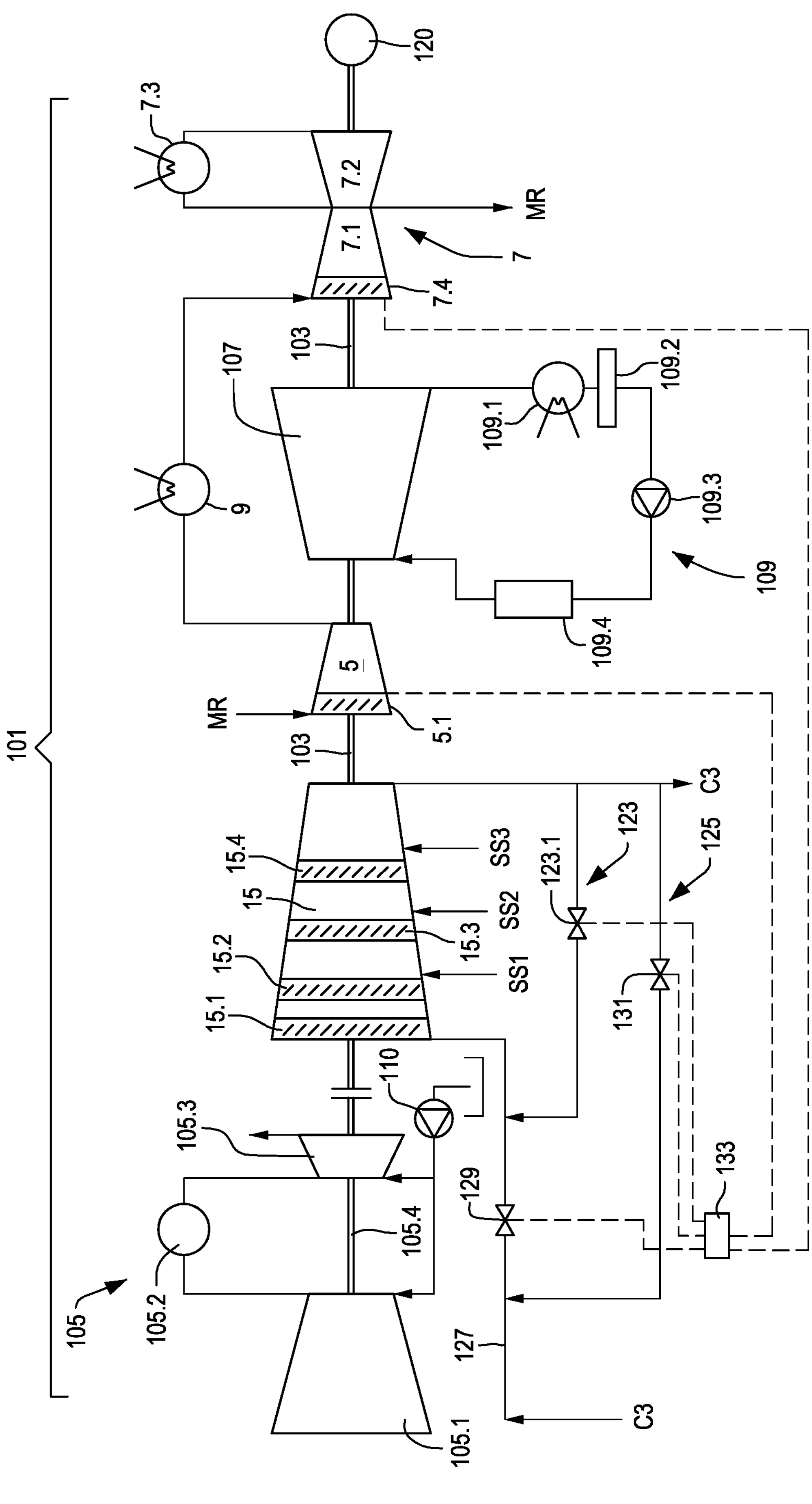
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Fig.2

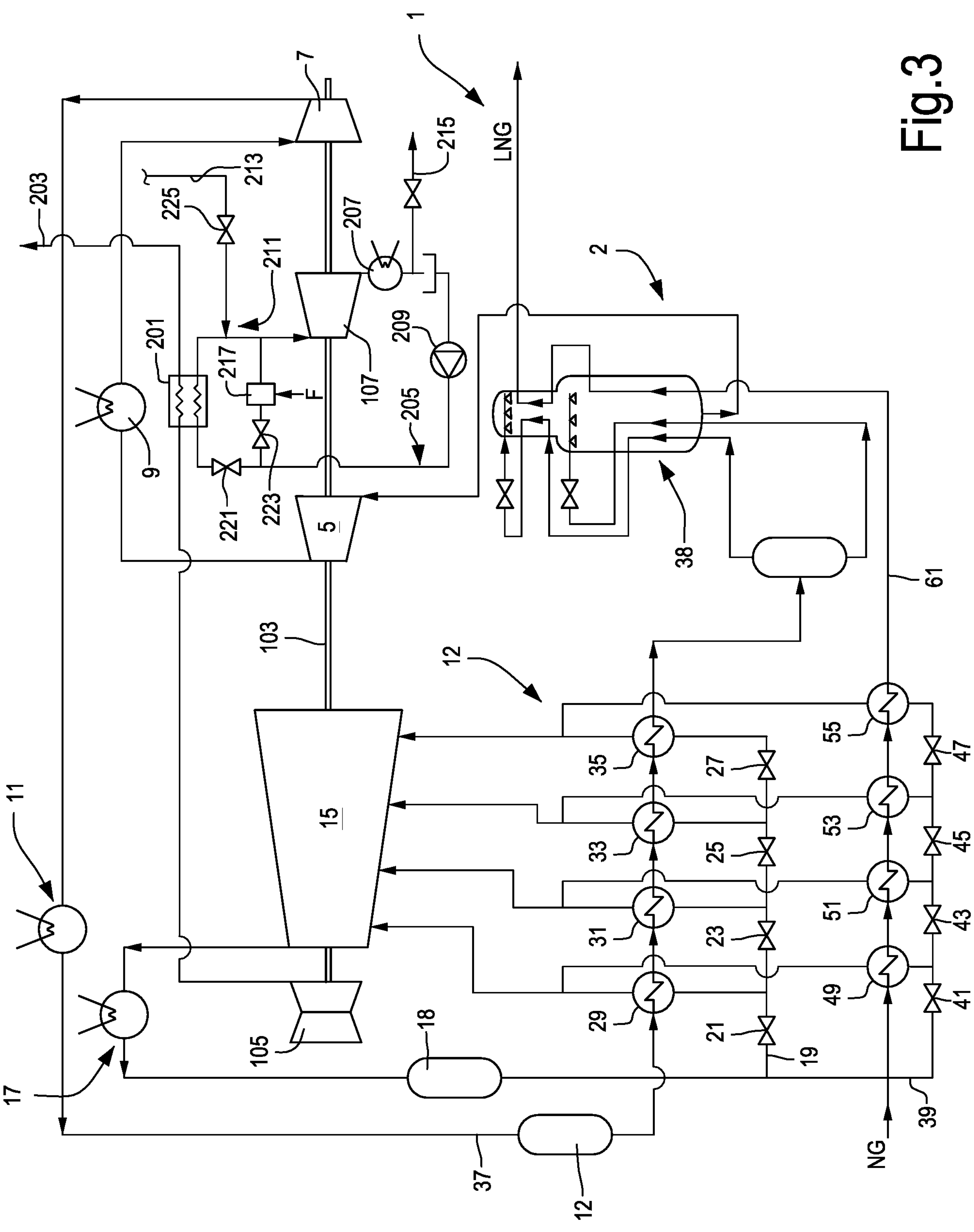
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Fig.3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2020/025217

A. CLASSIFICATION OF SUBJECT MATTER
INV. F25J1/00 F25J1/02 F04D27/02 F04D27/00
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F25J F04D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	WO 2018/206102 A1 (NUOVO PIGNONE TECNOLOGIE S R L [IT]) 15 November 2018 (2018-11-15) figures 1,2,5,23,24,26,27,29,33,40,43 page 7, lines 11-24 page 22, lines 4-7,13-16 page 28, lines 10-26 page 29, lines 21-28 page 30, lines 6-10 page 33, lines 1-11 page 34, lines 5-9 page 35, line 6 - page 36, line 8 page 38, lines 13-26 page 39, lines 21-25 page 40, lines 3-10 page 42, lines 6-9 page 45, lines 26-31 page 46, lines 20-26 page 58, lines 15-24 -/--	1-12, 16-18,20 3-10, 12-16,19

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 July 2020	24/07/2020

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Göritz, Dirk

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2020/025217

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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