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(54) TURBINE-DRIVEN RECIPROCATING COMPRESSOR AND METHOD

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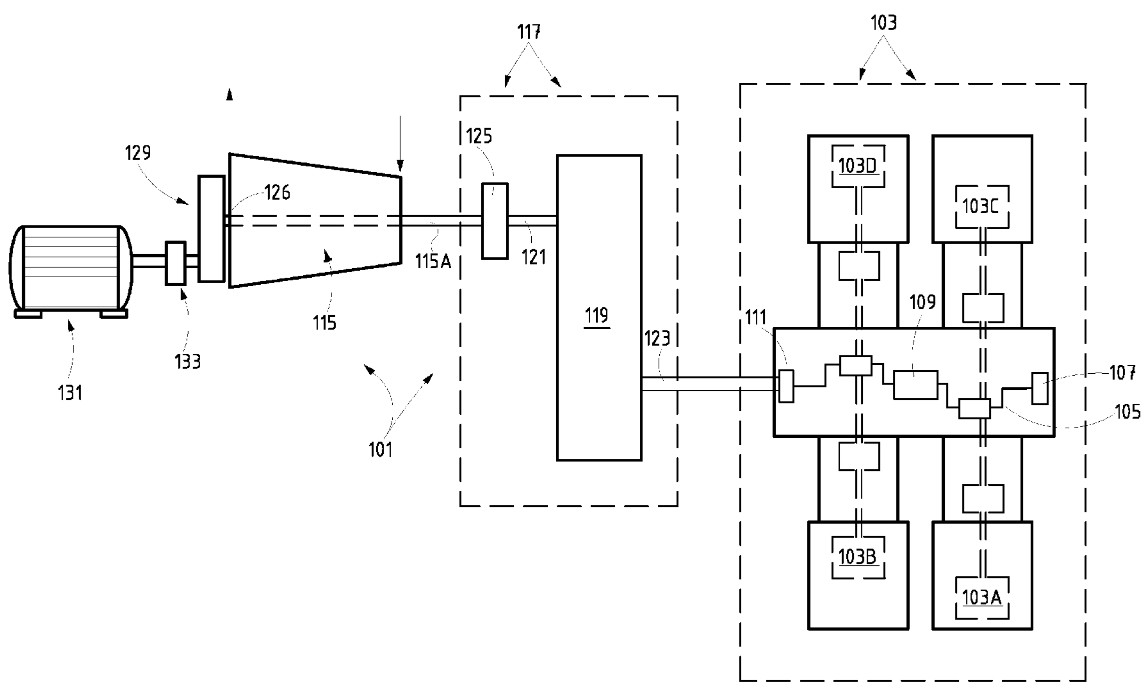
(57) **ABSTRACT**

A reciprocating compressor system is provided comprising: a turbine; a reciprocating compressor driven by the turbine; and a gearbox arranged between the turbine and the reciprocating compressor. The turbine is provided with a barring device arranged for slow-turning the turbine during a barring phase. A clutch is arranged between the turbine and the reciprocating compressor, for mechanically disconnecting the turbine from the reciprocating compressor during a transient phase of operation of the system.



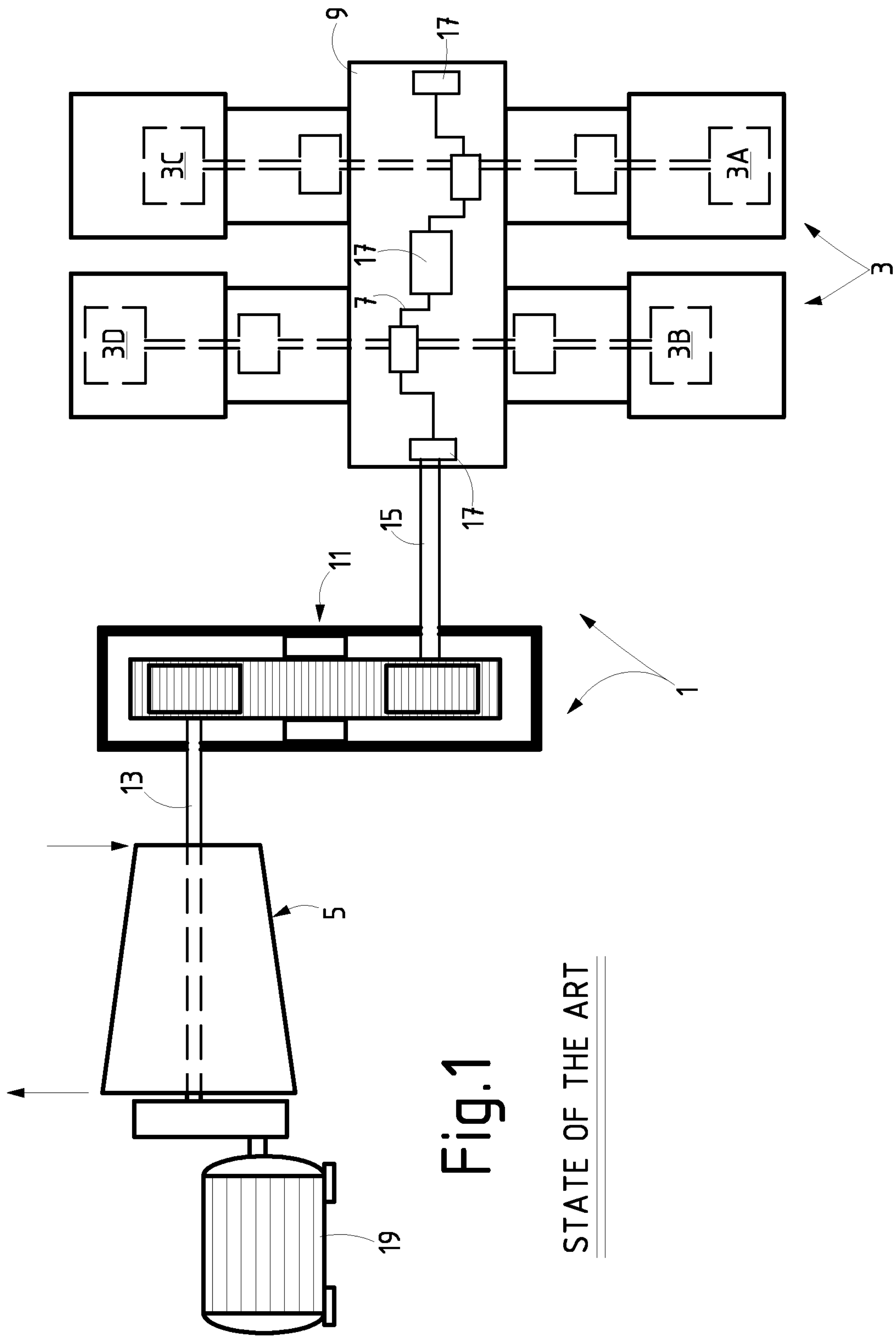


Fig.1

STATE OF THE ART

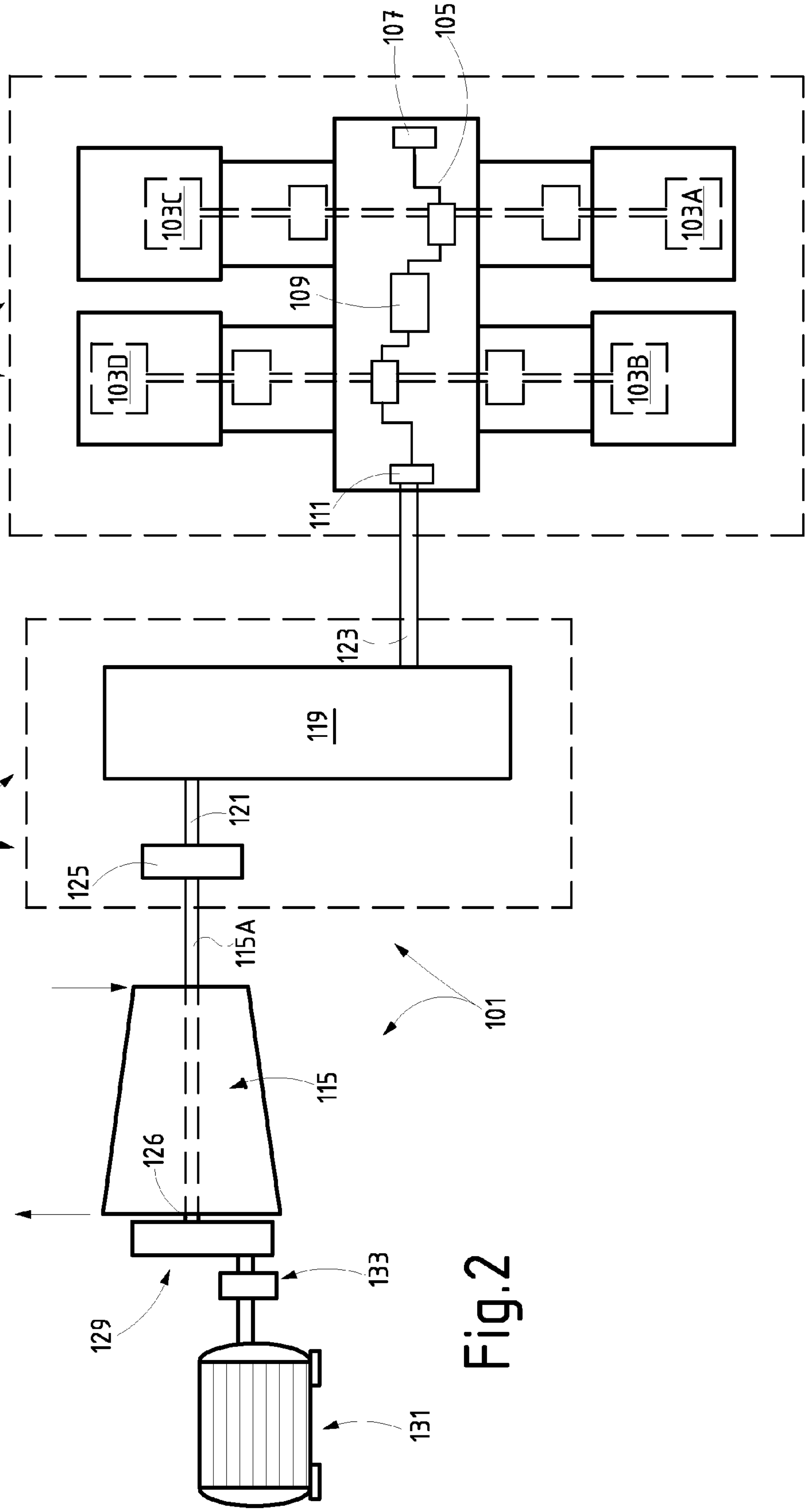

107
105
103C
103A
109
103
103D
103B
111
123
119
117
121
125
115A
101
115
126
133
129
131

Fig.2

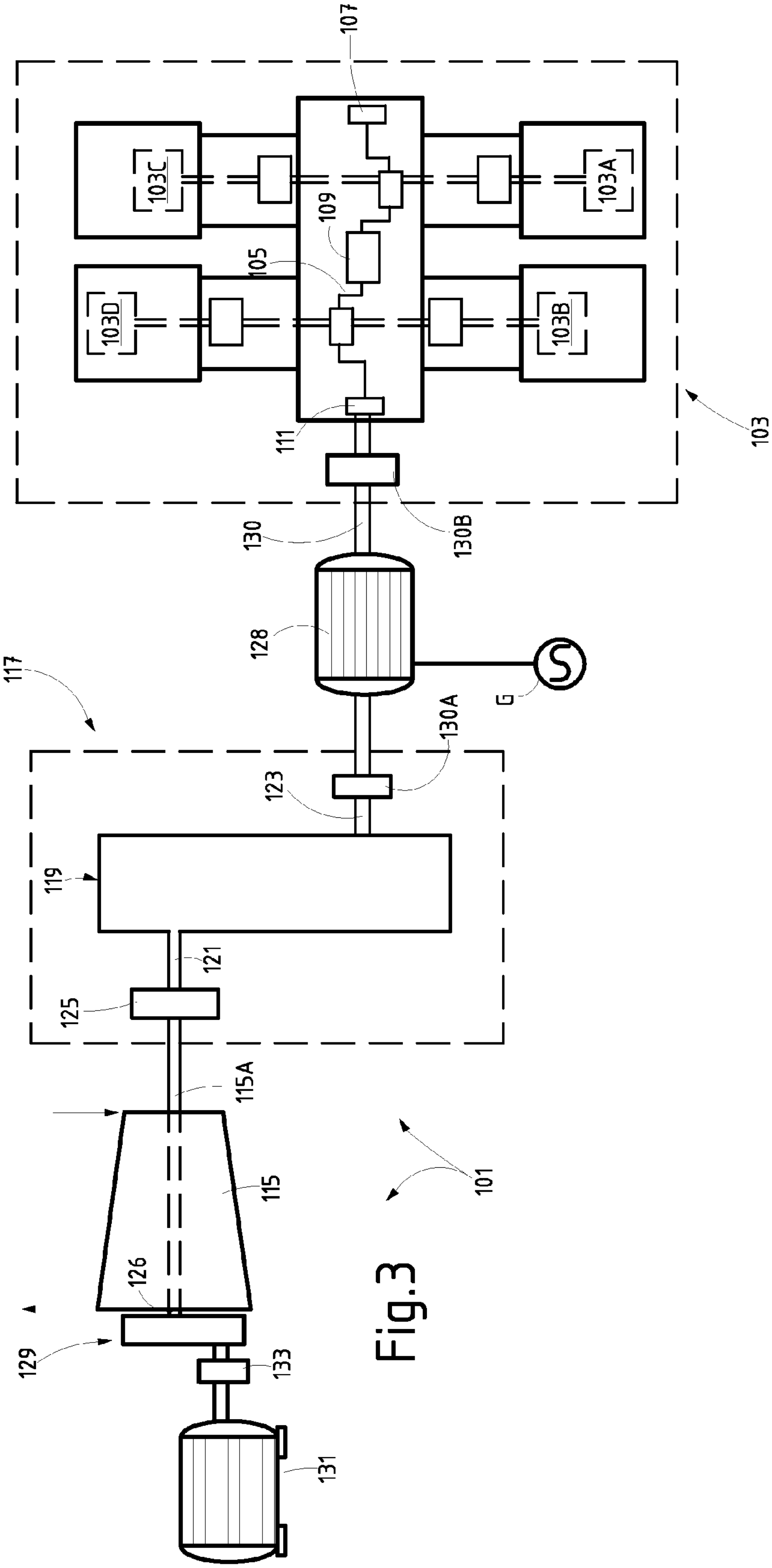

107
103C
103A
109
105
103D
103B
111
103
130
130B
128
G
117
130A
123
119
121
125
115A
101
115
126
129
133
131

Fig.3

Fig.4

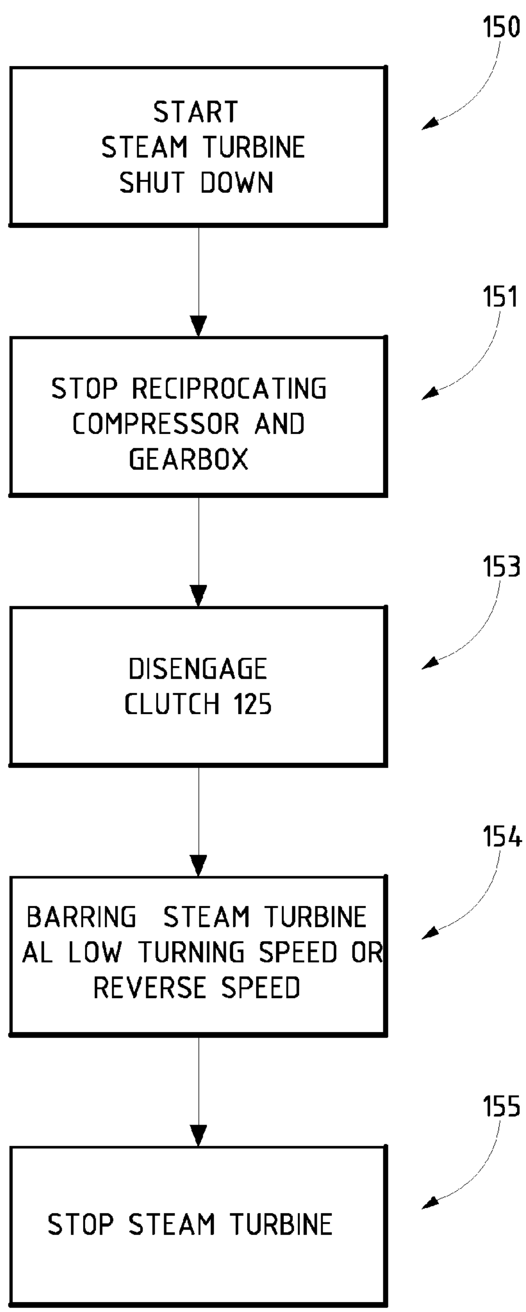

150
START
STEAM TURBINE
SHUT DOWN
151
STOP RECIPROCATING
COMPRESSOR AND
GEARBOX
153
DISENGAGE
CLUTCH 125
154
BARRING STEAM TURBINE
AL LOW TURNING SPEED OR
REVERSE SPEED
155
STOP STEAM TURBINE

Fig.5

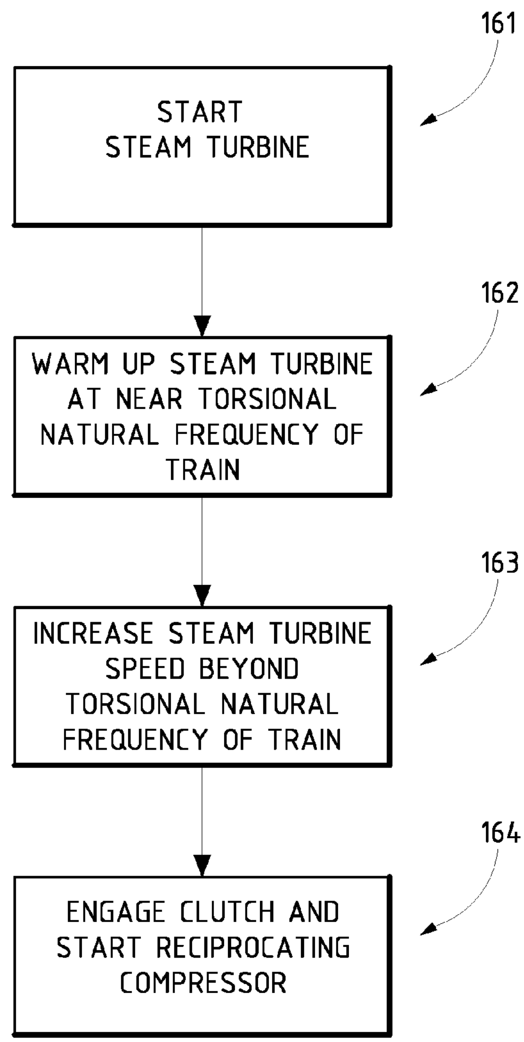

161
START
STEAM TURBINE
162
WARM UP STEAM TURBINE
AT NEAR TORSIONAL
NATURAL FREQUENCY OF
TRAIN
163
INCREASE STEAM TURBINE
SPEED BEYOND
TORSIONAL NATURAL
FREQUENCY OF TRAIN
164
ENGAGE CLUTCH AND
START RECIPROCATING
COMPRESSOR

Fig.6

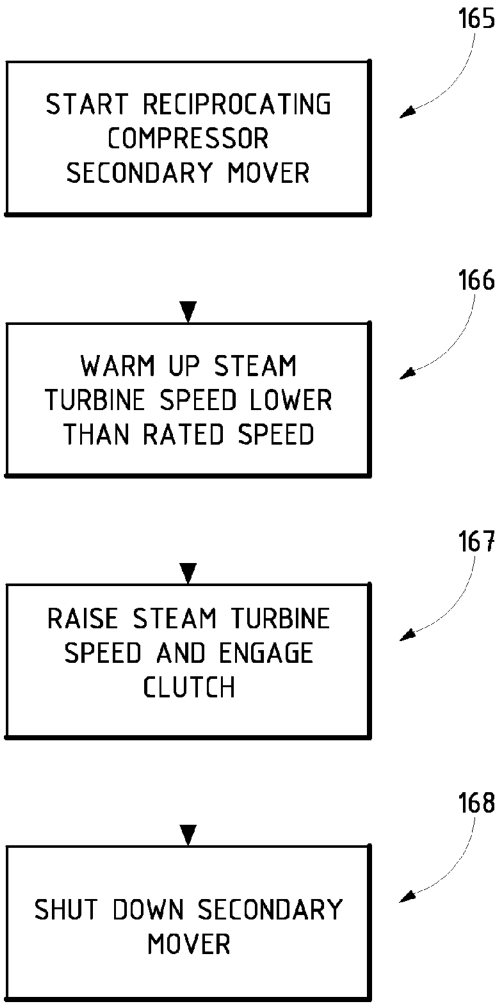
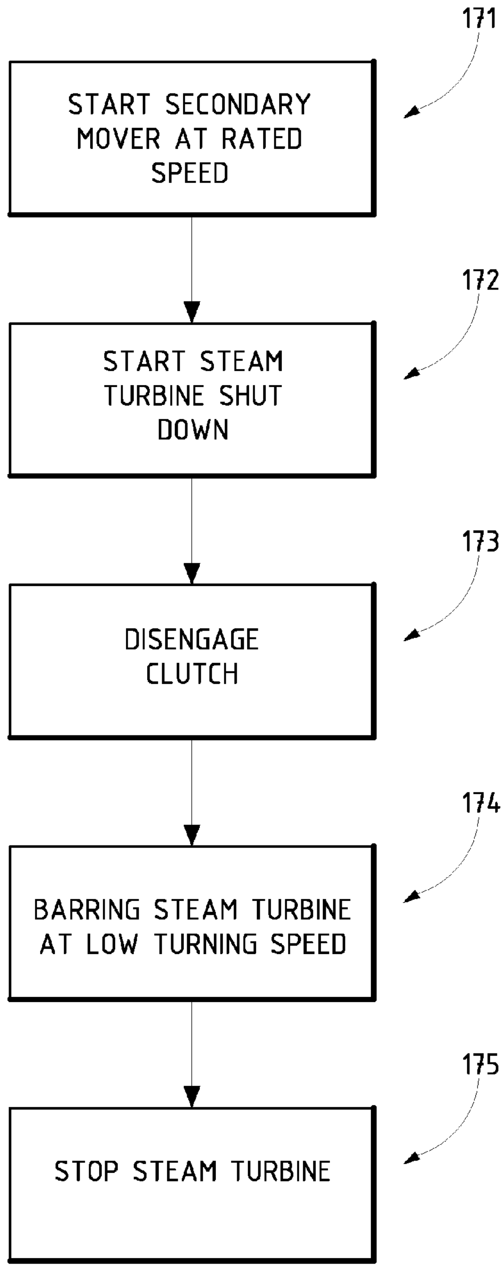

165
START RECIPROCATING COMPRESSOR SECONDARY MOVER
166
WARM UP STEAM TURBINE SPEED LOWER THAN RATED SPEED
167
RAISE STEAM TURBINE SPEED AND ENGAGE CLUTCH
168
SHUT DOWN SECONDARY MOVER

Fig.7


171
START SECONDARY MOVER AT RATED SPEED
172
START STEAM TURBINE SHUT DOWN
173
DISENGAGE CLUTCH
174
BARRING STEAM TURBINE AT LOW TURNING SPEED
175
STOP STEAM TURBINE

TURBINE-DRIVEN RECIPROCATING COMPRESSOR AND METHOD

BACKGROUND OF THE INVENTION

[0001] Embodiments of the present disclosure generally relate to reciprocating compressor systems and more specifically to reciprocating compressor systems driven by turbines, such as steam turbines.

[0002] Reciprocating compressors are commonly used in the industry for compressing gases in a wide range of applications. Reciprocating compressors are usually driven by a prime mover, which can be an electric motor, a reciprocating internal combustion engine or a gas or steam turbine.

[0003] FIG. **1** illustrates an arrangement **1** comprising a reciprocating compressor system, comprising a compressor **3**, and a steam turbine **5** used to drive the reciprocating compressor **3**. In FIG. **1** the reciprocating compressor **3** comprises a plurality of compressor cylinders **3**A, **3**B, **3**C and **3**D. A common crankshaft **7** drives the four reciprocating compressor cylinders **3**A-**3**D and supports a flywheel (not shown). The crankshaft **7** is rotatingly supported in a casing **9** and is driven into rotation by the steam turbine **5** through a gearbox **11** having an inlet shaft **13** and an outlet shaft **15** The inlet shaft **13** (high speed coupling) rotates at the rotary speed of the steam turbine **5**, while the output driven shaft **15** (low speed coupling), which connects the gearbox **11** to the crankshaft **7**, rotates at a substantially lower rotational speed.

[0004] The crankshaft **7** is usually supported by hydrodynamic bearings **17**. Correct operation of hydrodynamic bearings is dependent upon the speed between mutually moving parts, e.g. a fixed bushing and a rotary member, such as a pin or shaft. A lubrication oil film develops between the moving components when a sufficient speed is achieved. Lubrication of other components and parts of reciprocating compressor is also dependent upon the operation speed of the compressor, for instance lubrication of crossheads and runners, piston rods and the like.

[0005] Also the hafts in the gearbox **11** can be supported by hydrodynamic bearings and require to rotate at a speed sufficient to generate a lubrication oil film, to prevent bearing damages.

[0006] When the steam turbine **5** is shut down, the steam turbine **5** must be kept rotating at low turning speed in order to prevent bowing deformation and bending of the turbine rotor due to thermal gradients inside the turbine. Non-uniform temperature fields inside the turbine arise upon shutdown, since the lower portions of the turbine cool faster than the upper portions. To prevent bowing of the turbine rotor, the latter is maintained in a slow turning condition. This phase of the turbine operation is usually referred as "barring".

[0007] The system **1** therefore further comprises a slow turning motor **19**, also referred to as "barring motor" or "barring device". The barring motor **19** is usually an electric motor, which can be selectively connected to and disconnected from the rotor of the steam turbine **5** when requested. During barring of the steam turbine **5** the whole shaft line, i.e. the train comprising the steam turbine rotor, the gearbox **11**, the crankshaft **7**, the flywheel and the reciprocatingly moving components driven by the crankshaft **7**, such as the crossheads and reciprocating pistons of the one or more compressor cylinders **3**A-**3**D. The barring motor **19** must therefore have a rated power sufficient to overcome the high inertia of the tram and the high breakaway torque. The rated power of the barring motor **19** is therefore much higher than the power which would be required to turn just the rotor of the steam turbine.

[0008] Moreover, the barring speed is insufficient to develop a lubrication oil film in the hydrodynamic bearings, and therefore during slow turning of the turbine the bearings operate in a boundary lubrication condition involving high wear rate.

[0009] Furthermore, in case of sudden failure of the reciprocating compressor **3**, there is a risk of damage of the steam turbine shaft and seals, if the barring device **19** is not able to run, e.g. in case of locking of the crankshaft **7**.

[0010] During startup the rotary speed of the turbine is gradually increased to the rated speed. During acceleration, the frequency of rotation becomes equal to the natural torsional frequencies of the system. This can provoke resonance phenomena, which can damage components of the system, including the gearbox.

[0011] During turbine startup, time is required to remove thermal gradients within the turbomachinery. During this transient phase, the turbine cannot generate sufficient power to drive the reciprocating compressor under load. On the other hand, the reciprocating compressor cannot run under no-load conditions for a long period of time.

SUMMARY OF THE INVENTION

[0012] Embodiments disclosed herein alleviate or overcome one or more of the abovementioned problems of prior art reciprocating compressor systems driven by a turbine.

[0013] According to one embodiment, a reciprocating compressor system is provided, comprising a turbine and at least one reciprocating compressor driven by the turbine. In some embodiments the turbine is a steam turbine. A gearbox can be provided in the system and is arranged between the turbine and the reciprocating compressor. A clutch is provided, between the turbine and the reciprocating compressor, for mechanically disconnecting the turbine from the reciprocating compressor during a transient phase of operation of the system, for example during a barring phase or during a turbine warm-up phase. A barring device is further provided for slow-turning the turbine during a barring phase.

[0014] The system can comprise a reciprocating compressor section comprising at least one reciprocating compressor with one or more compressor cylinders and a common crankshaft driving the pistons of the compressor cylinders. The crankshaft is usually supported by hydrodynamic bearings.

[0015] The clutch can be disengaged for example upon shutdown of the turbine. The reciprocating compressor remains then stationary while the turbine is slow-turned at a barring rotary speed, to prevent bowing of the turbine rotor during cooling. The barring speed can be set at a very low value, since failures of the reciprocating compressor bearings due to insufficient rotary speed of the hydrodynamic bearings will not occur, as the reciprocating compressor is inoperative. The barring device can thus be designed to provide limited power, thus reducing the costs and dimension of the barring device.

[0016] In some embodiments the clutch can be arranged and controlled for performing a transient phase comprising warm-up of the turbine. The turbine can then be rotated steadily and continuously at one or more warm-up speeds, which can be equal or near to one or more critical speeds of the shaft line. The turbine being disengaged from the remaining shaft line, resonance phenomena of the system are prevented. Thus, the turbine can be maintained at a rotary speed near to or coinciding with one or more torsional natural frequencies of the train, i.e. the system comprised of the various components driven by the turbine.

[0017] The clutch can be arranged between the output shaft (low speed coupling) of the gearbox and the crankshaft of the reciprocating compressor. In some embodiments, however, the clutch is arranged between the turbine and the input shaft (high speed coupling) of gearbox. When the clutch is disengaged, the gearbox as well as the reciprocating compressor can be maintained stationary, while the turbine is operated in a transient condition, e.g. during barring or warm-up.

[0018] In some embodiments the clutch is externally operated, e.g. by a suitable actuator. In other embodiments the clutch is a self-synchronizing clutch.

[0019] The barring device can be comprised of an actuator, such as for example an electric motor or a hydraulic device. A barring gear or gear box can be provided between the actuator and the turbine rotor. A clutch can be provided for separating the barring device from the turbine rotor when the turbine is operating.

[0020] In some embodiments, the system can be a dual-drive system. In such case, during a slow-turning transient phase or during a warm-up phase of the turbine, the reciprocating compressor can be driven at an operative speed, which is different (e.g. higher) than the speed that would be provided by the slow-turning turbine, e.g. by means of a secondary mover, for instance an electric motor or a reversible electric machine. A reversible electric machine is a machine capable of being operated in a motor mode or in a generator mode. When a reversible electric machine is used, it can be driven by the turbine and operate in the generator mode when the turbine is in operative, steady-state conditions. If mechanical power is generated by the turbine in excess with respect to the power needed to drive the reciprocating compressor(s), the excess mechanical power can be converted into electric power and used to power facilities combined with the reciprocating compressor system and/or transferred to an electric distribution grid.

[0021] The electric machine can be arranged on a side-shaft engageable to or disengageable from the main shaft line. In other embodiments, the electric machine can be arranged on a side-shaft permanently engaged with the main shaft line, e.g. through a gearbox. In yet further embodiments, the electric machine comprises a through shaft with a first end and a second end, permanently engaged to the main shaft line connecting the turbine and the reciprocating compressor. For instance, the electric machine can be arranged between the gearbox and the crankshaft of the reciprocating compressor.

[0022] According to a further embodiment, a method of operating a turbine-driven reciprocating compressor system is provided. The method comprises a step of mechanically disengaging the turbine from at least one reciprocating compressor and operating the system in at least one transient condition, with the turbine rotating at a speed different from the steady-state rotary speed or rotary speed range. In some embodiments the method comprises rotating the turbine by means of a barring device at a barring speed below an operative speed range after shutdown of the turbine, and/or in a direction opposite to the normal rotation direction of the turbine.

[0023] In further embodiments, the method comprises the step of mechanically disengaging the turbine from a gearbox arranged between the turbine and the reciprocating compressor when the system is performing a transient phase, such as a barring phase.

[0024] In yet further embodiments, the method can comprise the steps of arranging a clutch between the turbine and the gearbox; driving the reciprocating compressor with the turbine via the clutch and the gearbox, at an operative speed; shutting down the turbine and disengaging the clutch, rotating the turbine after shutdown by means of a barring device at a barring speed below an operative speed (i.e. a rated steady-state speed or speed range), and/or in a direction opposite to the normal direction of rotation of the turbine, maintaining the reciprocating compressor and the gearbox stationary.

[0025] In other embodiments, at shutdown of the turbine, the reciprocating compressor can be maintained in operative conditions by driving the reciprocating compressor with a second mover.

[0026] According to further embodiments, a method is provided, comprising the steps of starting the turbine while the turbine is disengaged from the gearbox and the reciprocating compressor; increasing the speed of the turbine above at least one critical rotary speed of the shaft line; engaging the turbine to the gearbox and the reciprocating compressor, starting operation of the reciprocating compressor.

[0027] According to yet further embodiments, a method is provided, comprising the steps of starting the reciprocating compressor by means of a secondary mover at a rated speed; starting the turbine while the turbine is disengaged from the gearbox and the reciprocating compressor; warming up the turbine rotating the turbine at a speed lower than a minimum rated speed; increasing the speed of the turbine; engaging the turbine to the gearbox and the reciprocating compressor; deactivating the secondary mover.

[0028] Features and embodiments are disclosed here below and are further set forth in the appended claims, which form an integral part of the present description. The above brief description sets forth features of the various embodiments of the present invention in order that the detailed description that follows may be better understood and in order that the present contributions to the art may be better appreciated. There are, of course, other features of the invention that will be described hereinafter and which will be set forth in the appended claims. In this respect, before explaining several embodiments of the invention in details, it is understood that the various embodiments of the invention are not limited in their application to the details of the construction and to the arrangements of the components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced and carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein are for the purpose of description and should not be regarded as limiting.

[0029] As such, those skilled in the art will appreciate that the conception, upon which the disclosure is based, may readily be utilized as a basis for designing other structures, methods, and/or systems for carrying out the several purposes of the present invention. It is important, therefore, that the claims be regarded as including such equivalent constructions insofar as they do not depart from the spirit and scope of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] A more complete appreciation of the disclosed embodiments of the invention becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

[0031] FIG. **1** illustrates a reciprocating compressor arrangement driven by a steam turbine according to the related art;

[0032] FIG. **2** illustrates an arrangement including a reciprocating compressor system driven by a steam turbine according to an embodiment of the present disclosure;

[0033] FIG. **3** illustrates a further embodiment of the present disclosure; and

[0034] FIGS. **4** to **7** illustrate transient phases of the reciprocating compressor and steam turbine system according to some embodiments of the disclosure.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS OF THE INVENTION

[0035] The following detailed description of the embodiments refers to the accompanying drawings. The same reference numbers in different drawings identify the same or similar elements. Additionally, the drawings are not necessarily drawn to scale. Also, the following detailed description does not limit the invention. Instead, the scope of the invention is defined by the appended claims.

[0036] Reference throughout the specification to "one embodiment" or "an embodiment" or "some embodiments" means that the particular feature, structure or characteristic described in connection with an embodiment is included in at least one embodiment of the subject matter disclosed. Thus, the appearance of the phrase "in one embodiment" or "in an embodiment" or "in some embodiments" in various places throughout the specification is not necessarily referring to the same embodiment(s). Further, the particular features, structures or characteristics may be combined in any suitable manner in one or more embodiments.

[0037] The following embodiments of the subject matter disclosed herein include a steam turbine. At least some of the advantages of the disclosure can be achieved also with a system using a different turbine, e.g. a gas turbine.

[0038] Referring now to FIG. **2**, in one embodiment a system **101** is provided, comprising a reciprocating compressor **103**. The reciprocating compressor **103** can comprise a reciprocating compressor arrangement including one or more compressor cylinders and relevant pistons, driven by a common prime mover, as will be disclosed here below. In the embodiment of FIG. **2** the reciprocating compressor **103** comprises four compressor cylinders labeled **103**A, **103**B, **103**C, **103**D. A different number of reciprocating compressors or a different number of compressor cylinders can be provided. A crankshaft **105** drives the compressor pistons arranged in the compressor cylinders **103**A-**103**D of the reciprocating compressor **103**. The crankshaft **105** can be supported by bearings **107**, **109**, **111** schematically illustrated in FIG. **2**. The bearings **107**, **109** and **111** can be hydrodynamic bearings, wherein a lubrication-oil hydrodynamic film develops when the crankshaft **105** rotates at a sufficiently high rotational speed.

[0039] The system **101** further comprises a turbine **115**, e.g. a steam turbine. The steam turbine **115** is the prime mover, which turns the crankshaft **105** and drives the reciprocating movement of the pistons and of the cross-heads (not shown) of the compressor cylinders **103**A-**103**D in the reciprocating compressor **103**.

[0040] The steam turbine **115** is connected to the crankshaft **105** through a mechanical link labeled **117** as a whole. In some embodiments the mechanical link or connection **117** comprises a gearbox **119**, with an input shaft, or high speed coupling **121**, and an output shaft, or low speed coupling **123**. The gearbox **119** can be an epicyclical gearbox, to reduce the rotary speed of the steam turbine **115** to the relatively low rotary speed of the crankshaft **105**. Between the output shaft **123** of the gearbox **119** and the crankshaft **105** one or more joints, clutches, couplings, flywheels or the like, not shown, can be provided.

[0041] Between the steam turbine **115** and the input shaft **121** of the gearbox **119** a clutch **125** is arranged. The clutch **125** can be a self-synchronizing clutch. In other embodiments the clutch **125** can be externally operated, for example by means of a suitable actuator, not shown.

[0042] A self-synchronizing clutch is configured so that the clutch is automatically engaged once the input shaft thereof achieves a given speed value. Conversely, the clutch automatically disengages when the speed of the input shaft drops below a given speed value or is reversed. Self-synchronizing clutches are known to those skilled in the art and require no detailed description. With a self-synchronizing clutch **125** the steam turbine output shaft **115**A will be coupled to the input shaft **121** of the gearbox **119** only when the steam turbine has reached a certain rotary speed. Below that speed, and in case of reversal rotation of the steam turbine rotor, the clutch **125** disengages the output shaft **115**A of the turbine **115** from the input shaft **121** of the gearbox **119**.

[0043] In FIG. **2** reference number **126** schematically indicates the rotor shall of the steam turbine **115**. The rotor shaft **126** can be drivingly connected to a barring gear **129**. The barring gear **129** can be selectively connected to and disconnected from a barring device or slow turning device **131**. In some embodiments the slow turning device or barring device **131** is comprised of an electric motor. A selectively engageable and disengageable clutch **133** can be provided between the barring device **131** and the barring gear **129**. When barring or slow turning of the steam turbine **115** is required, the barring device **131** is energized to put into rotation the rotor of the steam turbine **115** through the barring gear **129**.

[0044] When the steam turbine **115** is shut down and the turbine rotor is put into slow rotation by the barring device **131**, the clutch **125** is advantageously disengaged. The shaft line downstream of the clutch **125** thus remains stationary, while the steam turbine rotor is maintained at a slow-turning barring condition. In some embodiments the direction of rotation during slow-turning can be reversed with respect to the normal operating rotary speed.

[0045] The barring device **131** can therefore be designed to developed a torque sufficient to drive into rotation the rotor of the steam turbine **115** only, without having to drive into rotation the remaining part of the shaft line. Since both the gearbox **119** as well as the reciprocating compressor **103** are disengaged from the output shaft **115**A of the steam turbine **115**, no hydrodynamic support is required from the bearings of the gearbox **119** and of the crankshaft **105**. Lubrication of the remaining components of the reciprocating compressor is also not required. Slow turning of the steam turbine **115** will not damage the bearings and mechanical components of the system arranged downstream of the clutch **125**.

[0046] The clutch **125** interposed between the steam turbine **115** and the gearbox **119** also allows the steam turbine

115 to be rotate during barring in a direction opposite the operative rotary speed of the system, if desired.

[0047] Sudden failure of the reciprocating-compressor **103**, for example involving locking of the crankshaft **105**, does not damage the steam turbine shaft and seals, since the steam turbine rotor can be put into barring conditions by disengaging the clutch **125**, and activating the barring device **131**.

[0048] FIG. **3** schematically illustrates another embodiment of the present disclosure. The same reference numbers are used to designate the same or similar components as in FIG. **2**. These components will not be described again.

[0049] The embodiment of FIG. **3** comprises a dual-drive reciprocating compressor arrangement, wherein the reciprocating compressor **103**, including compressor cylinders **103**A-**103**D, can be driven selectively by the prime mover including the steam turbine **115** or by a secondary mover, including an electric machine **128**. In some embodiments the electric machine **128** is a reversible electric machine. The reversible electric machine **128** can operate alternatively to convert electric power into mechanical power (motor mode), or to convert mechanical power into electric power (generator mode). The reversible electric machine **128** is electrically connected to an electric distribution grid, schematically shown at G. Electric power conditioning devices and circuits, not shown, can be provided between the electric machine and the grid.

[0050] In some embodiments the reversible electric machine **128** has a through shaft **130** with opposing ends connected, e.g. via joints **130**A and **130**B, to the output shaft **123** of the gearbox **119** and to the crankshaft **105** of the reciprocating compressor **103**, respectively.

[0051] In this embodiment the reciprocating compressor **103** can be driven alternatively by the reversible electric machine **128** or by the steam turbine **115**. When the reversible electric machine **128** is switched to the electric motor mode for driving the reciprocating compressor **103**, the clutch **125** can be disengaged and the steam turbine **115** can be maintained inoperative or can be rotated at a slow barring speed or a slow warm-up speed.

[0052] For example, in case of failure of the steam turbine cycle, the steam turbine **115** can be shutdown and brought into barring conditions, while the reciprocating compressor **103** continues operating by means of the reversible electric machine **128**.

[0053] In a warm-up transient phase, the steam turbine can be rotated at a below-rated speed until a required temperature regime has been reached, while the reciprocating compressor **103** is driven by the electric machine.

[0054] When the steam turbine **115** is running and drives the reciprocating compressor **103**, via clutch **125** and gearbox **119**, the reversible electric machine **128** is switched to the generator mode. Excess mechanical power generated by the steam turbine **115** can be converted into electric power by the reversible electric machine **128** and injected into the electric distribution grid G.

[0055] The operating conditions of the steam turbine **115** are thus made to some extent independent from the operating conditions of the reciprocating compressor **103**. The steam turbine **115** can be run at design conditions maximizing the efficiency of the thermodynamic cycle, irrespective of fluctuations in the operative conditions of the reciprocating compressor **103**. Excess mechanical power generated by the steam turbine **115** is converted in useful electric power.

[0056] In less advantageous embodiments the electric machine **128** can operate only as an electric motor and will rotate idly when the reciprocating compressor **103** is driven by the steam turbine **115**.

[0057] FIG. **4** schematically illustrates a method of operating the system **101** in a transient phase involving steam turbine **115** shutdown. The shutdown process starts at **150**. The reciprocating compressor **103** and the gearbox **119** are stopped (step **151**) and the clutch **125** is disengaged (step **153**), thus mechanically separating the steam turbine **115** from the gearbox **119** and the reciprocating compressor **103**.

[0058] Once the clutch **125** has been disengaged, slow turning (barring) of the steam turbine **115** by means of barring motor **131** and barring gear **121** can start (step **154**) and will continue until the steam turbine **115** has cooled down to a temperature sufficient to avoid bowing or thermal deformation of the steam turbine rotor. Once these conditions are reached, the steam turbine can be stopped (step **155**).

[0059] Upon start-up or resumption of the steam turbine operation, use of a clutch **125** to engage and disengage the steam turbine **115** with respect to the remaining shaft line provides for additional advantages. FIG. **5** illustrates the method of operating the system **101** during a transient phase involving start-up of the steam turbine **115**.

[0060] When the steam turbine **115** is started, a warm-up phase is usually required. During warm-up of the steam turbine **115**, it might be desirable or required to rotate the steam turbine at a transient rotary speed lower than the rated rotary speed of the system, i.e. the speed of the system in steady-state conditions.

[0061] The steam turbine **115** can be driven at a gradually increasing rotary speed from zero up to the rated rotary speed. Speeding up of the steam turbine **115** can be stepwise or continuous. In some embodiments, intermediate transient rotary speeds can be maintained for a certain period of time to allow the steam cycle to smoothly achieve the final steady state operative conditions.

[0062] The shaft line or train formed by steam turbine **115**, gearbox **119**, reciprocating compressor **103** with crankshaft **105**, relevant crossheads, pistons, and reversible electric machine (if provided as in FIG. **3**) is characterized by one or more torsional natural frequencies (critical speeds), which are usually lower than the frequency at the rated rotary speed of the system. This means that during warm-up of the steam turbine **115** the turbine shaft will rotate at a gradually increasing speed moving through the torsional natural frequencies of the system.

[0063] In known systems, to prevent damages to the train or series of rotary machines, the steam turbine **115** cannot be maintained in rotation at rotary speeds, which are near or equal to the torsional natural frequencies of the whole train. However, using the clutch **125** this limitation is removed. When the clutch **125** is disengaged, the steam turbine **115** can be put into rotation during warm-up at a speed which is close or equal to the torsional natural frequency of the train, since the shaft line downstream clutch **125** remains stationary or is rotated independently of the steam turbine by a secondary mover. Resonance phenomena are avoided. Clutch **125** can be engaged once the steam turbine **115** rotates at a speed above the torsional natural frequencies of the system.

[0064] FIG. **5** summarizes the method of operating the system **101** during a transient process from start-up of the steam turbine **115** up to steady-state conditions. At **161** the steam turbine **115** is started. A subsequent warm-up step **162**

follows, during which the steam turbine **115** can rotate at nearly the torsional natural frequency of the train. Clutch **125** is disengaged. The gearbox **119**, the reversible electric machine **128** (if present) and the reciprocating compressor **103** are at standstill.

[0065] At step **163** the steam turbine speed is increased beyond the torsional natural frequencies of the train and finally, at step **164**, the clutch **125** is engaged and the reciprocating compressor **103** starts operating.

[0066] FIG. **6** illustrates a method of turbine startup according to a further embodiment of the present disclosure, using a dual-drive system according to FIG. **3**, for instance. The first step of the startup process (step **165**) comprises starting the electric machine **128** in the motor mode and driving the reciprocating compressor **103**. While the clutch **125** is maintained in a disengaged condition, the steam turbine **115** can initiate a warm-up phase. The warm-up phase can start before, during or after start-up of the electric machine **128** and of the reciprocating compressor **103**. In the flowchart of FIG. **6** an embodiment is shown where warm-up starts (step **166**) after start-up of the secondary mover. This, however, is not mandatory.

[0067] The rotary speed of the steam turbine can then gradually increase (step **167**) until a rated speed is achieved, upon which the clutch **125** can be engaged. The electric machine (secondary mover) **128** can be shut down or switched to the generator mode (step **168**).

[0068] The reciprocating compressor **103** can thus be started and gradually accelerated to the rated speed avoiding running the reciprocating compressor **103** under no-load conditions for too long, a situation which could result in mechanical failures. The steam turbine **115** can run in a transient warm-up condition and the speed thereof can be increased following an optimal speed sequence, without influencing the operation of the reciprocating compressor **103**. Only once the rated rotary speed of the steam turbine **115** has been reached, the steam turbine takes up the task of driving the reciprocating compressor **103**.

[0069] FIG. **7** illustrates a flowchart showing an embodiment of a further method of operating the system **101** during a transient phase. More specifically, FIG. **7** illustrates a steam turbine shut-down procedure in a dual-drive system, for instance as shown in FIG. **3**. The shut-down method of FIG. **7** is aimed at shutting down the steam turbine **115** maintaining the reciprocating compressor **113** in operation. When shutdown of the steam turbine **115** is required, the secondary mover comprising the electric machine **128** is started and rotated at a rated speed (step **171**). Shut-down of the steam turbine **115** is then started (step **172**) and the clutch **125** is disengaged (step **173**). A slow-turning or barring step of the steam turbine **115** follows (step **174**), until the steam turbine **115** finally stops (step **175**). During steps **174** and **175** the reciprocating compressor **103** continues operating, being driven by the secondary mover **128**.

[0070] While the disclosed embodiments of the subject matter described herein have been shown in the drawings and fully described above with particularity and detail in connection with several embodiments, it will be apparent to those of ordinary skill in the art that many modifications, changes, and omissions are possible without materially departing from the novel teachings, the principles and concepts set forth herein, and advantages of the subject matter recited in the appended claims. Hence, the proper scope of the disclosed innovations should be determined only by the broadest interpretation of the appended claims so as to encompass all such modifications, changes, and omissions. In addition, the order or sequence of any process or method steps may be varied or re-sequenced according to embodiments.

What is claimed is:

1. A reciprocating compressor system comprising: a turbine; a reciprocating compressor driven by the turbine; a gearbox arranged between the turbine and the reciprocating compressor; a barring device arranged for slow-turning the turbine during a barring phase; wherein a clutch is arranged between the turbine and the reciprocating compressor, for mechanically disconnecting the turbine from the reciprocating compressor during a transient phase of operation of the system.

2. The system of claim **1**, wherein the transient phase comprises a barring phase after shut down of the turbine.

3. The system of claim **1**, wherein the transient phase comprises a warm-up phase of the turbine.

4. The system of claim **1**, wherein the clutch is arranged between the turbine and the gearbox.

5. The system of claim **1**, wherein the clutch is a self-synchronizing clutch.

6. The system of claim **1**, wherein the barring device is arranged for driving the turbine in a direction opposite an operative rotation direction of the turbine when driving the reciprocating compressor.

7. The system of claim **1**, wherein the barring device comprises a barring actuator and preferably a gearbox.

8. The system of claim **1**, comprising a secondary mover, configured and arranged for driving the reciprocating compressor when the clutch is disengaged.

9. The system of claim **8**, wherein the secondary mover comprises an electric machine.

10. The system of claim **9**, wherein the electric machine is a reversible electric machine.

11. The system of claim **9**, wherein the electric machine comprises a through shaft with a first end and a second end, permanently engaged to a shaft line connectable to the turbine and to the reciprocating compressor.

12. The system of claim **11**, wherein the electric machine is arranged between the gearbox and the reciprocating compressor.

13. The system of claim **1**, wherein the turbine is a steam turbine.

14. A method of operating a turbine driven reciprocating compressor system comprising a reciprocating compressor, a turbine driving the reciprocating compressor, a gearbox between the reciprocating compressor and the turbine, a clutch arranged for selectively engaging and disengaging the turbine to and from the reciprocating compressor, and a barring device; the method comprising mechanically disengaging the turbine from the reciprocating compressor and rotating the turbine at a rotary speed, different from a rated rotary speed, during at least one transient phase.

15. The method of claim **14**, wherein the transient phase is a slow-turning phase of the turbine at shut-down, and wherein during the transient phase the turbine is rotated at a barring speed by means of the barring device, the barring speed being different from a rated speed range.

16. The method of claim **14**, comprising mechanically disengaging the turbine from the gearbox and the reciprocating compressor during the transient phase.

17. The method of claim **15**, comprising:

arranging the clutch between the turbine and the gearbox;

driving the reciprocating compressor with the turbine via the clutch and the gearbox, at a rated speed;

shutting down the turbine and disengaging the clutch, rotating the turbine after shut-down by means of the barring device at the barring speed below the rated speed, maintaining the reciprocating compressor and the gearbox stationary.

18. The method of claim **14**, comprising:

starting the turbine while the turbine is disengaged from the gearbox and the reciprocating compressor;

increasing the speed of the turbine above at least one critical rotary speed;

engaging the turbine to the gearbox and the reciprocating compressor, starting operation of the reciprocating compressor.

19. The method of claim **14**, comprising:

providing a secondary mover, arranged and configured for selectively driving the reciprocating compressor;

driving selectively the reciprocating compressor with the secondary mover maintaining the clutch disengaged, or with the turbine maintaining the clutch engaged.

20. The method of claim **19**, wherein the secondary mover comprises an electric machine.

21. The method of claim **19**, wherein the secondary mover is a reversible electric machine, and wherein, when the reciprocating compressor is driven by the turbine, the reversible electric machine is driven into rotation by the turbine and is switched in a generator mode, the electric machine converting excess mechanical power generated by the turbine into electric power.

22. The method of claim **19**, comprising:

starting the secondary mover;

driving the reciprocating compressor by means of the secondary mover;

starting the turbine;

warming-up the turbine at a speed lower than a rated speed;

raising the turbine speed at the rated speed;

engaging the clutch, starting driving the reciprocating compressor by means of the turbine;

shutting down the secondary mover of switching the secondary mover to a generator mode,

23. The method of claim **19**, comprising:

starting the secondary mover, while the reciprocating compressor driven by the turbine;

starting shut-down of the turbine;

disengaging the clutch, driving the reciprocating compressor by means of the secondary mover;

rotating the turbine at a barring speed, while the reciprocating compressor is driven by the secondary mover; and

stopping the turbine.

24. The method of claim **14**, wherein the turbine is a steam turbine.

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