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(54) TURBOMACHINE AND CORRESPONDING METHOD OF OPERATING

STRÖMUNGSMASCHINE UND ZUGEHÖRIGES BETRIEBSVERFAHREN

TURBOMACHINE ET PROCÉDÉ ASSOCIÉ D'EXPLOITATION

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Description

Field of the invention

[0001] The invention relates to a turbo-machine with active clearance control as well as to a method of operation of such a machine with active clearance control. Clearance control allows a reduction in clearances of a turbo-machine, mainly the clearance between rotating blades and casing, and the clearance between vanes and rotor.

Background of the invention

[0002] In a turbo-machine the radial and axial clearances are a result of the relative movements of rotating (rotor, rotor blades) and fixed components (stator, stator vanes). Typically no active clearance control is used but all parts are passively expanding or contracting as a function of mechanical and thermal boundary condition.

[0003] Careful design of the components can minimize the clearances by finding a good thermal match of rotor and stator. Thermal match means that the components react on thermal transients with the same speed, i.e. they expand and contract with the same speed and therefore maintain the same clearance. This is called Passive Clearance Control. However, the design can only be optimized for certain transient operation modes and regimes and not for the whole operation regime (e.g. stand still, part load, base load) and transients operating modes (e.g. start-up, loading, de-loading, and shut down).

[0004] In some engines cold or warm air is blown to the stator components depending on the operating conditions to heat them or cool them as for example known from the US 7 329 953.

[0005] FR 2 949 808 discloses a turbo-machine according to the preamble of claim 1, respectively a method for operating a turbo-machine according to the preamble of claim 9.

Summary of the invention

[0006] The invention is defined in the accompanying claims and provides a turbo-machine according to claim 1, and a method for operating a turbo-machine according to claim 9. One aspect of the present disclosure is to provide a Turbo-machine comprising a stator and a rotor arranged rotatable inside the stator with at least one electric heating device, which is arranged on the surface of at least one stator part for active clearance control. The stator in this context includes all non-rotating components of the turbo-machine, in particular the casing, which typically comprises an inner casing, an outer casing and a connecting wall, as well as a support for the casing and a bearing support for the bearings, which hold the rotor.

[0007] Active clearance control allows a reduction in clearances of a turbo-machine, mainly the clearance be-

tween rotating blades and casing, and the clearance between vanes and rotor. Clearances can be reduced by active clearance control in order to increase the efficiency and power of the turbo-machine.

[0008] According to one embodiment the electrical heating device is arranged in a cavity of the stator part to heat the fluid, which is at least partly surrounding the stator part and/or in that the electrical heating device is arranged with direct mechanical contact on the stator part to allow conductive heat transfer from the electrical heating device to the stator part. A suitable cavity in which a heating device can be arranged is for example a compressor bleed or a cooling air distribution plenum.

[0009] According to another embodiment the electrical heating device is arranged in a cooling air supply bore. For example it can be arranged on the surface of a cooling air supply bore of the stator.

[0010] In a further embodiment the stator part on which the electrical heating device is arranged is an inner and/or outer casing of the turbo-machine.

[0011] In addition or as an alternative the electrical heating device is arranged on a connecting wall, which is connecting the inner casing with the outer casing.

[0012] In yet another embodiment the electrical heating device comprises an induction heating. Typically an induction heating can be arranged on the surface of the respective stator part to induce an alternating electromagnetic field into the stator part and to thereby induction heat the stator part. For induction heating an electromagnet can be arranged on or above the surface of a stator part. The stator part can then be heated by inducing an eddy current into the stator part by the electromagnet.

[0013] According to one embodiment a plurality of electrical heating devices is arranged distributed in axial and circumferential direction around the casing of the turbo-machine. The different electrical heating devices are configured and connected to a power source such that they can be individually controlled to control the heating intensity in circumferential and axial direction of the turbo-machine. To allow individual control of the heating intensity the different electrical heating devices can for example be individually connected to a power source.

[0014] According to one embodiment the turbo-machine is a gas turbine and according to another embodiment the turbo-machine is a steam turbine.

[0015] Besides the turbo-machine comprising an electric heating device for a stator part a method to actively control clearances in a turbo-machine with an electric heating device is an object of the disclosure.

[0016] According to one embodiment of the method for operating a turbo-machine comprising a stator and a rotor arranged rotatable inside the stator and at least one electric heating device arranged on the surface of at least a stator part, the at least one electric heating device is controlled to heat the at least one stator part for controlling the clearance of the rotor to the stator.

[0017] According to a further embodiment of the method at least one heating element is arranged at a position

on the upper or lower half of the casing. The heating element is controlled to heat the region of the casing on which it is arranged to reduce circumferential temperature inhomogeneity of the casing. For example if a temperature measurement indicates that a region in the upper half of the casing has a lower temperature than the corresponding region in the lower half (for example at the same axial position) the heating element in the region of the upper half of the casing can be activated to heat that region until it has the same temperature as the corresponding region in the lower half.

[0018] A temperature inhomogeneity can be caused for example by cooling air supply lines which are entering the casing on one side or which are not equally distributed around the casing. A temperature inhomogeneity can for example also be caused by a damaged insulation leading to higher heat loss of the casing on one side.

[0019] In another embodiment at least one electrical heating device is controlled to keep the temperature profile of the turbo-machine's casing in axial direction within a predetermined range. Depending on the load and operating condition (steady state or transient) a certain temperature profile is expected in axial direction of the gas turbine. If a measured temperature profile of the casing is outside the expected profile, the casing can be locally heated to establish the expected temperature profile.

[0020] According to one embodiment of the method at least one heating element is arranged at a position on the lower half of the casing and it is used for heating the lower half of the casing during shut down and cooling of the turbo-machine. It is heating the lower half of the casing to compensate for an increase in the temperature of the upper half relative to the temperature of the lower half due to convective heat transfer from the bottom to the top half. By heating the lower half so called buckling, which is due to a higher temperature in the upper half, can be mitigated.

[0021] According to yet another embodiment at least one heating element is arranged to heat a flange connecting the lower and upper half casing to reduce or avoid ovalisation of the casing. The flange typically at least partially remains cooler than the circular portion of the casing. It remains cooler because of additional heat loss due to the flange surface and in particular remains cooler during loading of the turbo-machine (i.e. heating of the turbo-machine) because the additional flange material needs more time to be heated.

[0022] In a further embodiment at least one heating element is arranged on a bearing support of the turbo-machine. The at least one electrical heating device arranged on a bearing support is used for heating the bearing support. The heating is controlled such that the rotor is kept centrally aligned relative to the casing.

[0023] Typically the bearing support is thermally insulated. Therefore its thermal expansion is at least partly decoupled from the thermal expansion of the casing. If the casing's expansion is different from the expansion of the bearing support this can lead to a misalignment of

the rotor and therefore increases the required cold clearance of the turbo-machine. This misalignment can be mitigated by heating the bearing support. For example if the casing heats up during operation the bearing support is heated such that the bearing support's expansion compensates the expansion of the warm casing and thereby keeps the rotor and the casing aligned.

[0024] The control of the power supplied to the electric heating device can be carried out according to different control schemes. In one example the heating is done according to a schedule. The temperature changes in a turbo-machine during a change of operating conditions are known from measurements and calculations. Therefore, starting from a defined condition as for example a cold turbo-machine at standstill the typical transient changes are known and the electric heating required to specific stator parts to minimize clearances is also known as a function of time. Therefore the heat input for the electric heating device can be given for example with a schedule as a function of time. The heating schedule can for example begin from a defined operating state. The heating schedule typically starts from a defined steady state operating point such as the starting of the turbo-machine, or from a steady load point.

[0025] The heating can also be carried out depending on an operating parameter of the turbo-machine such as the speed, the power, a mass flow, or an operating temperature. Relevant mass flows are for example the inlet mass flow, the exhaust mass flow, the fuel flow or mass flow of water or steam injected for power augmentation or emission control as well as cooling air mass flows.

[0026] The heating can also be used to control the temperature of at least one section of the casing based on a temperature measurement. The temperature of a specific part can be used or multiple temperature measurements as well as a temperature difference or a combination of both.

[0027] Further, the heating can be controlled based on a direct measurement of the clearance with a blade clearance transducer and/ or a vane clearance transducer.

[0028] During standstill of a turbo-machine heat can be transferred to a fluid flowing through the machine. For example air can flow through a gas turbine due to a chimney draft. Such a fluid flow can lead an adverse temperature distribution in the gas turbine. Further, if parts of the engine are kept warm to allow a better restart this fluid flow can increase the heat losses and therefore can lead to a higher heating requirement. According to one embodiment of the method the inlet and/or the outlet of the turbo-machine are closed during standstill of the turbo-machine to reduce a fluid flow. Accordingly, an embodiment of the turbo-machine comprises an inlet shutter and/or outlet shutter to close the fluid flow path at the inlet or outlet of the turbo-machine.

[0029] The heating control can be limited to certain operating conditions such as stand still, cooling of the engine, e.g. at less than 5% rotational speed (relative to the design operating speed) or during run up to the operating

speed and loading, e.g. at more than 50% rotational speed. The control can be carried out with an open or closed loop controller.

[0030] The above gas turbine can be a single combustion gas turbine or a sequential combustion gas turbine as known for example from EP0620363 B1 or EP0718470 A2. The disclosed method and use as well as retrofit method can also be applied to a single combustion gas turbine or a sequential combustion gas turbine.

Brief description of the drawing

[0031] The invention, its nature as well as its advantages, shall be described in more detail below with the aid of the accompanying drawings. Referring to the drawings:

Fig. 1 schematically shows an example of a turbo-machine according to the present invention. Here a gas turbine is given as an example for a turbo-machine.

Fig. 2 schematically shows the detail II of the turbine casing of Fig. 1 with an electric heating arranged in a cooling air supply bore.

Ways of implementing the invention

[0032] The same or functionally identical elements are provided with the same designations below. The examples do not constitute any restriction of the invention to such arrangements.

[0033] An exemplary arrangement is schematically shown in Fig. 1. The gas turbine 10 is supplied with compressor inlet gas 11. In the gas turbine 10 a compressor 12 is followed by a first combustor comprising a first burner 24 and a first combustion chamber 13. In the first burner 24 fuel 37 is added to the compressed gas and the mixture burns in the first combustion chamber 13. Hot combustion gases are fed from the first combustion chamber 13 into a first turbine 14 which is followed by a second combustor comprising a sequential burner 25 (also known as second burner) and a sequential combustion chamber 15 (also known as second combustion chamber). Fuel 37 can be added to the gases leaving the first turbine 14 in the sequential burner 35 and the mixture burns in the sequential combustion chamber 15. Hot combustion gases are fed from the sequential combustion chamber 15 into a second turbine 16.

[0034] Steam and/or water 38 can be injected into the first and/or sequential burner for emission control and to increase the power output.

[0035] The stator of the gas turbine comprises a casing. The casing comprises a vane carrier or inner casing wall 22 and an outer casing wall 23. The inner and outer casing walls 22, 23 can be connected by a connecting wall 49. Further the casing comprises an inlet casing 27

and an exhaust casing 17.

[0036] In the example of Fig. 1 electrical heating devices for the connecting wall 40 are placed on several connecting walls 49, heating devices for the inner casing 41 are placed on the inner casing walls 22 (also called vane carrier) and heating devices for the outer casing 42 are placed on the outer casing walls 23.

[0037] In the example shown in Fig. 1 blade clearance transducer 20 are arranged on the inner casing wall 22 at locations facing rotating blades of the compressor 12 and at locations facing rotating blades of the first and second turbine 14, 16. Vane clearance transducers 21 are arranged at the tip of a vane in the compressor 12 and on the tip of a turbine vane 18, 19 of the first and second turbine 14, 16 facing the rotor 28.

[0038] The rotor 28 is supported and kept in position by a bearing support 45. A bearing support heating device 46 is arranged on the bearing support 45 to enable heating of the bearing support 45.

[0039] Exhaust gas 47 leaves the second turbine 16. The exhaust gas 47 is typically used in a heat recovery steam generator to generate steam for cogeneration or for a water steam cycle in a combined cycle (not shown).

[0040] Optionally, part of the exhaust gas 47 can be branched off in a flue gas recirculation 34 (typically downstream of heat recovery steam generator) and admixed to the inlet air 35. Typically the recirculation 34 comprises a recooler for cooling the recirculated flue gas.

[0041] Further, the compressor inlet can be closed by an inlet shutter 36 and the turbine exit can be closed by an outlet shutter 39.

[0042] Fig. 2 schematically shows the section II - II of turbine casing of Fig. 1. In this region of the second turbine 16 a cooling air supply bore 43 is shown. In this example an electrical heating device in cooling air supply bore 43 is shown in the cooling air supply bore 44.

Designations

[0043]

- 10 gas turbine
- 11 compressor inlet gas
- 12 compressor
- 13 first combustion chamber
- 14 first turbine
- 15 second combustion chamber
- 16 second turbine
- 17 exhaust casing
- 18 vane (of first turbine)
- 19 vane (of second turbine)
- 20 blade clearance transducer
- 21 vane clearance transducer
- 22 inner casing wall
- 23 outer casing wall
- 24 first burner
- 25 sequential burner
- 26 compressor plenum

27 inlet casing
 28 rotor
 34 flue gas recirculation (optional)
 35 air
 36 inlet shutter
 37 fuel
 38 water/ Steam injection
 39 outlet shutter
 40 electrical heating devices for the connecting wall
 41 electrical heating devices for the inner casing/ vane carrier
 42 electrical heating devices for the outer casing
 43 electrical heating devices in cooling air supply bore
 44 cooling air supply bore
 45 bearing support
 46 bearing support heating device
 47 exhaust gas
 49 connecting wall

Claims

1. Turbo-machine (10) comprising a stator (22, 23, 45, 49) and a rotor (28) arranged rotatably inside the stator (22, 23, 45, 49) and electrical heating devices (40, 41, 42, 43, 46) arranged on a surface of at least part of the stator (22, 23, 45, 49) for clearance control, the stator comprising a casing;
characterized in that at least one of the electrical heating devices is a bearing support electrical heating device (46) arranged on a bearing support (45) to heat the bearing support to keep the rotor (28) centrally aligned relative to the casing, and at least one of the electrical heating devices (42) is arranged to heat a flange connecting a lower half casing and an upper half casing to reduce or avoid ovalisation of the casing (22, 23, 49).
2. Turbo-machine (12) according to claim 1 **characterized in that** at least one of the electrical heating devices (40, 41, 42, 43, 46) is arranged in a cavity of the stator (22, 23, 45, 49) to heat a fluid which is at least partly surrounding the stator part (22, 23, 45, 49) and/or **in that** at least one of the electrical heating devices (40, 41, 42, 43, 46) is arranged with direct mechanical contact on the stator part (22, 23, 45, 49) to allow conductive heat transfer from the electrical heating device (40, 41, 42, 43, 46) to the stator (22, 23, 45, 49).
3. Turbo-machine (10) according to claim 1 or 2 **characterized in that** at least one of the electrical heating devices (40, 41, 42, 43, 46) is arranged in a cooling air supply bore of the stator (22, 23, 49).
4. Turbo-machine (10) according to one of the claim 1 to 3 **characterized in that** at least one of the electrical heating devices (41, 42) is arranged in an inner

casing (22) and/or outer casing (23) of the stator of the turbo-machine.

5. Turbo-machine (10) according to claim 4 **characterized in** at least one of the electrical heating devices (40) is arranged on a connecting wall (49) connecting the inner casing (22) with the outer casing (23).
6. Turbo-machine (10) according to one of the claim 1 to 5 **characterized in that** at least one of the electrical heating devices (40, 41, 42, 43, 46) comprises an induction heating.
7. Turbo-machine (10) according to one of the claim 1 to 6 **characterized in that** a plurality of the electrical heating devices (40, 41, 42, 46) is arranged distributed in axial and circumferential directions around the casing (22, 23, 49) of the turbo-machine (12) and **in that** distinct electrical heating devices of the plurality of the electrical heating devices (40, 41, 42, 46) are configured and connected to a power source such that they can be individually controlled to control the heating intensity in circumferential and axial direction of the turbo-machine (12).
8. Turbo-machine (10) according to one of the claims 1 to 7 **characterized in that** the turbo-machine (10) is a gas turbine (10) or a steam turbine.
9. Method for operating a turbo-machine (10) comprising a stator (22, 23, 45, 49) and a rotor (28) arranged rotatably inside the stator (22, 23, 49) and electrical heating devices (40, 41, 42, 43) arranged on a surface of at least part of the stator (22, 23, 45, 49), the stator comprising a casing;
characterized in that
 the at least one electrical heating device (40, 41, 42, 43) is controlled to heat the at least part of the stator (22, 23, 45, 49) for controlling a clearance between the rotor (28) and the stator (22, 23, 45, 49), and **in that** at least one of the electrical heating devices is a bearing support electrical heating device (46) arranged on a bearing support (45) and is used to keep the rotor (28) centrally aligned relative to a casing (22, 23, 49) by controlled heating of the bearing support (45), and
 at least one of the electrical heating devices (42) is arranged to heat a flange connecting a lower half casing and an upper half casing to reduce or avoid ovalisation of the casing (22, 23, 49).
10. Method according to claim 9 **characterized in that** at least one electrical heating device (40, 41, 42, 43) is arranged at a position on the upper half casing (22, 23, 49) or lower half casing (22, 23, 49) and **in that** it is controlled to heat a region of the casing (22, 23, 49) on which it is arranged to reduce circumferential temperature inhomogeneity in the casing (22,

23, 49).

11. Method according to claim 9 or 10 **characterized in that** the at least one electrical heating device (40, 41, 42, 43) is controlled to keep a temperature profile of the casing (22, 23, 49) of the turbo-machine (10) in an axial direction within a predetermined range.

12. Method according to one of the claims 9 to 11 **characterized in that** at least one of the electrical heating devices (40, 41, 42, 43) is arranged at a position on the lower half casing (22, 23, 49) and **in that** it is used for heating during shut down and cooling of the turbo-machine to compensate for an increase in the temperature of the upper half casing (22, 23, 49) relative to the temperature of the lower half casing (22, 23, 49) due to convective heat transfer from the lower half casing (22, 23, 49) to the upper half casing (22, 23, 49) to mitigate buckling.

13. Method according to one of the claims 9 to 12 **characterized in that** power is supplied to the at least one electrical heating device (40, 41, 42, 43) based on one of the following:

- heating according to a schedule
- heating depending on an operating parameter of the turbo-machine (10) such as the speed, the power, a mass flow, or an operating temperature
- heating to control the temperature of at least one section of the casing (22, 23, 49) based on a temperature measurement
- direct measurement of the clearance with a blade clearance transducer (20) and/ or a vane clearance transducer (21) and heating to control the measured clearance
- closing an inlet and/or an outlet of the turbo-machine (10) during standstill of the turbo-machine (10) to reduce a flow of fluid and heat transfer to the fluid in the turbo-machine (10).

Patentansprüche

1. Turbomaschine (10), umfassend einen Stator (22, 23, 45, 49) und einen Rotor (28), der drehbar im Inneren des Stators (22, 23, 45, 49) angeordnet ist, und elektrische Heizvorrichtungen (40, 41, 42, 43, 46), die auf einer Oberfläche wenigstens eines Teils des Stators (22, 23, 45, 49) zur Spaltsteuerung/-regelung angeordnet sind, wobei der Stator ein Gehäuse aufweist;
dadurch gekennzeichnet, dass wenigstens eine der elektrischen Heizvorrichtungen eine elektrische Heizvorrichtung (46) für einen Lagerträger ist, die auf dem Lagerträger (45) angeordnet ist, um den Lagerträger zu erwärmen, um den Rotor (28) relativ

zu dem Gehäuse zentral ausgerichtet zu halten, und wenigstens eine der elektrischen Heizvorrichtungen (42) so angeordnet ist, dass sie einen Flansch erwärmt, der eine untere Gehäusehälfte und eine obere Gehäusehälfte verbindet, um eine Ovalisierung des Gehäuses (22, 23, 49) zu reduzieren oder zu vermeiden.

2. Turbomaschine (12) nach Anspruch 1, **dadurch gekennzeichnet, dass** wenigstens eine der elektrischen Heizvorrichtungen (40, 41, 42, 43, 46) in einem Hohlraum des Stators (22, 23, 45, 49) angeordnet ist, um ein Fluid zu erwärmen, das zumindest teilweise den Statorteil (22, 23, 45, 49) umgibt, und/oder dass wenigstens eine der elektrischen Heizvorrichtungen (40, 41, 42, 43, 46) mit direktem mechanischen Kontakt auf dem Statorteil (22, 23, 45, 49) angeordnet ist, um eine leitende Wärmeübertragung von der elektrischen Heizvorrichtung (40, 41, 42, 43, 46) zu dem Stator (22, 23, 45, 49) zu ermöglichen.

3. Turbomaschine (10) nach Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** wenigstens eine der elektrischen Heizvorrichtungen (40, 41, 42, 43, 46) in einer Kühlluftzuführungsbohrung des Stators (22, 23, 49) angeordnet ist.

4. Turbomaschine (10) nach einem der Ansprüche 1 bis 3, **dadurch gekennzeichnet, dass** wenigstens eine der elektrischen Heizvorrichtungen (41, 42) in einem Innengehäuse (22) und/oder einem Außengehäuse (23) des Stators der Turbomaschine angeordnet ist.

5. Turbomaschine (10) nach Anspruch 4, **dadurch gekennzeichnet, dass** wenigstens eine der elektrischen Heizvorrichtungen (40) an einer Verbindungswand (49) angeordnet ist, die das Innengehäuse (22) mit dem Außengehäuse (23) verbindet.

6. Turbomaschine (10) nach einem der Ansprüche 1 bis 5, **dadurch gekennzeichnet, dass** wenigstens eine der elektrischen Heizvorrichtungen (40, 41, 42, 43, 46) eine Induktionsheizung umfasst.

7. Turbomaschine (10) nach einem der Ansprüche 1 bis 6, **dadurch gekennzeichnet, dass** mehrere elektrische Heizvorrichtungen (40, 41, 42, 46) in axialer Richtung und in Umfangsrichtung um das Gehäuse (22, 23, 49) der Turbomaschine (12) herum verteilt angeordnet sind, und dass verschiedene elektrische Heizvorrichtungen der mehreren elektrischen Heizvorrichtungen (40, 41, 42, 46) so konfiguriert und mit einer Energiequelle verbunden sind, dass sie individuell gesteuert werden können, um die Heizintensi-

tät in Umfangsrichtung und axialer Richtung der Turbomaschine (12) zu steuern.

8. Turbomaschine (10) nach einem der Ansprüche 1 bis 7,
dadurch gekennzeichnet, dass die Turbomaschine (10) eine Gasturbine (10) oder eine Dampfturbine ist. 5

9. Verfahren zum Betreiben einer Turbomaschine (10),
 die einen Stator (22, 23, 45, 49) und einen Rotor (28), der drehbar im Inneren des Stators (22, 23, 49) angeordnet ist, und elektrische Heizvorrichtungen (40, 41, 42, 43), die auf einer Oberfläche wenigstens eines Teils des Stators (22, 23, 45, 49) angeordnet sind, umfasst, wobei der Stator ein Gehäuse aufweist; 10
dadurch gekennzeichnet, dass
 die wenigstens eine elektrische Heizvorrichtung (40, 41, 42, 43) gesteuert wird, um wenigstens den Teil des Stators (22, 23, 45, 49) zu erwärmen, um einen Spalt zwischen dem Rotor (28) und dem Stator (22, 23, 45, 49) zu steuern/regeln, und dass wenigstens eine der elektrischen Heizvorrichtungen eine elektrische Heizvorrichtung (46) für einen Lagerträger ist, die auf einem Lagerträger (45) angeordnet ist und dazu verwendet wird, durch gesteuertes Erwärmen des Lagerträgers (45) den Rotor (28) relativ zu dem Gehäuse (22, 23, 49) zentral ausgerichtet zu halten, und 20
 wenigstens eine der elektrischen Heizvorrichtungen (42) so angeordnet ist, dass sie einen Flansch erwärmt, der eine untere Gehäusehälfte und eine obere Gehäusehälfte verbindet, um eine Ovalisierung des Gehäuses (22, 23, 49) zu reduzieren oder zu vermeiden. 25 30 35

10. Verfahren nach Anspruch 9, **dadurch gekennzeichnet, dass** wenigstens eine elektrische Heizvorrichtung (40, 41, 42, 43) an einer Position auf der oberen Gehäusehälfte (22, 23, 49) oder der unteren Gehäusehälfte (22, 23, 49) angeordnet ist, und dass sie so gesteuert wird, dass sie einen Bereich des Gehäuses (22, 23, 49) erwärmt, auf dem sie angeordnet ist, um eine Inhomogenität der Umfangstemperatur im Gehäuse (22, 23, 49) zu reduzieren. 40 45

11. Verfahren nach Anspruch 9 oder 10, **dadurch gekennzeichnet, dass** die wenigstens eine elektrische Heizvorrichtung (40, 41, 42, 43) gesteuert wird, um ein Temperaturprofil des Gehäuses (22, 23, 49) der Turbomaschine (10) in axialer Richtung innerhalb eines vorgegebenen Bereichs zu halten. 50

12. Verfahren nach einem der Ansprüche 9 bis 11, **dadurch gekennzeichnet, dass** wenigstens eine der elektrischen Heizvorrichtungen (40, 41, 42, 43) an einer Position auf der unteren Gehäusehälfte (22, 23, 49) angeordnet ist, und dass sie zum Heizen während des Abschaltens und Kühlens der Turbomaschine verwendet wird, um einen Anstieg der Temperatur der oberen Gehäusehälfte (22, 23, 49) relativ zu der Temperatur der unteren Gehäusehälfte (22, 23, 49) aufgrund einer konvektiven Wärmeübertragung von der unteren Gehäusehälfte (22, 23, 49) zu der oberen Gehäusehälfte (22, 23, 49) zu kompensieren, um ein Ausbeulen zu vermindern. 55

23, 49) angeordnet ist, und dass sie zum Heizen während des Abschaltens und Kühlens der Turbomaschine verwendet wird, um einen Anstieg der Temperatur der oberen Gehäusehälfte (22, 23, 49) relativ zu der Temperatur der unteren Gehäusehälfte (22, 23, 49) aufgrund einer konvektiven Wärmeübertragung von der unteren Gehäusehälfte (22, 23, 49) zu der oberen Gehäusehälfte (22, 23, 49) zu kompensieren, um ein Ausbeulen zu vermindern.

13. Verfahren nach einem der Ansprüche 9 bis 12, **dadurch gekennzeichnet, dass** der wenigstens einen elektrischen Heizvorrichtung (40, 41, 42, 43) Strom zugeführt wird, basierend auf einem der folgenden Aspekte:

- Erwärmen gemäß einem Zeitplan
- Erwärmen in Abhängigkeit von einem Betriebsparameter der Turbomaschine (10), wie z.B. der Drehzahl, der Leistung, einem Massenstrom oder einer Betriebstemperatur
- Heizen zur Steuerung/Regelung der Temperatur wenigstens eines Abschnitts des Gehäuses (22, 23, 49) auf der Grundlage einer Temperaturmessung
- direktes Messen des Spalts mit einem Schaufelspalt-Geber (20) und/oder einem Leitschau-felspalt-Geber (21), und Heizen zur Steuerung/Regelung des gemessenen Spalts
- Schließen eines Einlasses und/oder eines Auslasses der Turbomaschine (10) während des Stillstands der Turbomaschine (10), um einen Fluidstrom und eine Wärmeübertragung auf das Fluid in der Turbomaschine (10) zu reduzieren.

Revendications

1. Turbomachine (10) comprenant un stator (22, 23, 45, 49) et un rotor (28) agencé de manière rotative à l'intérieur du stator (22, 23, 45, 49) et des dispositifs électriques chauffants (40, 41, 42, 43, 46) agencés sur une surface d'au moins une partie du stator (22, 23, 45, 49) pour le contrôle des jeux, le stator comprenant un carter ;
caractérisé en ce qu'au moins un des dispositifs électriques chauffants est un dispositif électrique chauffant (46) de support de palier agencé sur un support de palier (45) pour chauffer le support de palier afin de maintenir le rotor (28) aligné au centre par rapport au carter, et
 au moins l'un des dispositifs électriques chauffants (42) est agencé pour chauffer une bride reliant un demi-carter inférieur et un demi-carter supérieur pour réduire ou éviter l'ovalisation du carter (22, 23, 49).

2. Turbomachine (12) selon la revendication 1, **caractérisée en ce qu'**au moins l'un des dispositifs électriques chauffants (40, 41, 42, 43, 46) est agencé dans une cavité du stator (22, 23, 45, 49) pour chauffer un fluide qui entoure au moins partiellement la partie de stator (22, 23, 45, 49) et/ou **en ce qu'**au moins l'un des dispositifs électriques chauffants (40, 41, 42, 43, 46) est agencé en contact mécanique direct sur la partie de stator (22, 23, 45, 49) pour permettre un transfert de chaleur par conduction du dispositif électrique chauffant (40, 41, 42, 43, 46) vers le stator (22, 23, 45, 49).
3. Turbomachine (10) selon la revendication 1 ou 2, **caractérisée en ce qu'**au moins l'un des dispositifs électriques chauffants (40, 41, 42, 43, 46) est agencé dans un alésage d'alimentation en air de refroidissement du stator (22, 23, 49).
4. Turbomachine (10) selon l'une des revendications 1 à 3, **caractérisée en ce qu'**au moins l'un des dispositifs électriques chauffants (41, 42) est agencé dans un carter interne (22) et/ou un carter externe (23) du stator de la turbomachine.
5. Turbomachine (10) selon la revendication 4, **caractérisée en ce qu'**au moins l'un des dispositifs électriques chauffants (40) est agencé sur une paroi de raccordement (49) raccordant le carter interne (22) au carter externe (23).
6. Turbomachine (10) selon l'une des revendications 1 à 5, **caractérisée en ce qu'**au moins l'un des dispositifs électriques chauffants (40, 41, 42, 43, 46) comprend un chauffage par induction.
7. Turbomachine (10) selon l'une des revendications 1 à 6, **caractérisée en ce qu'**une pluralité des dispositifs électriques chauffants (40, 41, 42, 46) est agencée répartie dans des directions axiales et circonférentielles autour du carter (22, 23, 49) de la turbomachine (12) et **en ce que** des dispositifs électriques chauffants distincts de la pluralité des dispositifs électrique chauffants (40, 41, 42, 46) sont configurés et connectés à une source d'alimentation électrique de telle sorte qu'ils peuvent être contrôlés individuellement pour contrôler l'intensité de chauffage dans la direction circonférentielle et axiale de la turbomachine (12).
8. Turbomachine (10) selon l'une des revendications 1 à 7, **caractérisée en ce que** la turbomachine (10) est une turbine à gaz (10) ou une turbine à vapeur.
9. Procédé de commande d'une turbomachine (10) comprenant un stator (22, 23, 45, 49) et un rotor (28) agencé de manière rotative à l'intérieur du stator (22, 23, 49) et des dispositifs électriques chauffants (40, 41, 42, 43) agencés sur une surface d'au moins une partie du stator (22, 23, 45, 49), le stator comprenant un carter ;
caractérisé en ce que l'au moins un dispositif électrique chauffant (40, 41, 42, 43) est contrôlé pour chauffer l'au moins une partie du stator (22, 23, 45, 49) pour contrôler un jeu entre le rotor (28) et le stator (22, 23, 45, 49), et **en ce que** au moins l'un des dispositifs électriques chauffants est un dispositif électrique chauffant (46) de support de palier agencé sur un support de palier (45) et est utilisé pour maintenir le rotor (28) aligné au centre par rapport au carter (22, 23, 49) par chauffage contrôlé du support de palier (45), et au moins l'un des dispositifs électriques chauffants (42) est agencé pour chauffer une bride raccordant un demi-carter inférieur et un demi-carter supérieur pour réduire ou éviter l'ovalisation du carter (22, 23, 49).
10. Procédé selon la revendication 9, **caractérisé en ce qu'**au moins un dispositif électrique chauffant (40, 41, 42, 43) est agencé dans une position sur le demi-carter supérieur (22, 23, 49) ou le demi-carter inférieur (22, 23, 49) et **en ce qu'**il est contrôlé pour chauffer une région du carter (22, 23, 49) sur laquelle il est agencé pour réduire le défaut d'homogénéité de la température circonférentielle dans le carter (22, 23, 49).
11. Procédé selon la revendication 9 ou 10, **caractérisé en ce que** l'au moins un dispositif électrique chauffant (40, 41, 42, 43) est contrôlé pour maintenir un profil de température du carter (22, 23, 49) de la turbomachine (10) dans une direction axiale au sein d'une plage prédéterminée.
12. Procédé selon l'une des revendications 9 à 11, **caractérisé en ce qu'**au moins l'un des dispositifs électriques chauffants (40, 41, 42, 43) est agencé dans une position sur le demi-carter inférieur (22, 23, 49) et **en ce qu'**il est utilisé pour chauffer au cours de l'arrêt et du refroidissement de la turbomachine pour compenser une augmentation de la température du demi-carter supérieur (22, 23, 49) par rapport à la température du demi-carter inférieur (22, 23, 49) due au transfert de chaleur par convection du demi-carter inférieur (22, 23, 49) vers le demi-carter supérieur (22, 23, 49) pour atténuer le flambage.
13. Procédé selon l'une des revendications 9 à 12, **caractérisé en ce qu'**une puissance électrique est fournie à l'au moins un dispositif électrique chauffant (40, 41, 42, 43) sur la base d'un des éléments suivants :
- chauffage selon un plan d'exécution

- chauffage en fonction d'un paramètre d'exploitation de la turbomachine (10) tel que la vitesse, la puissance, un débit massique ou une température d'exploitation
- chauffage pour contrôler la température d'au moins une section du carter (22, 23, 49) sur la base d'une mesure de température 5
- mesure directe du jeu avec un transducteur de jeu entre les pales (20) et/ou un transducteur de jeu entre les aubes (21) et chauffage pour contrôler le jeu mesuré 10
- fermeture d'une entrée et/ou d'une sortie de la turbomachine (10) au cours d'une période d'arrêt de la turbomachine (10) pour réduire un écoulement de fluide et un transfert de chaleur vers le fluide dans la turbomachine (10). 15

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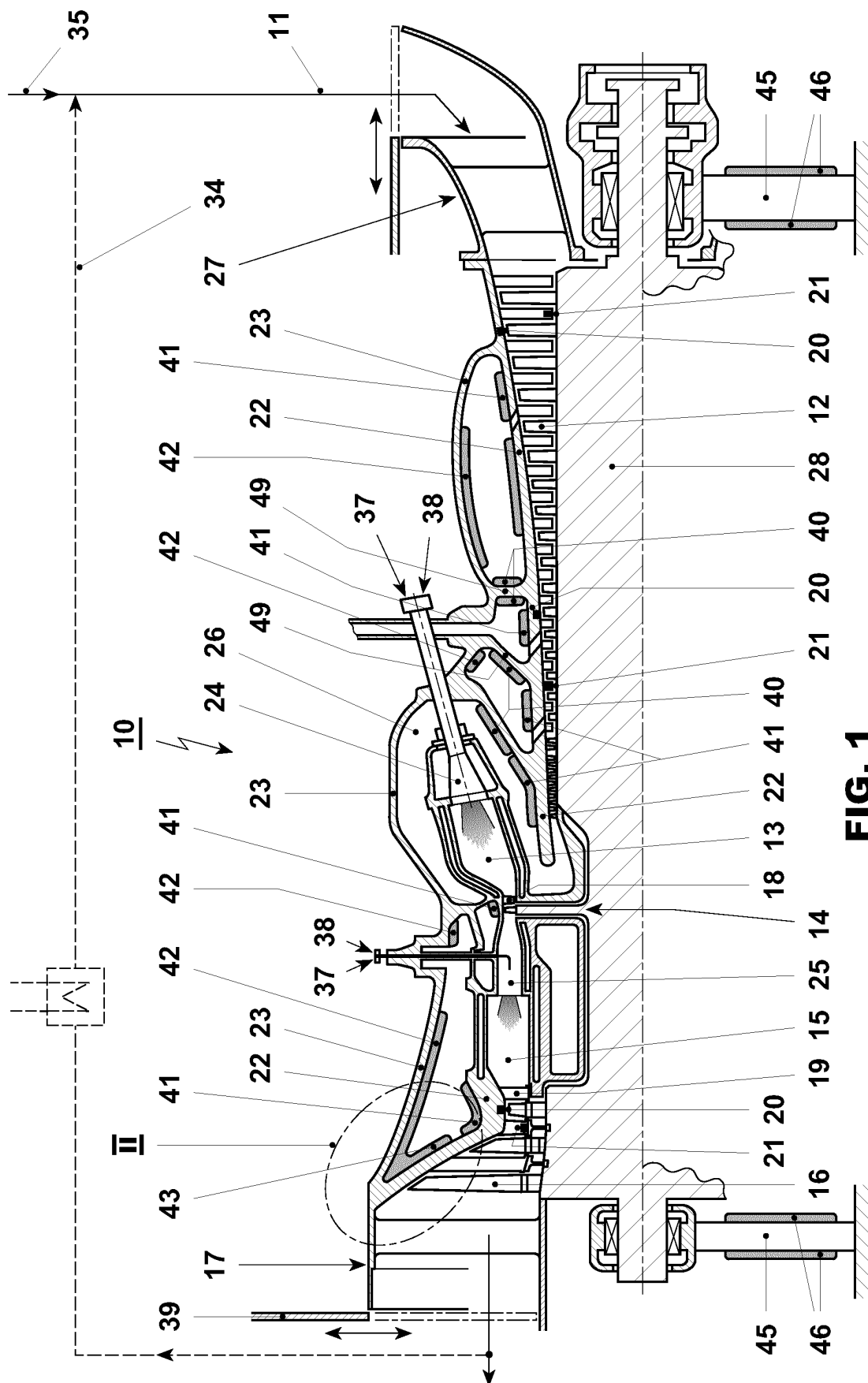
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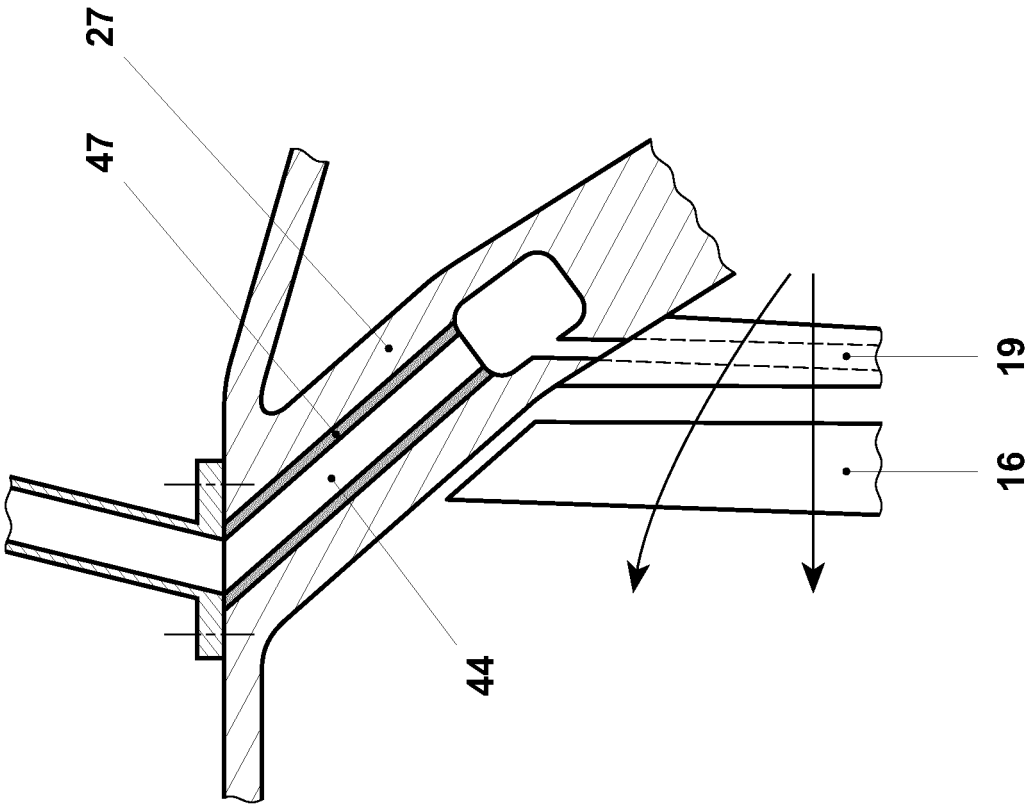


FIG. 2

REFERENCES CITED IN THE DESCRIPTION

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