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(54) **Turbomachine with active electrical clearance control and corresponding method**

(57) The disclosure relates to a turbo-machine (10) comprising a stator (22, 23, 45, 49) and a rotor (28) arranged rotatable inside the stator (22, 23, 45, 49) as well as at least one electric heating device (40, 41, 42, 43, 46), which is arranged on the surface of at least part of

the stator (22, 23, 45, 49) for active clearance control.

Besides the turbo-machine a method for operating the active clearance control comprising electric heating devices is disclosed.

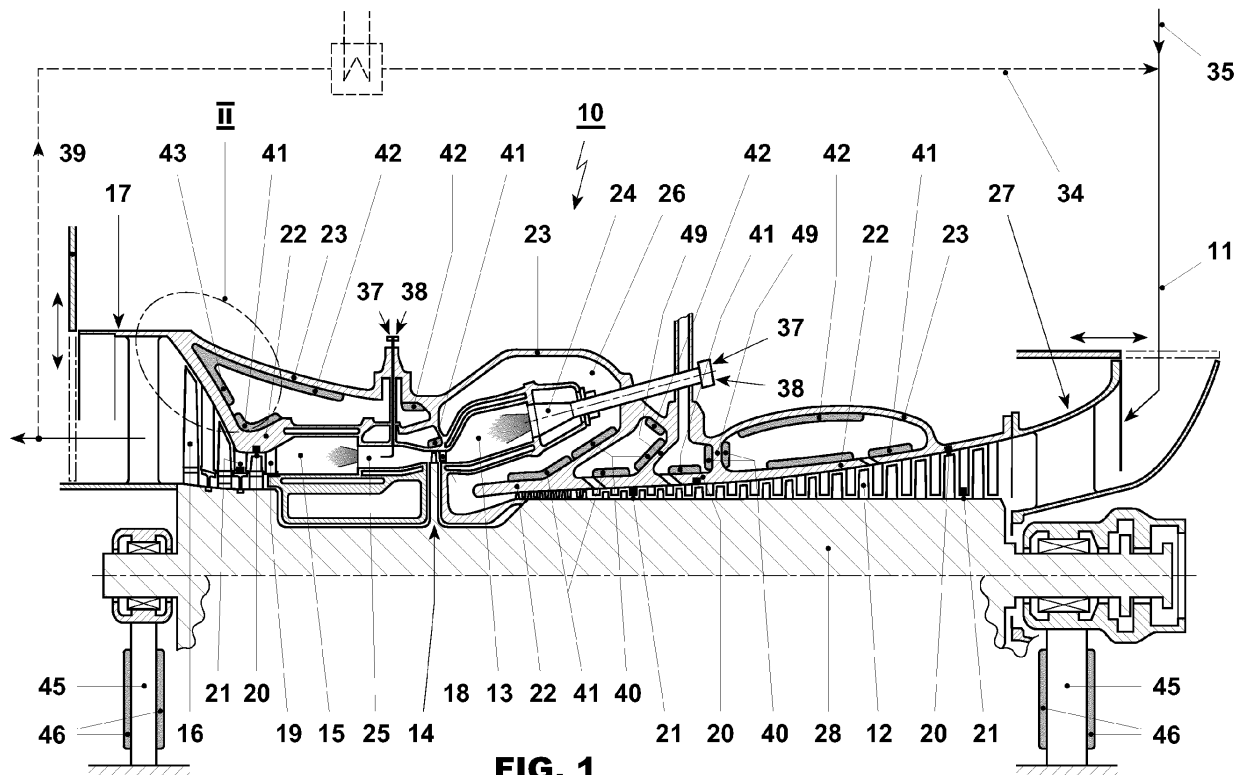


FIG. 1

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.

Summary of the invention

[0005] 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.

[0006] Active 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. Clearances can be reduced by active clearance control in order to increase the efficiency and power of the turbo-machine.

[0007] 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.

[0008] 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.

[0009] 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.

[0010] 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.

[0011] 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.

[0012] 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.

[0013] According to one embodiment the turbo-machine is a gas turbine and according to another embodiment the turbo-machine is a steam turbine. 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.

[0014] 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.

[0015] 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.

[0016] 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.

[0017] 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.

[0018] 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.

[0019] 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.

[0020] 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.

[0021] 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.

[0022] 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.

[0023] 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.

[0024] 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.

[0025] 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.

[0026] 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. 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.

[0027] 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 com-

bustion gas turbine or a sequential combustion gas turbine.

Brief description of the drawing

[0028] 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

[0029] 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.

[0030] 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 25 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.

[0031] Steam and/or water 38 can be injected into the first and/or sequential burner for emission control and to increase the power output.

[0032] 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.

[0033] 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.

[0034] 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.

[0035] 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.

[0036] 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).

[0037] 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 recoler for cooling the recirculated flue gas.

[0038] Further, the compressor inlet can be closed by an inlet shutter 36 and the turbine exit can be closed by an outlet shutter 39.

[0039] 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

[0040]

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 5
- 44 cooling air supply bore
- 45 bearing support
- 46 bearing support heating device
- 47 exhaust gas
- 49 connecting wall 10

Claims

1. Turbo-machine (10) comprising a stator (22, 23, 45, 49) and a rotor (28) arranged rotatable inside the stator (22, 23, 45, 49) **characterized in that** at least one electric heating device (40, 41, 42, 43, 46) is arranged on the surface of at least part of the stator (22, 23, 45, 49) for clearance control. 15
2. Turbo-machine (12) according claim 1 **characterized in that** the electrical heating device (40, 41, 42, 43, 46) is arranged in a cavity of the stator part (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** the electrical heating device (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 part (22, 23, 45, 49). 20 25 30
3. Turbo-machine (10) according claim 1 or 2 **characterized in that** the electrical heating device (40, 41, 42, 43, 46) is arranged in a cooling air supply bore of the stator (22, 23, 49). 35
4. Turbo-machine (10) according to one of the claim 1 to 3 **characterized in that** the stator part on which the electrical heating device (41, 42) is arranged is an inner and/or outer casing (22, 23) of the turbo-machine. 40
5. Turbo-machine (10) according to one of the claim 1 to 4 **characterized in that** the electrical heating device (40) is arranged on a connecting wall (49) connecting the inner casing (22) with the outer casing (23). 45
6. Turbo-machine (10) according to one of the claim 1 to 5 **characterized in that** the electrical heating device (40, 41, 42, 43, 46) comprises an induction heating. 50
7. Turbo-machine (10) according to one of the claim 1 to 6 **characterized in that** a plurality of electrical heating devices (40, 41, 42, 46) is arranged distributed in axial and circumferential direction around the casing (22, 23, 49) of the turbo-machine (12) and **in that** 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 (12). 55
8. Turbo-machine (10) according to one of the claim 1 to 7 **characterized in that** at least one bearing support electrical heating device (46) is arranged on a bearing support (45). 10
9. Turbo-machine (10) according to one of the claim 1 to 8 **characterized in that** the turbo-machine (10) is a gas turbine 10) or a steam turbine. 15
10. Method for operating a turbo-machine (10) comprising a stator (22, 23, 45, 49) and a rotor (28) arranged rotatable inside the stator (22, 23, 49) and at least one electric heating device (40, 41, 42, 43) arranged on the surface of at least part of the stator (22, 23, 45, 49) **characterized in that** the at least one electric heating device (40, 41, 42, 43) is controlled to heat the at least a part of the stator (22, 23, 45, 49) for controlling the clearance between the rotor (28) and the stator (22, 23, 45, 49). 20 25 30
11. Method according to claim 10 **characterized in that** at least one electrical heating device (40, 41, 42, 43) is arranged at position on the upper or lower half of the casing (22, 23, 49) and **in that** it is controlled to heat the region of the casing (22, 23, 49) on which it is arranged to reduce circumferential temperature inhomogeneity in the casing (22, 23, 49). 35
12. Method according to claim 10 or 11 **characterized in that** the at least one electrical heating device (40, 41, 42, 43) is controlled to keep the temperature profile of the turbo-machine's casing (22, 23, 49) in axial direction within a predetermined range. 40
13. Method according to one of the claims 10 to 12 **characterized in that** at least one electrical heating device (40, 41, 42, 43) is arranged at a position on the lower half of the 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 of the casing (22, 23, 49) relative to the temperature of the lower half of the casing (22, 23, 49) due to convective heat transfer from the bottom to the top half to mitigate buckling, and/or at least one electrical heating device (42) is arranged to heat a flange connecting the lower and upper half casing to reduce or avoid ovalisation of the casing (22, 23, 49). 45 50 55
14. Method according to one of the claims 10 to 13 **characterized in that** at least one bearing support electrical heating device (46) arranged on a bearing support (45). 60

port (45) is used to keep the rotor (28) centrally aligned relative to the casing (22, 23, 49) by controlled heating of the bearing support (45).

15. Method according to one of the claims 10 to 14 **characterized in that** the power supplied to the at least one electric heating device (40, 41, 42, 43) is based on one of the following:

- heating according to a schedule 10
- 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 15
- 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 20
- closing the inlet and/or the outlet of the turbo-machine (10) during standstill of the turbo-machine (10) to reduce a fluid flow and heat transfer to the fluid in the turbo-machine (10). 25

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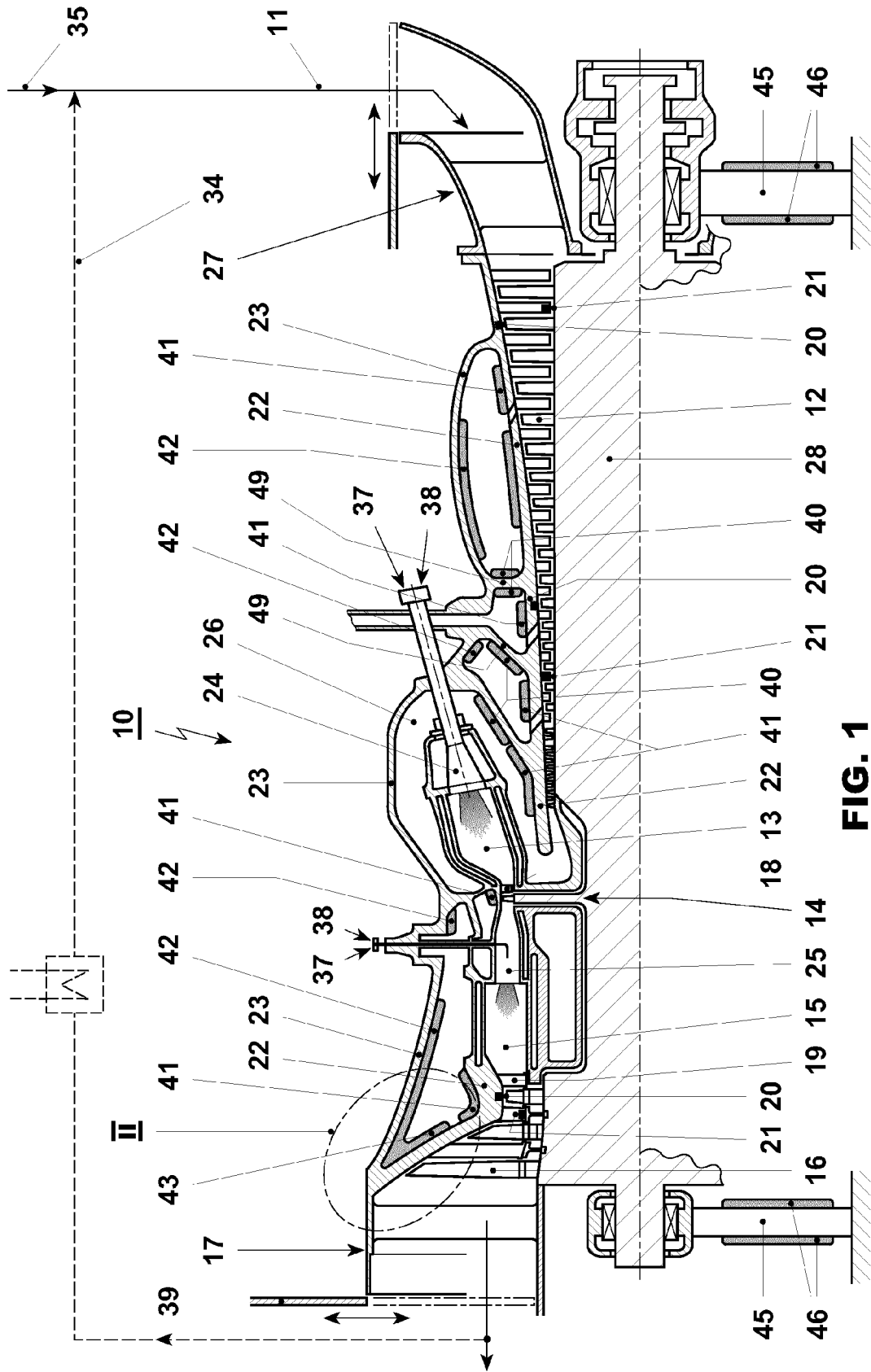


FIG. 1

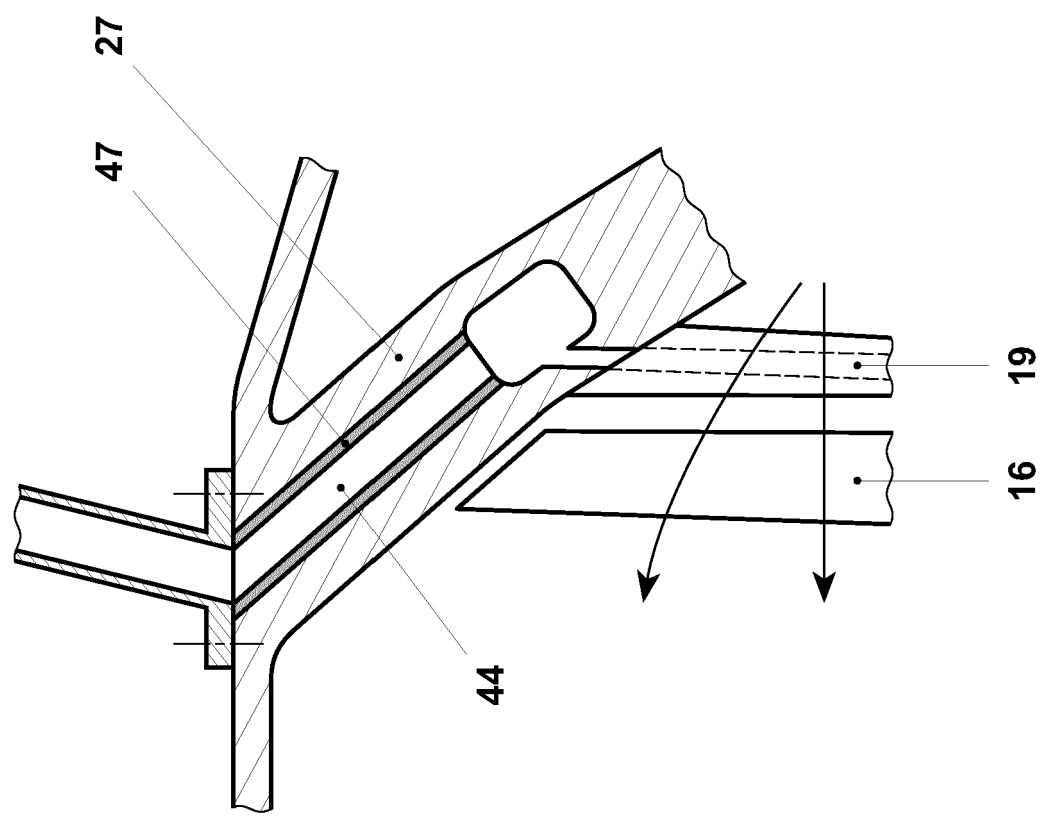


FIG. 2



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