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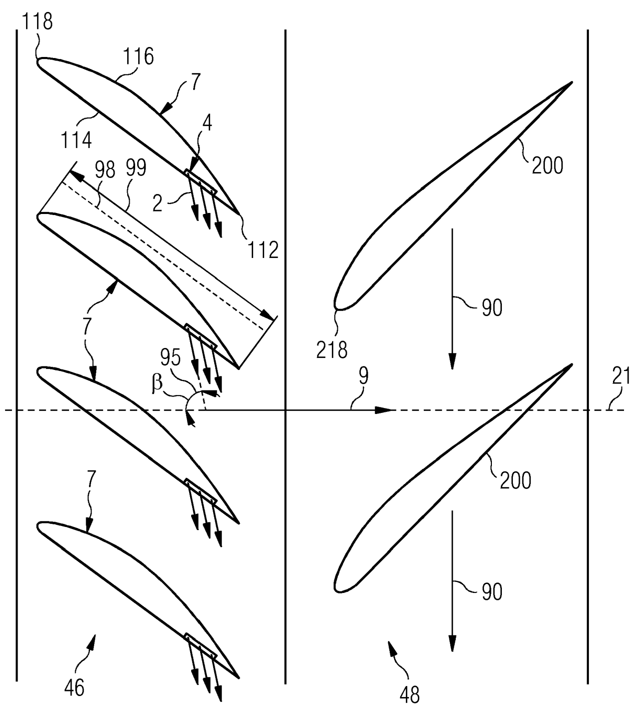
(54) **GAS TURBINE ENGINE CONTROL METHOD AND SYSTEM**

(57) A method (100) and system for controlling rotor blade resonant frequencies in a compressor (14) for a gas turbine engine (10). A flow injection (2) is introduced into an axial air flow path (56) of the compressor (14) via a flow-injection opening (4) located at a pressure side (114) of at least one guide vane (7) of a plurality of guide vanes (7) forming a guide vane stage (46) in the compressor (14). The flow injection (2) is directed towards a neighbouring guide vane (7) located adjacent the guide vane (7) having the flow-injection opening (4). The flow injection is introduced at a predetermined operating condition to thereby enhance vane flow mixing and thereby reduce flow induced vibrations of a rotor blade (200) downstream of the vanes (7).

FIG 2



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Description

[0001] The present disclosure relates to controlling rotor blade resonant frequencies in a compressor for a gas turbine engine.

[0002] In particular the disclosure is concerned with a method and system for controlling rotor blade resonant frequencies in a compressor for a gas turbine engine.

Background

[0003] In a compressor operating under normal, i.e. stable flow conditions, the flow through the compressor is essentially uniform around the annulus, i.e. it is axis-symmetric, and the annulus-averaged flow rate is steady.

[0004] Typically compressors comprise an array of stator vanes upstream of an array of rotor blades. As air flows over the stator vanes the flow will separate from the surface of the vanes causing a turbulent wake which travels downstream to the rotating blades.

[0005] This may cause the rotor blades to vibrate, and if the vibrations excite the blades at a particular frequency then the rotor blades may start to resonate. If the forcing frequencies generated by the wakes of the vanes are maintained then significant blade damage and reduction in performance may occur.

[0006] Although during design of the compressor care is taken to avoid the possibility of such "synchronous" vibrations occurring, vibration response of one or more of the blade rows could turn out to be different than expected.

[0007] Conventionally this is resolved by redesigning the compressor components so that the resonant vibrations do not occur, for example through changing the aerodynamic shape of the blade to change its natural frequency, or by cropping critical regions of the blades, or by controlling the engine so that the engine conditions at which resonant vibrations are expected to occur are avoided. However all of these solutions incur cost, performance penalty and do not guarantee that the problem is ultimately overcome.

[0008] Therefore a method or system which avoids compressor component redesign, and does not restrict operating conditions of the compressor, is highly desirable.

Summary

[0009] According to the present disclosure there is provided a method and system as set forth in the appended claims. Other features of the invention will be apparent from the dependent claims, and the description which follows.

[0010] Accordingly there may be provided a method (100) for controlling rotor blade resonant frequencies in a compressor (14) for a gas turbine engine (10). The method (100) may comprise introducing a flow injection (2) in the compressor (14), wherein the flow injection (2) is introduced into an axial air flow path (56) of the compressor (14) via a flow-injection opening (4) located at a pressure side (114) of at least one guide vane (7) of a plurality of guide vanes (7) forming a guide vane stage (46) in the compressor (14). The flow injection (2) may be directed towards a neighbouring guide vane (7) located adjacent the guide vane (7) having the flow-injection opening (4). The flow injection may be introduced at a predetermined operating condition to thereby enhance vane flow mixing and thereby reduce flow induced vibrations of a rotor blade (200) downstream of the vanes (7).

[0011] The predetermined operational condition may be an engine speed of 75% of maximum operating engine speed.

[0012] The predetermined operational condition may be an engine speed equivalent to at least 70% of ISO maximum engine speed but no more than about 115% of ISO maximum engine speed.

[0013] When the predetermined engine operating condition may comprise a deceleration, the fluid injection (2) mass flow rate increases as the engine speed decreases.

[0014] For every 1% decrease in engine speed, the fluid injection mass flow rate may increase by 0.1 %.

[0015] Flow injection may be selectively introduced from some, but not all, of the vanes (7).

[0016] There may also be provided a system (10) for controlling rotor blade resonant frequencies in a compressor (14) for a gas turbine engine (10). The system (100) may comprise a guide vane stage (46) of the compressor (14), wherein the guide vane stage (46) includes a plurality of guide vanes (7) and wherein at least one of the guide vanes (7) includes a flow-injection opening (4) located at a pressure side (114) of the guide vane (7), the flow-injection opening (4) adapted to introduce a flow injection (2) into an axial air flow path (56) of the compressor (14) and the flow injection (2) is directed towards a neighbouring guide vane (7) located adjacent the guide vane (7) having the flow-injection opening (4). The system may also comprise a controller (60) adapted to : initiate introduction of the flow injection (2) only at a predetermined operating condition of the gas turbine engine (10) to thereby enhance vane flow mixing and thereby reduce flow induced vibrations of a rotor blade (200) downstream of the vanes (7).

[0017] The predetermined operating condition may be defined as a function of engine speed. The system may comprises a sensor (70) for detecting engine speed. The controller (60) may be operable to receive a signal indicative of engine speed from the sensor (70).

[0018] The system may further comprise a flow controlling mechanism (80) adapted to regulate the flow injection (2) emanating from the flow-injection opening (4) of the guide vane (7), and wherein the controller (60) is further adapted to control the flow controlling mechanism (80) to regulate the flow injection (2).

[0019] The flow controlling mechanism (80) may be operable to regulate the flow injection (2) emanating from the flow-injection opening (4) of the guide vane (7) between at least 2% but no more than 5% of mass flow at inlet (12) to the compressor (14).

[0020] The flow-injection opening (4) may be located between a distance A from a trailing edge (112) of the guide vane (7); where distance A has a value of about 5% of a chord length (99) of the guide vane (7); and a distance C from a leading edge (118) of the guide vane (7); where distance C has a value in the range of 65% to 85% of a chord length (99) of the guide vane (7).

[0021] The flow-injection opening (4) may extend from, or may be close to, a base of the guide vane (7) and spans a distance D where distance D may have a value of about 95% of the guide vane.

[0022] The flow-injection opening (4) has a width B; where width B may have a value of between 10 % and 30 % of a chord length (99) of the guide vane (7).

[0023] The flow-injection opening (4) may be adapted to introduce the flow injection (2) into the axial air flow path (56) of the compressor (14) at an angle β (95) between 30 degrees and 60 degrees with respect to an axis (21) parallel to a rotational axis (20) of the compressor (14).

[0024] The flow injection opening (4) may be in fluid communication with a duct which is in turn in fluid communication with a location on the compressor downstream of the location of the guide vane (7) with respect to an axial flow direction (9) of air in the compressor (14) such that flow from the downstream region is delivered to the fluid injection opening (4).

[0025] Hence there is provided a method and system for controlling rotor blade resonant frequencies in a compressor by injecting flow between adjacent guide vanes such that the flow is injected from one vane towards a neighbouring vane to reduce vane trailing edge wake.

[0026] By injecting flow from the pressure side of a stator vane and directing it towards the neighbouring stator vane, flow mixing is enhanced which reduces vane flow separation and/or strength of a vane trailing edge wake which in turn reduces the amplitude of the resulting forcing on the downstream rotor blade, and hence reduces the rotor blades subsequent vibration response.

[0027] Hence there is provided a means of controlling rotor blade dynamic response at predetermined engine operating conditions thus extending rotor blade life by avoiding rotor blade resonant frequencies, or at least the duration for which such frequencies are generated.

Brief Description of the Drawings

[0028] Examples of the present disclosure will now be described with reference to the accompanying drawings, in which:

Figure 1 shows part of a gas turbine engine in a sectional view and in which an exemplary embodiment of a method of the present technique is applied, and in which an exemplary embodiment of a system of the present technique is incorporated;

Figure 2 is a schematic view of an array of state vanes and rotor blades according to the present disclosure;

Figure 3 is a side view of a stator vane according to the present disclosure;

Figure 4 shows a schematic view of an example of a stator vane array operable for injection flow according to the present disclosure;

Figure 5 is a schematic view showing operation and effect of injection flow; and

Figure 6 illustrates a method of control according to the present disclosure.

Detailed Description

[0029] Figure 1 shows an example of a gas turbine engine 10 in a sectional view. The gas turbine engine 10 comprises, in flow series, an inlet 12, a compressor or compressor section 14, a combustor section 16 and a turbine section 18 which are generally arranged in flow series and generally about and in the direction of a rotational axis 20. The gas turbine engine 10 further comprises a shaft 22 which is rotatable about the rotational axis 20 and which extends longitudinally through the gas turbine engine 10. The shaft 22 drivingly connects the turbine section 18 to the compressor section 14.

[0030] In operation of the gas turbine engine 10, air 24, which is taken in through the air inlet 12 is compressed by the compressor 14 and delivered to the combustion section or burner section 16. The burner section 16 comprises a burner plenum 26, one or more combustion chambers 28 extending along a longitudinal axis 35 and at least one burner 30 fixed to each combustion chamber 28. The combustion chambers 28 and the burners 30 are located inside the burner plenum 26. The compressed air passing through the compressor 14 enters a diffuser 32 and is discharged from the diffuser 32 into the burner plenum 26 from where a portion of the air enters the burner 30 and is mixed with a gaseous or liquid fuel. The air/fuel mixture is then burned and the combustion gas 34 or working gas from the combustion is channelled through the combustion chamber 28 to the turbine section 18 via a transition duct 17.

[0031] This exemplary gas turbine engine 10 has a cannular combustor section arrangement 16, which is constituted by an annular array of combustor cans 19 each having the burner 30 and the combustion chamber 28, the transition duct 17 has a generally circular inlet that interfaces with the combustor chamber 28 and an outlet in the form of an annular segment. An annular array of transition duct outlets form an annulus for channelling the combustion gases to the turbine 18.

[0032] The turbine section 18 comprises a number of blade carrying discs 36 attached to the shaft 22. In the present example, two discs 36 each carry an annular array of turbine blades 38 are shown. However, the number of blade carrying discs could be different, i.e. only one disc or more than two discs. In addition, guiding vanes 40, which are fixed to a stator 42 of the gas turbine engine 10, are disposed between the stages of annular arrays of turbine blades 38. Between the exit of the combustion chamber 28 and the leading turbine blades 38 inlet guiding vanes 44 are provided and turn the flow of working gas onto the turbine blades 38.

[0033] The combustion gas 34 from the combustion chamber 28 enters the turbine section 18 and drives the turbine blades 38 which in turn rotate the shaft 22. The guiding vanes 40, 44 serve to optimise the angle of the combustion or working gas 34 on the turbine blades 38.

[0034] The turbine section 18 drives the compressor 14, i.e. particularly a compressor rotor. The compressor 14 comprises an axial series of vane stages 46, or guide vane stages 46, and rotor blade stages 48. The rotor blade stages 48 comprise a rotor disc supporting an annular array of blades. The compressor 14 also comprises a casing 50 that surrounds the rotor blade stages 48 and supports the guide vane stages 46. The guide vane stages 46 include an annular array of radially extending guide vanes 7 (not shown in Figure 1) that are mounted to the casing 50. The guide vanes 7, hereinafter also referred to as the vanes 7, are provided to present gas flow at an optimal angle for the blades of the rotor blade stage 48 that is present adjacent to and downstream of, with respect to a flow direction of the air 24 along the compressor 14 at a given engine operational point.

[0035] Some of the guide vane stages 46 have variable guide vanes 7 (not shown in Figure 1), where the angle of the guide vanes 7, about their own longitudinal axis (not shown), can be adjusted for angle according to air flow characteristics that can occur at different engine operations conditions. Some of the other guide vane stages 46 have stationary guide vanes 7 (not shown in Figure 1) where the angle of the guide vanes 7, about their own longitudinal axis, is fixed and thus not adjustable for angle. The guide vanes 7 i.e. the stationary and the variable guide vanes are well known in the art of compressors 14 and thus have not been described herein in detail for sake of brevity.

[0036] The casing 50 defines a radially outer surface 52 of the passage 56 of the compressor 14. The guide vane stages 46 and the rotor blade stages 48 are arranged in the passage 56, generally alternately axially. The passage 56 defines a flow path for the air through the compressor 14 and is also referred to as an axial flow path 56 of the compressor 14. The air 24 coming from the inlet 12 flows over and around the guide vane stages 46 and the rotor blade stages 48. A radially inner surface 54 of the passage 56 is at least partly defined by a rotor drum 53 of the rotor which is partly defined by the annular array of blades.

[0037] The present method and system is described with reference to the above exemplary turbine engine having a single shaft or spool connecting a single, multi-stage compressor and a single, one or more stage turbine. However, it should be appreciated that the present system and method is equally applicable to two or three shaft engines and which can be used for industrial, aero or marine applications. Furthermore, the cannular combustor section arrangement 16 is also used for exemplary purposes and it should be appreciated that the present technique is equally applicable to gas turbine engines 10 having annular type and can type combustion chambers.

[0038] The terms axial, radial and circumferential are made with reference to the rotational axis 20 of the engine, unless otherwise stated.

[0039] A schematic view of the compressor 14 the guide vane stage 46 and the rotor blade stage 48 are shown in Figure 2. The guide vane stage 46, hereinafter also referred to as the vane stages 46, may be variable guide vane stages 46 having a plurality of variable guide vanes (VGVs) 7, or may be stationary guide vane stages 46 having a plurality of stationary guide vanes (SGVs) 7. The VGV stages 46 are generally present in initial stages of the compressor 14 for example in first, second and third stages, whereas the SGV stages 46 are generally present in later stages of the compressor 14, for example in fourth to tenth stages of the compressor 14. The guide vanes 7, hereinafter also referred to as the vane 7 or vanes 7, are arranged in a row forming the vane stage 46.

[0040] The vane 7 has a pressure side 114, suction side 116, a leading edge 118 and a trailing edge 112. In Figures 2, 3 a chord of the vane 7 has been represented by a dotted line 98 and a chord length by the arrow marked by reference numeral 99.

[0041] In Figure 2 only one vane stage 46 of the compressor 14 and only one rotor blade stage 48, hereinafter also referred to as the blade stage 48, located immediately downstream with respect to an axial direction 9 of the air flow has been depicted. However in general the compressor 14 comprises a plurality of vane stages 46 and blade stages 48. The blade stage 48 comprises of a row of compressor rotor blades 200, hereinafter also referred to as the blades 200.

[0042] When the gas turbine engine 10 is operational, air 24 (shown in Figure 1) enters through the inlet 12 and is guided by the first set of vane stage 46, i.e. by the vanes 7, towards the downstream located blades 200. The blades 200 rotate about the axis 20 (shown in Figure 1) for compressing the air 24 as it passes through the axial air flow path 56 of the compressor 14. A direction of rotation of the blades 200 has been depicted in Figure 2 with an arrow marked by reference numeral 90.

[0043] A side view of a vane 7 according to the present disclosure is shown in Figure 3, of which one or more may be provided in the guide vane stage 46 of the compressor 14. The vane 7 is provided with a flow-injection opening 4 located at a pressure side 114 of the guide vane 7. The flow-injection opening 4, hereinafter also referred to as the opening 4, is configured to introduce a flow injection 2 into the axial air flow path 56 (shown in

Figures 1, 2) of the compressor 14. As described below the flow injection 2 is configured to inject flow to control rotor blade resonant frequencies in the compressor.

[0044] The opening 4 may be understood as a hole that is supplied by air from within the vane 7 and that injects air so supplied into the flow path 56.

[0045] The opening 4 may have any suitable shape, although in the example shown is rectangular. The opening 4 may be provided as a slot or hole defined by walls of the pressure side 114. The slot may comprise a continuous aperture along the height of the opening 4, or comprise a plurality of smaller apertures (not shown) arranged substantially in alignment with one another along the height of the opening 4.

[0046] That is to say, the opening 4 may be present in form of smaller openings (not shown) for example as an array of small holes or openings that together function to produce one or more jets together forming the flow injection 2.

[0047] The air used for forming the flow injection 2, i.e. the air injected into the flow path 56 via the opening 4 may be channelled from a location downstream, with respect to the axial flow direction 9, of a location of the guide vane 7 from within the compressor 14. Alternatively, the air forming the flow injection 2 may be supplied from an outside source (not shown) for example a pressurized air tank.

[0048] The air is generally sent from the casing 50 (shown in Figure 1), i.e. from pathways or passages or channels (not shown) in the casing 50 through the body of the vane 7 and out into the flow path 56 via the opening 4 in form of one or more jets of air. Generally the air injected into the flow path 56 is at same or higher pressure than the pressure of the flow path 56 at the location of the guide vane 7 having the opening 4.

[0049] That is to say, the flow injection opening 4 may be in fluid communication with a duct (not shown) which is in turn in fluid communication with a location on the compressor downstream of the location of the guide vane 7 with respect to an axial flow direction 9 of air in the compressor 14 such that flow from the downstream region is delivered to the fluid injection opening 4. The axial flow direction 9 is aligned with an axis 21 parallel to a rotational axis 20 of the compressor 14.

[0050] As shown in Figure 3, the flow-injection opening 4 may be located between a distance A from a trailing edge 112 of the guide vane 7, where distance A has a value of about 5% of a chord length 99 of the guide vane 7 and a distance C from a leading edge 118 of the guide vane 7, where distance C has a value in the range of 65% to 85% of a chord length 99 of the guide vane 7.

[0051] The flow-injection opening 4 may extend from, or close to, a base of the guide vane 7 and spans a distance D where distance D has a value of about 95% of the guide vane.

[0052] The flow-injection opening 4 has a width B may have a value of between 10% and 30% of a chord length 99 of the guide vane 7.

[0053] As shown in Figures 2, 5 the flow-injection opening 4 may be adapted to introduce the flow injection 2 into the axial air flow path 56 of the compressor 14 at an angle 95 (i.e. "β") between 30 degrees and 60 degrees with respect to the axis 21 parallel to the rotational axis 20 of the compressor 14. In this way the flow injection 2 is directed towards a suction surface 116 of a neighbouring guide vane 7 located adjacent the guide vane 7 having the flow-injection opening 4.

[0054] Furthermore, the flow injection 2 is preferably angular to a surface of the pressure side 114 and not perpendicular to the surface of the pressure side 114. The angular flow injection 2 may be achieved by physical dimensions of the opening 4 for example by forming the opening 4 slanted in within the body of the vane 7.

[0055] An example of a part of the system 1 of the present disclosure is shown in Figure 4. The system 1 includes an array/stage 46 of guide vanes 7, and a controller 60. The guide vane 7 is same as the vane 7 explained in reference to Figures 2, 3.

[0056] The controller 60 determines a condition for introducing flow injection 2 in the compressor 14 during operation of the gas turbine engine 10. The controller 60 may be a processor, e.g. a microprocessor, a programmable logic controller (PLC).

[0057] The controller 60 is also operable to initiate introduction of the flow injection 2 only at a predetermined operating condition of the gas turbine engine 10 to thereby enhance vane flow mixing and thereby reduce (that is to say "limit" and/or control) flow induced vibrations of a rotor blade downstream of the vanes.

[0058] The controller 60 initiates the introduction of the flow injection 2 when the condition for introducing flow injection 2 in the compressor 14 is determined.

[0059] The predetermined operating condition may be defined as a function of engine speed.

[0060] Hence, as shown in Figure 4, the system may also comprise a sensor 70 for detecting engine speed. In such an example, the controller 60 is operable to receive a signal indicative of engine speed from the sensor 7.

[0061] The controller 60 receives the engine speed signal, and based on this signal may initiate the introduction of the flow injections 2 at one or multiple axial locations within the compressor 14.

[0062] Furthermore, the system 1 may include a flow controlling mechanism 80 that regulates the flow injection 2, i.e. starts the flow injection 2, and/or stops the flow injection 2, and/or decreases and/or increases strength of the flow injection 2 i.e. rate of flow of air forming the flow injection 2.

[0063] The flow controlling mechanism 80 is operable to regulate the total flow injection 2 emanating from the or each flow-injection opening 4 of the or all vane(s) 7 between at least 2% but no more than 5% of mass flow at inlet 12 to the compressor.

[0064] Thus controller 60 controls or directs the flow controlling mechanism 80 to regulate the flow injection

2. As shown in Figure 4, the flow controlling mechanism 80 may include control valves 82, but the main additionally or alternatively include actuators and other equipment required to regulate the flow injection.

[0065] In general mechanisms such as the flow controlling mechanism 80, that regulate a flow of a fluid through an opening or a hole, are well known in the art of gas turbine performance monitoring and in the art of fluid mechanics, respectively, and thus not been explained further herein in details for sake of brevity.

[0066] In the example shown in figure 4, two control valves 82 are shown. Each of these have an inlet 84 from a compressed air source for supplying compressed air to the vanes. Each of these control valves 82 are in fluid communication with a different fluid manifold 86, 88, each of the fluid manifolds 86, 88 being fluidly isolated from one another. Each vane 7 is in fluid communication with one of the different fluid manifolds 86, 88, but none are in fluid communication with both of the fluid manifolds 86, 88. Hence, in the example shown, the system enables flow injection to selected vanes 7. By controlling the control valves 82, all, some or none of the vanes 7 may inject flow into the compressor axial flow, as required.

[0067] In the example shown in Figure 4 the system is configured to feed alternate vanes 7 around the circumference of the compressor stage 46. However in other examples, a different supply arrangement may be provided, for example every third vane 7, or vanes 7 at specific locations relative to other engine features which may affect air flow to promote deleterious conditions.

[0068] As shown in Figure 5 the system is configured such that flow injection 2 is directed towards the suction surface 116 of a neighbouring guide vane 7 located circumferentially adjacent the guide vane 7 having the flow-injection opening 4.

[0069] Also as shown in Figure 5, the compressor rotor blade 200, hereinafter also referred to as the blade 200, is located immediately or adjacently downstream i.e. physically distanced but next to or close to, of the vane 7 and forms one or more blades of the blade stage 48, or the blade assembly 48. The blade 200 has a leading edge 218 aligned close to the trailing edge 112 of the vanes 7.

[0070] Figure 6 is a flow diagram illustrating a method 100 of operation of the system of the present disclosure for controlling rotor blade resonant frequencies in the compressor 14.

[0071] Thus, in the method 100, once initiated (started) 110 the operating condition of the engine and or compressor is monitored 120. When it is detected 130 that the engine and/or compressor are operating within a predetermined operating condition then a flow injection 2 is introduced 140 into the compressor. If the compressor and engine is not operating within the predetermined operating condition, then there is no flow injection 150.

[0072] Hence the method comprises introducing a flow injection 2 in the compressor 14, into the axial air flow path 56 of the compressor 14 via a flow-injection opening 4 located at a pressure side 114 of at least one guide vane 7 of a plurality of guide vanes 7 which forms a guide vane stage 46 in the compressor 14.

[0073] The flow injection is introduced only at a predetermined operating condition to thereby enhance vane flow mixing and thereby reduce, limit and/or control flow induced vibrations of the rotor blades 200 downstream of the vanes 7.

[0074] Put another way, the controlled flow injection is controlled to enhance flow mixing around and downstream of at least some of the vanes 7 and thereby reduce vane flow separation and/or strength of vane trailing edge wake to thereby reduce amplitude of resultant forcing of a vibration response of the rotor blade downstream of the vanes.

[0075] Hence the method inhibits excitation of rotor blades immediately downstream of the vanes.

[0076] Critically, the flow injection 2 is directed towards a neighbouring guide vane 7 located circumferentially adjacent the guide vane 7 having the flow-injection opening 4.

[0077] In one example, the predetermined operational condition may be an engine speed of 75% of maximum operating engine speed.

[0078] In another example the predetermined operational condition may be an engine speed equivalent to at least 70% of ISO maximum engine speed but may be no more than about 115% of ISO maximum engine speed. That is to say the predetermined operational condition may be an engine speed of at least 70% of the maximum engine speed (i.e. shaft speed) corrected to ISO temperature, but may be no more than about 115% the maximum engine speed (i.e. shaft speed) corrected to ISO temperature.

[0079] Hence the flow injection only occurs at a specific speed of the engine which the compressor forms part of. Put another way, the flow injection 2 is scheduled to occur in dependence upon a specific engine speed and/or a range of engine speeds.

[0080] That is to say, the method further comprises the step of monitoring the engine condition, and generating a signal to trigger flow injection when the engine is operating at predetermined operating condition.

[0081] In one example, when the predetermined engine operating condition comprises a deceleration, the fluid injection mass flow rate increases as the engine speed decreases.

[0082] That is to say, when the predetermined engine operating condition comprises a deceleration, the fluid injection mass flow rate as a percentage of inlet mass flow may increase as the engine speed decreases.

[0083] For every 1% decrease in engine speed, the fluid injection mass flow rate may increase by 0.1 %.

[0084] Flow injection may be selectively introduced from some, but not all, of the vanes.

[0085] That is to say, the method includes the step of providing in flow injection via some or all of the vanes 7. As discussed above, flow injection may be provided from alternate vanes, or some other selection of vanes as required.

[0086] By injecting flow from the pressure side 114 of a vane 7 and directing it towards the suction side 116 of a neighbouring vane, flow mixing is enhanced which reduces the vane flow separation and/or strength of the vane trailing edge wake which in turn reduces the amplitude of the resulting forcing. The effect is illustrated in Figure 5 by illustrating the flow pattern without flow injection in solid lines 300 and the flow pattern with flow injection in dotted lines 302, which shows how flow injection enhances flow mixing and thus reduces flow separation. Also in Figure 5 the force amplitude at different locations downstream of the vanes 7 is illustrated by way of a sinusoidal curve, the forcing without flow injection shown in a solid line 304 and forcing with flow injection shown in a dotted line 306. The reduction in force reduces the rotor blades 200 subsequent vibration response, and thus reduces the likelihood of the rotor blade excitation and damage.

[0087] Hence there is provided a method and system for controlling rotor blade resonant frequencies in a compressor by injecting flow between adjacent guide vanes such that the flow is injected from one vane towards a neighbouring vane to reduce vane trailing edge wake.

[0088] By injecting flow from the pressure side of a stator vane and directing it towards the neighbouring stator vane, flow mixing is enhanced which reduces vane flow separation and/or strength of the vane trailing edge wake which in turn reduces the amplitude of the resulting forcing on the downstream rotor blade, and hence reduces the rotor blades subsequent vibration response.

[0089] Hence there is provided a means of controlling rotor blade dynamic response at predetermined engine operating conditions thus extending rotor blade life by avoiding rotor blade resonant frequencies, or at least the duration for which such frequencies are generated. The method and system of the present disclosure also increase the range of conditions at which an engine comprising the compressor system of the present disclosure may operate, thus optimising performance of the engine.

[0090] Flow injection is limited to specific engine operating conditions (for example flow injection is scheduled to occur at predetermined engine speeds and/or engine speed ranges), and hence there is no requirement for flow injection to be operable for all compressor operating conditions.

[0091] The method and system or also advantageous as they are configured to be sensitive to not just engine speed, but other conditions at which forced vibrations which may result in resonance may occur, for example during an engine deceleration. Hence the method and system of the present disclosure may progressively introduce greater mass flow as the engine decelerates between a range of engine speeds, as described above.

[0092] The method and system of the present disclosure are also advantageous since flow injection may be provided from one or more of the vanes in a predetermined pattern, thereby increasing the amount of control of the flow mixing, and providing the possibility of optimising flow injection for a given compressor operating condition and configuration, as well as avoiding use of an unnecessary amount of injection flow, thereby reducing the effect of compressor performance.

[0093] Attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

[0094] All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

[0095] Each feature disclosed in this specification (including any accompanying claims, abstract and drawings) may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

[0096] The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

Claims

1. A method (100) for controlling rotor blade resonant frequencies in a compressor (14) for a gas turbine engine (10) the method (100) comprising:

introducing a flow injection (2) in the compressor (14),
wherein the flow injection (2) is introduced into an axial air flow path (56) of the compressor (14) via a flow-injection opening (4) located at a pressure side (114) of at least one guide vane (7) of a plurality of guide vanes (7) forming a guide vane stage (46) in the compressor (14), and
wherein the flow injection (2) is directed towards a neighbouring guide vane (7) located adjacent the guide vane (7) having the flow-injection opening (4); and
the flow injection is introduced at a predetermined operating condition
to thereby enhance vane flow mixing and thereby reduce flow induced vibrations of a rotor blade (200) downstream of the vanes (7).

2. A method as claimed in claim 1 wherein

the predetermined operational condition is an engine speed of 75% of maximum operating engine speed.

3. A method as claimed in claim 1 wherein

the predetermined operational condition is an engine speed equivalent to at least 70% of ISO maximum engine speed but no more than about 115% of ISO maximum engine speed.

4. A method as claimed in claim 2 or claim 3 wherein :

when the predetermined engine operating condition comprises a deceleration, the fluid injection (2) mass flow rate increases as the engine speed decreases.

5. A method as claimed in claim 4 wherein :

for every 1% decrease in engine speed, the fluid injection mass flow rate increases by 0.1%.

6. A method as claimed in any one of the preceding claims wherein
flow injection is selectively introduced from some, but not all, of the vanes (7).

7. A system (10) for controlling rotor blade resonant frequencies in a compressor (14) for a gas turbine engine (10), the system 100) comprising:

a guide vane stage (46) of the compressor (14),

wherein the guide vane stage (46) includes a plurality of guide vanes (7) and
wherein at least one of the guide vanes (7) includes a flow-injection opening (4) located at a pressure side (114) of the guide vane (7),

the flow-injection opening (4) adapted to introduce a flow injection (2) into an axial air flow path (56) of the compressor (14) and
the flow injection (2) is directed towards a neighbouring guide vane (7) located adjacent the guide vane (7) having the flow-injection opening (4); and

a controller (60) adapted to :

initiate introduction of the flow injection (2) only at a predetermined operating condition of the gas turbine engine (10) to thereby enhance vane flow mixing and thereby reduce flow induced vibrations of a rotor blade (200) downstream of the vanes (7).

8. The system (1) according to claim 7, wherein:

the predetermined operating condition is defined as a function of engine speed,
the system comprises a sensor (70) for detecting engine speed; and
the controller (60) is operable to receive a signal indicative of engine speed from the sensor (70).

9. The system (1) according to claim 7 or 8, comprising:

a flow controlling mechanism (80) adapted to regulate the flow injection (2) emanating from the flow-injection opening (4) of the guide vane (7), and
wherein the controller (60) is further adapted to control the flow controlling mechanism (80) to regulate the flow injection (2).

10. The system (1) according to claim 9, wherein

the flow controlling mechanism (80) is operable to regulate the flow injection (2) emanating from the flow-injection opening (4) of the guide vane (7) between at least 2% but no more than 5% of mass flow at inlet (12) to the compressor (14).

11. The system (1) according to any of claims 7 to 10, wherein the

flow-injection opening (4) is located between

a distance A from a trailing edge (112) of the guide vane (7);
where distance A has a value of about 5 % of a chord length (99) of the guide vane (7); and
a distance C from a leading edge (118) of the guide vane (7);
where distance C has a value in the range of 65% to 85% of a chord length (99) of the guide vane (7).

12. The system (1) according to any of claims 7 to 11, wherein

the flow-injection opening (4) extends from, or is close to, a base of the guide vane (7) and spans a distance D,
where distance D has a value of about 95% of the guide vane.

13. The system (1) according to any of claims 7 to 12, wherein

the flow-injection opening (4) has a width B;
where width B has a value of between 10 % and 30 % of a chord length (99) of the guide vane (7).

14. The system (1) according to any of claims 7 to 13, wherein

the flow-injection opening (4) is adapted to introduce the flow injection (2) into the axial air flow path (56) of the compressor (14)
at an angle β (95) between 30 degrees and 60 degrees
with respect to an axis (21) parallel to a rotational axis (20) of the compressor (14).

15. The system (1) according to any of claims 7 to 14, wherein,

the flow injection opening (4) is in fluid communication with a duct
which is in turn in fluid communication with
a location on the compressor downstream of the location of the guide vane (7) with respect to an axial flow direction (9) of air in the compressor (14)
such that flow from the downstream region is delivered to the fluid injection opening (4).

FIG 1

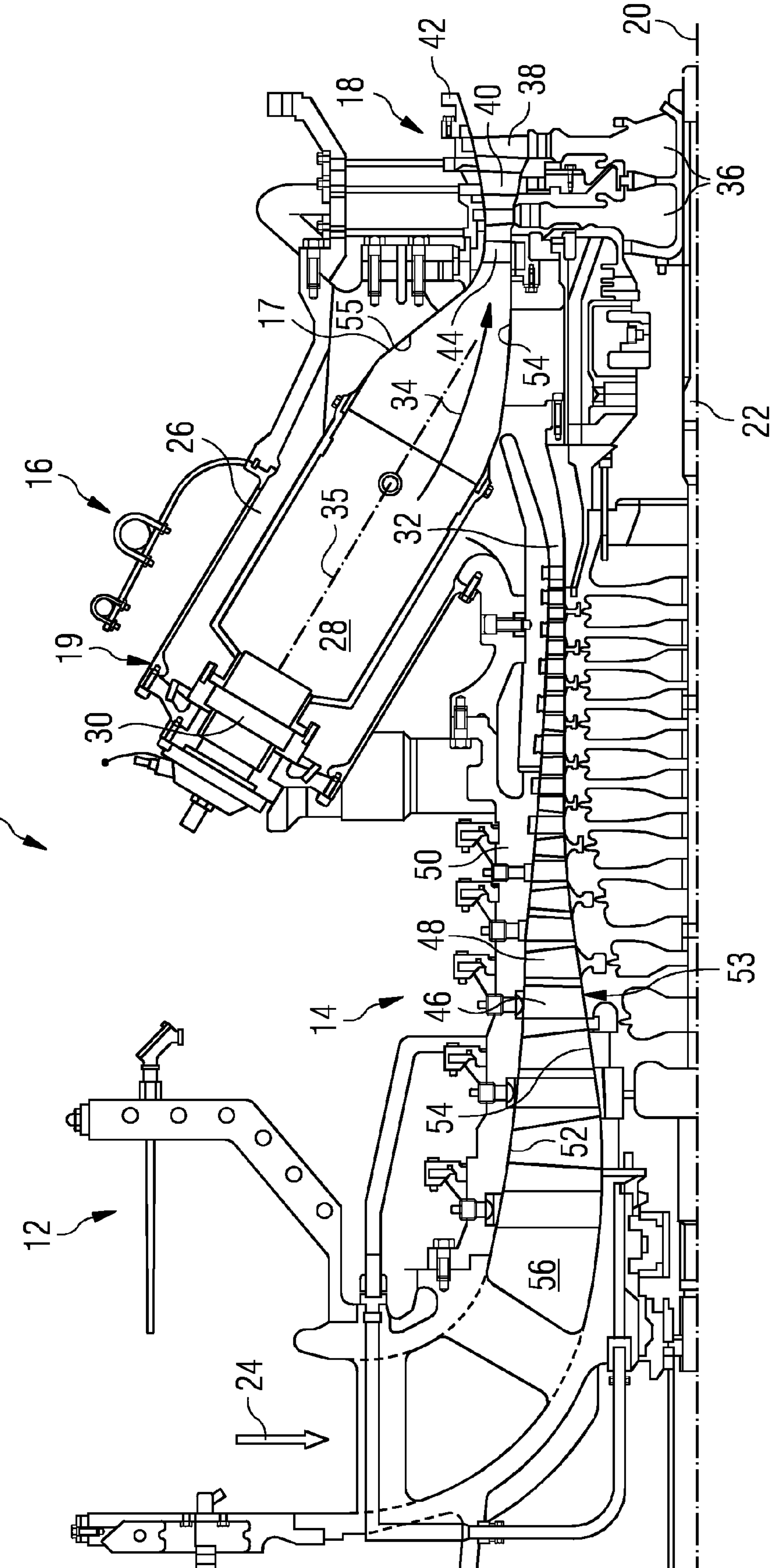
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FIG 2

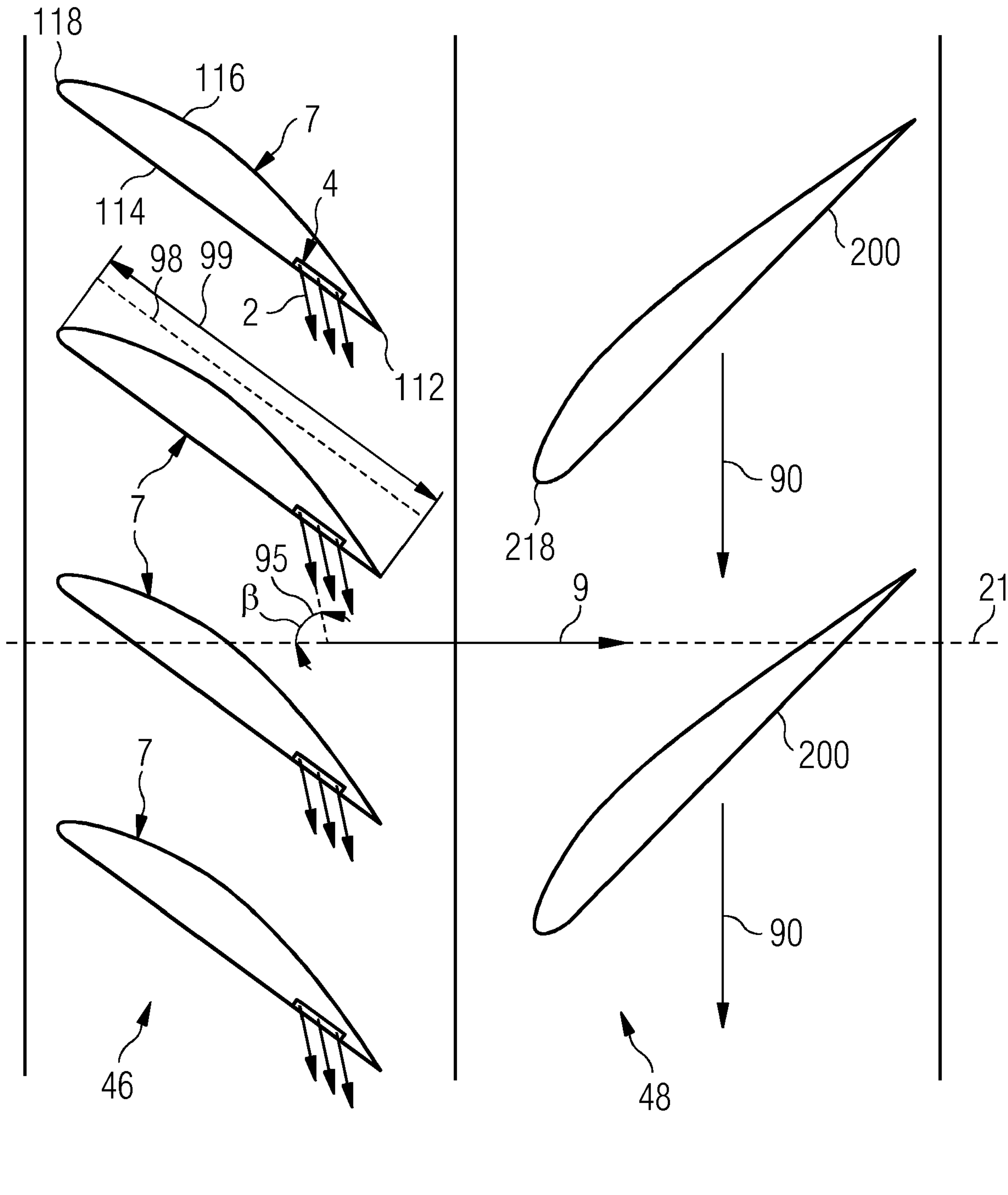


FIG 3

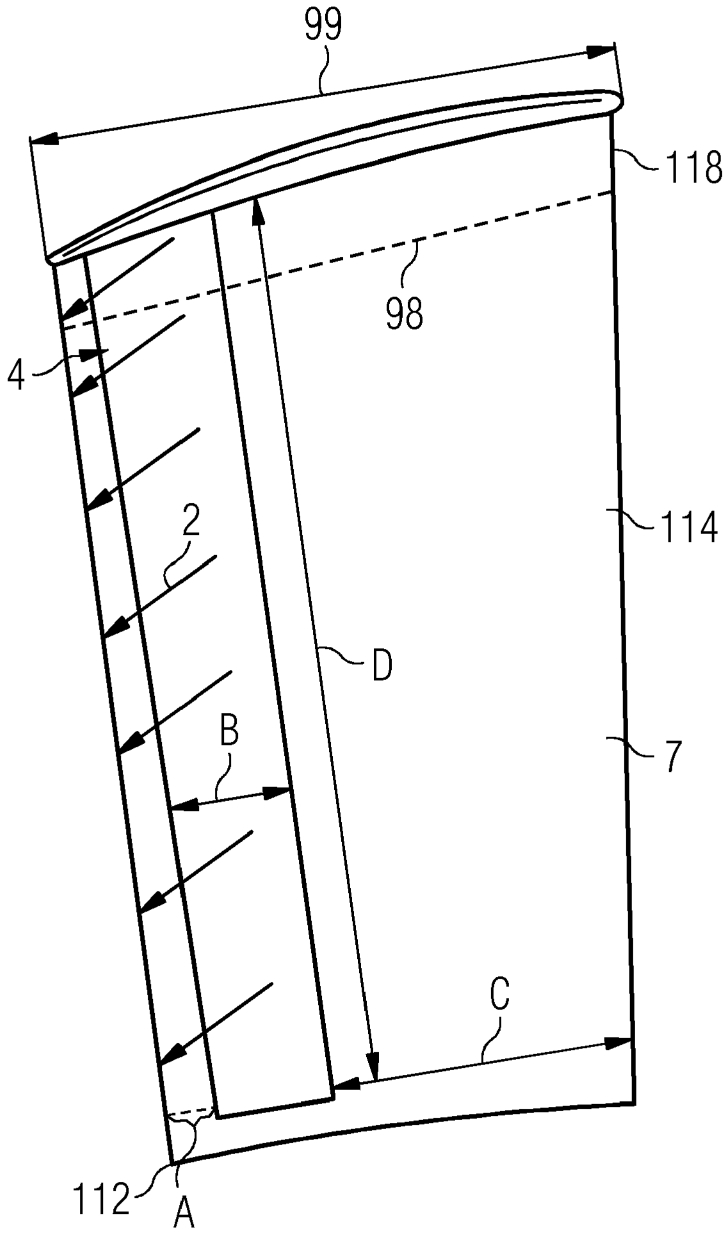


FIG 4

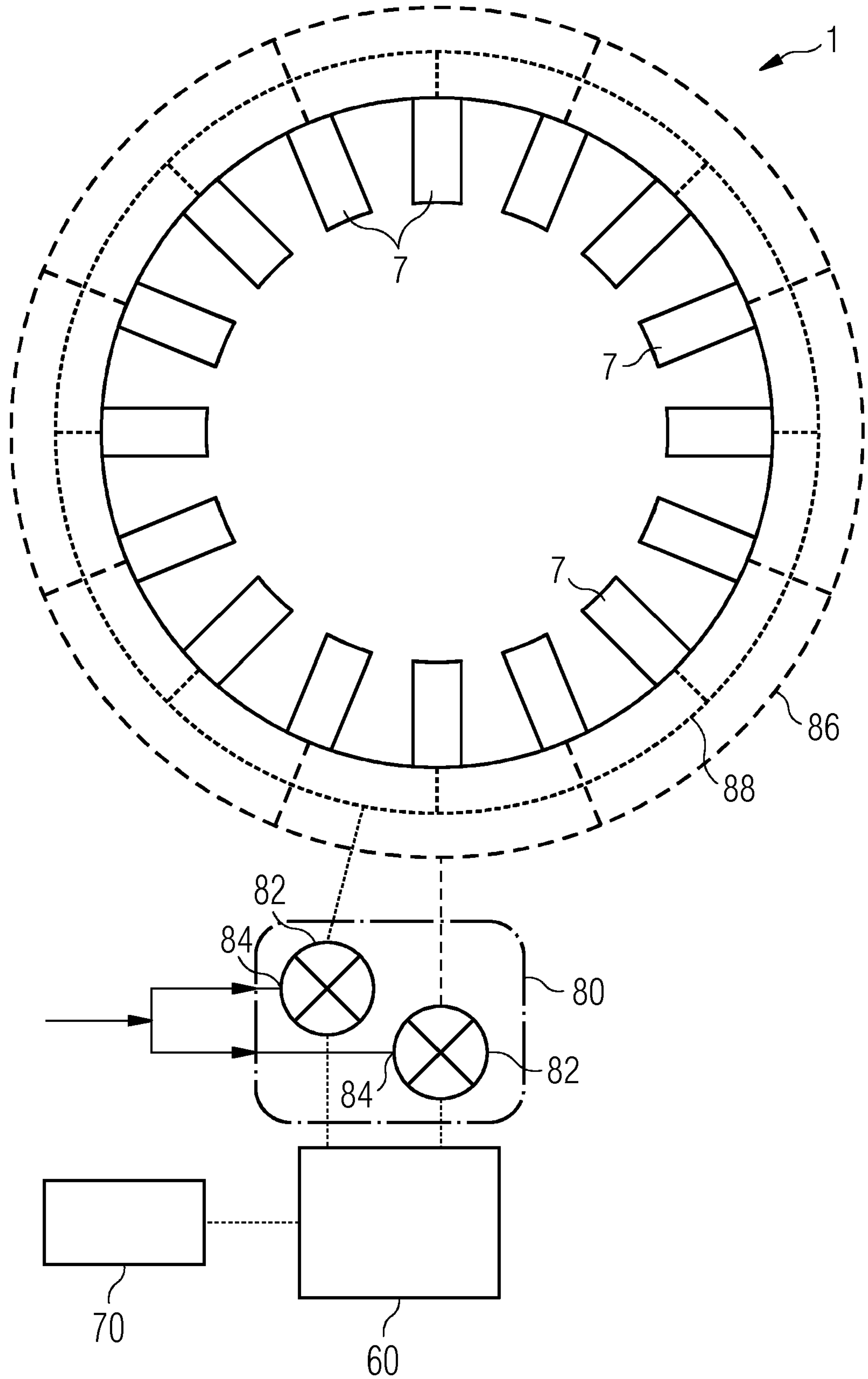
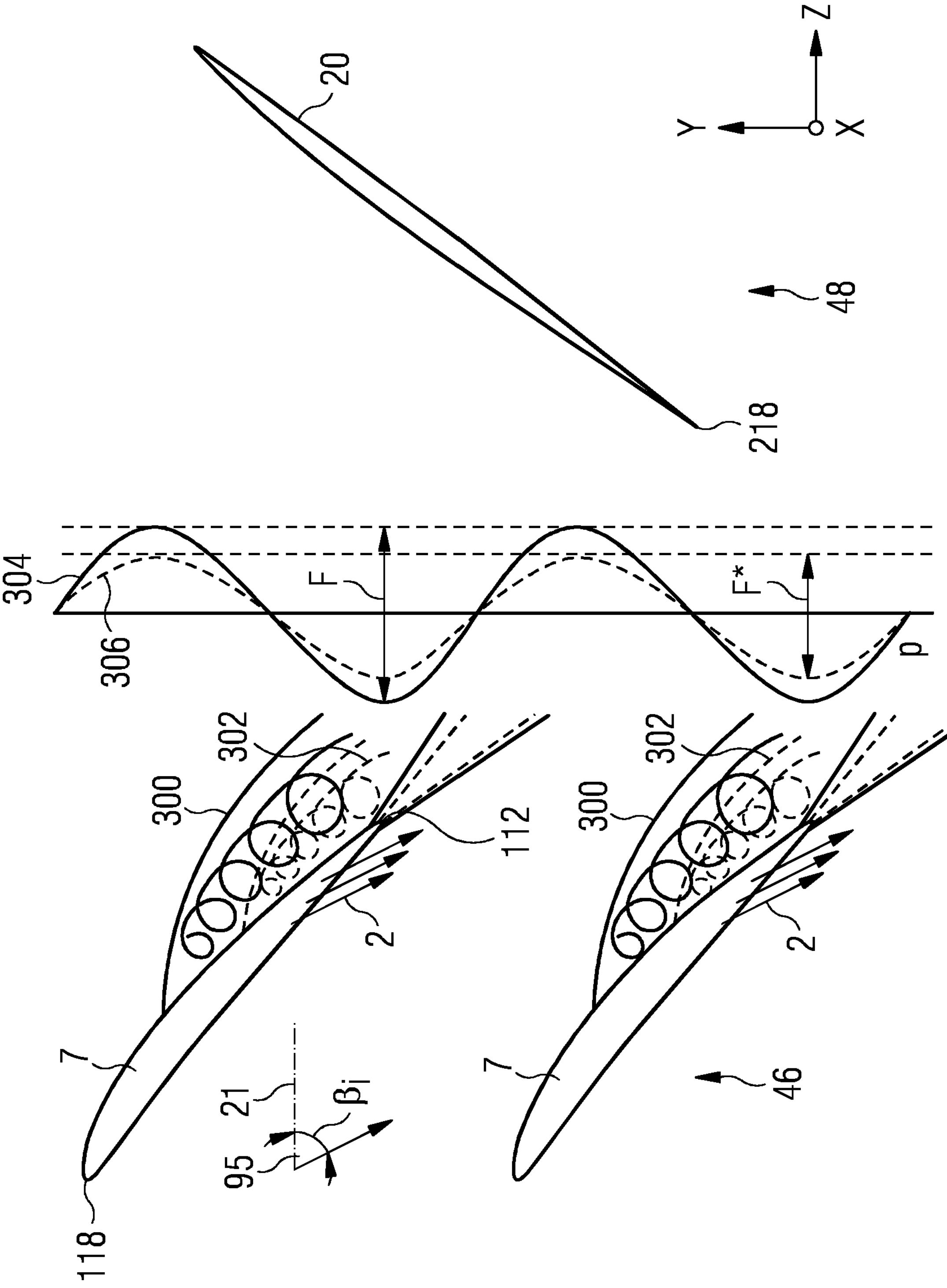


FIG 5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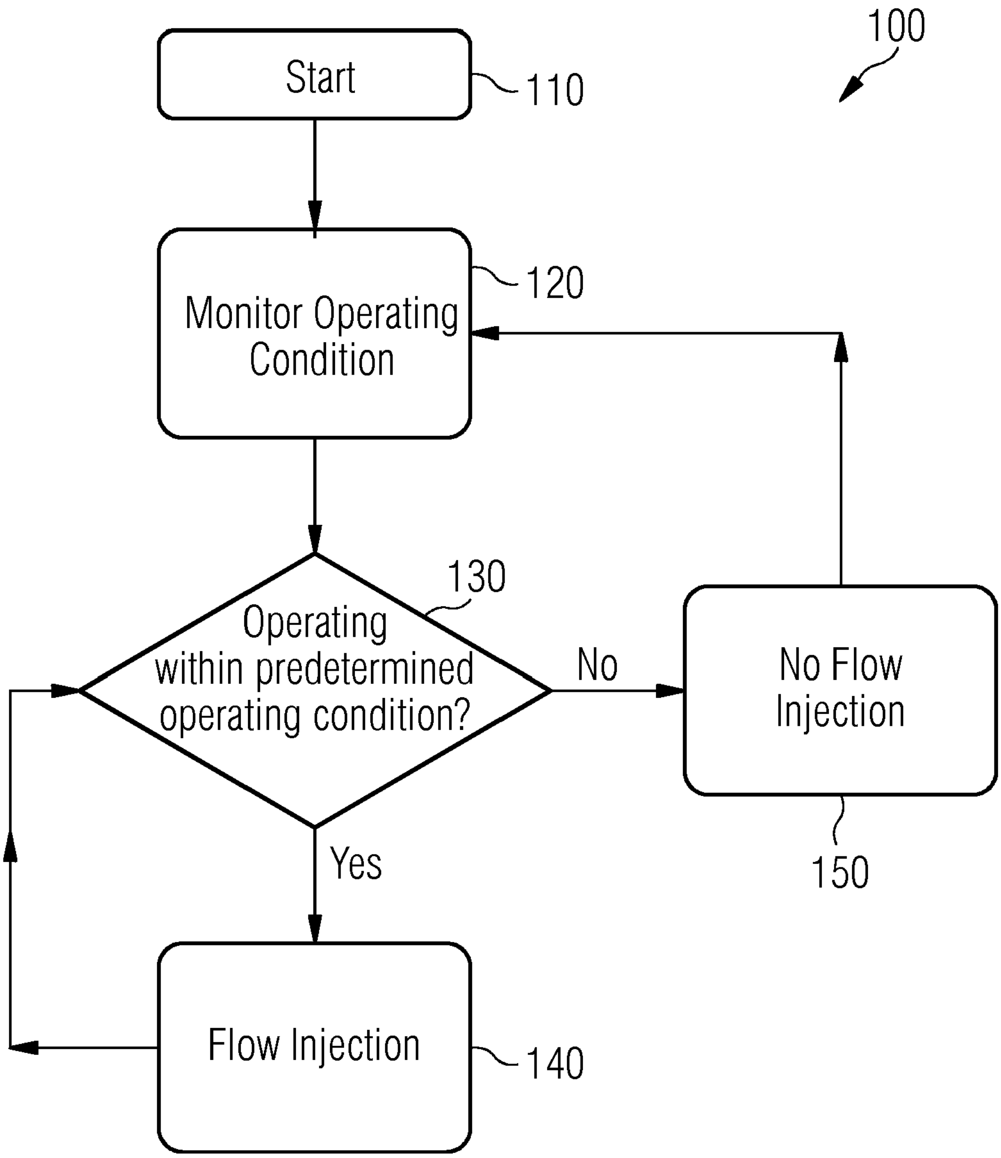
302
2
7
46

FIG 6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120
130
Operating within predetermined operating condition?
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No Flow Injection
150
Yes
Flow Injection
140

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EUROPEAN SEARCH REPORT

Application Number
EP 17 19 8621

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The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
The Hague	17 April 2018	Oliveira, Damien

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