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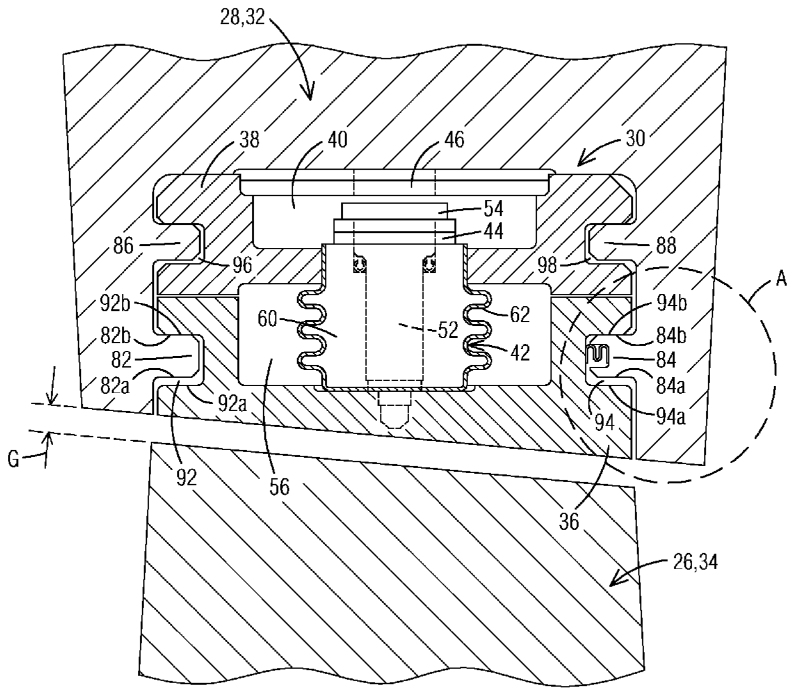
(54) **Title:** PNEUMATICALLY OPERATED CLEARANCE CONTROL SEAL

FIG. 2
View II-II



(57) **Abstract:** A sealing apparatus (30) for sealing a clearance between a rotatable component (34) and a surrounding stationary component (32) in a gas turbine engine (10), includes a seal shoe (36) positioned proximate to the rotatable component (34) to create a non-contact seal therewith. The seal shoe (36) is displaceable with respect to the stationary component (32) in a radial direction. The sealing apparatus (30) also includes a fixed support structure (38) secured to the stationary component (32). The support structure (38) at least partially defines a manifold (40) for receiving a pressurized fluid from a fluid supply passage (46) extending through the stationary component (32). At least one actuator element (42) is positioned between the seal shoe (36) and the support structure (38). The actuator element (42) is in fluid communication with the manifold (40) such that when pressurized fluid is supplied to the manifold (40), the actuator element (42) acts on the seal shoe (36) to displace the seal shoe (36) radially inward toward the rotating component

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[Continued on next page]

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(34), to reduce a radial gap (G) between the seal shoe (36) and the rotating component (34).

PNEUMATICALLY OPERATED CLEARANCE CONTROL SEAL

BACKGROUND

1. Field

[0001] The present invention relates to gas turbine engines, and in particular to a pneumatically operated seal for controlling a clearance between a rotating component and a surrounding stationary component.

2. Description of the Related Art

[0002] A gas turbine engine typically includes a compressor section for compressing ambient air, a combustor section for mixing the compressed air with fuel and igniting the mixture to form a hot working medium fluid and a turbine section for expanding the working medium fluid for extracting power from the working medium fluid. The compressor section and the turbine section may include multiple stages of alternating rows of stationary vanes and rotating blades. The clearance between the tip of the rotating blades and the surrounding stationary component (such as an outer casing or shroud), in either the compressor or turbine stages, has a significant impact on the efficiency and power output of the engine. The higher the clearances are, the more is the leakage of the working medium fluid, leading to a loss in efficiency due to secondary flow losses. For the next generation high efficiency gas turbine engine development, novel measures for better blade tip clearance control are required to achieve performance targets.

[0003] An adaptive self-adjusting seal, various configurations of which are disclosed in the patent publications US8919781B2, US8641045B2, US8172232B2, US8002285B2, US7896352B2, US7410173B2, US7182345B2 and US6428009B2, has been developed as an effective non-contact seal for traditional rotor-stator sealing systems. The use of such a seal has so far not been realized for blade tip clearance control.

SUMMARY

[0004] Briefly, aspects of the present invention relate to a pneumatically operated clearance control seal between a stationary and a rotating component of a gas turbine engine.

[0005] According to a first aspect of the invention, a sealing apparatus is provided for sealing a clearance between a rotatable component and a surrounding stationary component in a gas turbine engine. The sealing apparatus comprises a seal shoe positioned proximate to the rotatable component to create a non-contact seal therewith. The seal shoe is displaceable with respect to the stationary component in a radial direction. The sealing apparatus further comprises a fixed support structure secured to the stationary component. The support structure at least partially defines a manifold for receiving a pressurized fluid from a fluid supply passage extending through the stationary component. At least one actuator element is positioned between the seal shoe and the support structure. The actuator element is in fluid communication with the manifold such that when pressurized fluid is supplied to the manifold, the actuator element acts on the seal shoe to displace the seal shoe radially inward toward the rotating component, to reduce a radial gap between the seal shoe and the rotating component.

[0006] According to a second aspect of the invention, a gas turbine engine is provided. The gas turbine engine comprises a rotatable component defined by a rotor blade and a stationary component defined by a casing structure positioned radially outward of a tip of the rotor blade. The gas turbine engine comprises a sealing apparatus, as described above, for sealing a clearance between the tip of the rotor blade and the casing structure.

[0007] According to a third aspect of the invention, a method is provided for operating the sealing apparatus, as described above, for actively controlling a clearance between a rotating component and a surrounding stationary component in a gas turbine engine. In accordance with the method during a transient operating

condition, fluid flow in the supply passage is controlled so as to allow pressurized fluid into the manifold, causing the actuator element to push the seal shoe radially inward toward the rotating component, so as to reduce a radial gap between the seal shoe and the rotating component.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The invention is shown in more detail by help of figures. The figures show preferred configurations and do not limit the scope of the invention.

[0009] FIG. 1 is a longitudinal sectional view of an example gas turbine engine;

[0010] FIG. 2 is an enlarged longitudinal cross-sectional view illustrating a sealing apparatus according to an example embodiment of the present invention;

[0011] FIG. 3 is a perspective cut out view of the example sealing apparatus;

[0012] FIG. 4 is an axial end view of the example sealing apparatus;

[0013] FIG. 5 is a schematic illustration depicting a portion of the sealing apparatus during an open position;

[0014] FIG. 6 is a schematic illustration depicting a portion of the sealing apparatus during a closed position; and

[0015] FIG. 7 is a graph illustrating a variation of tip clearance with time during engine operation.

DETAILED DESCRIPTION

[0016] In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration, and not by way of limitation, a specific embodiment in which the invention may be practiced. It is to be understood that other embodiments may be utilized and that changes may be made without departing from the spirit and scope of the present invention.

[0017] In the context of the present specification, the terms “radial”, “axial” and “circumferential” are defined in relation to a rotational engine axis 11.

[0018] Referring to FIG. 1, a gas turbine engine 10 is illustrated, which is generally rotationally symmetrical in relation to the engine axis 11. The gas turbine engine broadly includes a compressor section 12 for compressing ambient air, a combustor section 14 for mixing the compressed air with fuel and igniting the mixture to form a hot working medium fluid, and a turbine section 16 for extracting power from the working medium fluid. The compressor section 12 typically comprises multiple compressor stages housed in a casing 18. Each compressor stage includes a row of stationary guide vanes 20 positioned upstream of a row of rotating compressor blades 22. In each compressor stage, a radial clearance is defined between the tip of the compressor blades 22 and the stationary casing structure 18. The turbine section 16 is also typically comprised of multiple turbine stages, with each turbine stage comprising a row of stationary vanes 24 followed by a row of rotating turbine blades 26. In each turbine stage, a radial clearance is defined between the tip of the turbine blades 26 and a respective casing structure or shroud 28, which is also referred to as a ring segment.

[0019] For minimizing a loss in engine efficiency due to secondary flow losses, it is desirable to run a tight clearance between the tip of the rotating blades and the surrounding stationary components, in both the compressor and the turbine stages. During transient conditions, such as during engine start-up or shut-down, the rotating parts (blades, rotor, and discs) and stationary parts (outer casing, blade rings, and ring segments) thermally expand at different rates. As a result, blade tip clearances can actually decrease during transient conditions until steady state operation is achieved, at which point the clearances can increase due to rubbing or contact of the blade tip, thereby reducing the efficiency of the engine. Thus, a need exists to reduce the likelihood of blade tip rub and control this undesirably large blade tip clearance.

[0020] Embodiments of the present invention provide a pneumatically operated sealing apparatus 30 for blade tip clearance control that addresses at least some of the technical problems stated above.

[0021] An embodiment of an inventive sealing apparatus 30 is illustrated in FIG. 2 and 3, with continued reference to FIG. 1. The sealing apparatus 30 may be provided at one or more of the turbine stages, as exemplarily depicted in FIG. 1, for controlling a radial clearance between the rotating turbine blades 26 and the stationary casing structure 28. Additionally, or alternately, a sealing apparatus in accordance with certain embodiments of the present invention may be provided at one or more compressor stages, for controlling a radial clearance between the rotating compressor blades 22 and the stationary casing structure 18.

[0022] As shown in FIG. 2, the exemplary sealing apparatus 30 seals a clearance between a stationary component 32 and a rotatable component 34 of the gas turbine engine 10. The stationary component 32 is, in this example, part of a turbine casing structure 28, while the rotatable component 34 is, in this example, a blade 26 of a turbine stage (see FIG. 1). The term “rotatable component 34” and “rotating component 34”, as used herein, refer to the same component, the latter defining an operating state of the component. The sealing apparatus 30 is formed of a stationary or fixed support structure 38 and a movable seal shoe 36. The support structure 38 is positioned radially inward of the stationary component 32 and is secured to the stationary component 32. The seal shoe 36 is positioned proximate to, and radially outward of the rotatable component 34. The seal shoe 36 is spaced from the rotatable component 34 by a tight gap G, to form a non-contact sealing interface with the rotatable component 34. As described herein, during operation of the gas turbine engine 10, the seal shoe 36 is displaceable in a radial direction with respect to the stationary component 32, to maintain a desired clearance or gap G with respect to the rotating component 34.

[0023] In the illustrated embodiments, a clearance control is achieved by pneumatically actuating the seal shoe 36 via at least one actuator element 42 using pressurized fluid. As shown in FIG. 2, the sealing apparatus 30 comprises a manifold 40 for receiving a pressurized fluid from a supply passage 46. The manifold 40 may be defined, at least partially, by a cavity or trench formed on a radially outward facing side of the support structure 38. The supply passage 46 may extend through the stationary component 32, in this case, the casing structure 28, to be fluidly coupled to the manifold 40. The actuator element 42 is positioned between the seal shoe 36 and the support structure 38. The manifold 40 may be located on a cold side (radially outward) of the actuator element 42. The actuator element 42 is in fluid communication with the manifold 40 and is configured to be responsive to fluid pressure in the manifold 40 to actuate the seal shoe 36 in a radial direction. During operation, when pressurized fluid is supplied to the manifold 40 the actuator element 42 acts on the seal shoe 36 to displace the seal shoe 36 radially inward, toward a closed position of the seal. In one embodiment, as illustrated herein, the sealing apparatus 30 further includes a spring return mechanism, comprising at least one spring element 44 configured exert a radially outward spring force, to urge the seal shoe 36 toward an open position of the seal.

[0024] The supply passage 46 may connect the manifold 40 to a source 50 of pressurized fluid, as shown in FIG. 1. In one embodiment, the pressurized fluid may include compressed air diverted from a compressor stage of the gas turbine engine 10 via a bleed line (not shown in the drawings). In other embodiments (not shown), the supply passage 46 may be connected to an external source of pressurized fluid. A fluid flow controller 48, such as a valve, may be connected to the supply passage 46 for controlling the fluid feed to the manifold 40, to influence the radial position of the seal shoe 36 of the sealing apparatus 30. In one embodiment, as shown in FIG. 1, the sealing apparatus 30 of a given stage may be provided with a dedicated fluid flow controller or valve 48 for the respective stage. In other embodiments (not shown), the sealing apparatus 30 of multiple stages may be jointly controlled by a single fluid flow controller or valve 48. As described herein, the valve 78 may be controlled as a function of the operating state of the engine 10, to influence a pressure exerted on the seal shoe 36 by the actuator element 42, to thereby control the radial gap G between seal shoe 36 and the rotating component 34.

[0025] Referring to FIG. 3 and 4, the support structure 38 and the seal shoe 36 may extend in a circumferential direction of the gas turbine engine 10. In this configuration, the support structure 38 may form an outer arc and the seal shoe 36 may form an inner arc. In one embodiment, as best illustrated in FIG. 4, the support structure 38 may extend continuously along the outer arc, while the seal shoe 36 may be formed of multiple discrete segments positioned circumferentially adjacent to each other along the inner arc. In the illustrated example, the support structure 38 extends continuously along a 180 degrees arc, defining a ½ case ring. The segmented configuration of the seal shoe 36 may provide smaller actuation distances and allow axial contact sealing.

[0026] In the illustrated embodiments, a closed pneumatic actuator system is described, in which the at least one actuator element 42 is configured such that the manifold 40 is fluidically isolated from a cavity 56 between the seal shoe 36 and the support structure 38. In one embodiment, as shown in FIG. 2 and 3, the actuator element 42 may be configured as a bellow having a hollow interior portion 60 enclosed by an outer wall 62. The interior portion 60 is in fluid communication with the manifold 40. The outer wall 62 may be corrugated. The corrugated wall 62 may be configured to allow the bellow 42 to be extended length-wise (in the radial direction of the turbine engine 10) responsive to fluid pressure in the interior portion 60. The bellow 42 may be closed at its radially inner end. The radially outer end of the bellow 42 may be fixed to the support structure 38, for example, by welding. The bellow 42 thus forms a closed pneumatic actuator system in which the pressurized fluid, being confined to the inner portion 60 of the bellow by the outer wall 62, is effectively fluidically isolated from the cavity 56 between the seal shoe 36 and the support structure 38. A closed pneumatic actuator system, as described herein, ensures that the leakage through the gap G is not affected by the supply pressure in the manifold 40. In this case, any leakage is driven by the pressure ratio between the leading and trailing edges of the seal.

[0027] Referring to FIG. 3, in the present example, a plurality of (in this case, two) discrete actuator elements 42 are provided, which are spaced in the circumferential direction. The manifold 40 may extend continuously along the arc-length of the support structure 38 in a circumferential direction, being in fluid communication with each of the actuator elements 42. The manifold 40 may thus form a common supply plenum that feeds all actuator elements 42 of a stage simultaneously.

[0028] As shown in FIG. 2 and 3, in one embodiment, the spring element 44 may be configured as a leaf spring. The leaf spring 44 may be disposed on a radially outwardly facing side of the support structure 38, in the cavity defining the manifold

40. In this embodiment, the spring force of the leaf spring 44 is transmitted to the seal shoe 36 by a plunger 52. The plunger 52 may be connected to the seal shoe 36 at its radially inner end and connected to the support structure 38 at its radially outer end. The radially outer end of the plunger 52 may be flanged, defining a shoulder 54. The leaf spring 44 may be positioned radially inward of the shoulder 54 and may act on a radially inner side of the shoulder 54, causing the plunger 52 to push the seal shoe 36 radially outward.

[0029] In the embodiment illustrated in FIG. 2 and 3, the seal shoe 36 includes a pair of axially extending recesses 92, 94 on axially opposite sides. The recesses 92, 94 are configured to loosely receive a respective axially extending protrusion 82, 84 formed on the stationary component 32, which allows relative radial motion between the seal shoe 36 and the stationary component 32. Furthermore, the support structure 38 may also include a pair of recesses 96, 98 on axially opposite sides. The recesses 96, 98 may be configured to receive therein a respective axially extending protrusion 86, 88 of the stationary component 32 with a tight clearance, which ensures that the radial position of the support structure 38 is substantially fixed in relation to the stationary component 32.

[0030] The axial protrusions 82, 84 of the stationary component 32, in combination with the corresponding axial recesses 92, 94 in the seal shoe 36, define a mechanical stopper for limiting the displacement of the seal shoe 36. The mechanical stopper is thus provided on opposite axial sides of the seal and may extend along a circumferential length of the stationary component 32. In the present embodiment, as shown in FIG. 2 and FIG. 5 and 6, each protrusion 82, 84 of the stationary component 32 has a radially inwardly facing first face 82a, 84a and a radially outwardly facing second face 82b, 84b. Each recess 92, 94 in the seal shoe 36 has a radially outwardly facing first shoulder 92a, 94a and a radially inwardly facing second shoulder 92b, 94b. The first face 82a, 84a of each protrusion 82, 84 is configured to engage with the first shoulder 92a, 94a of the respective recess 92, 94 to form the radially outer stop, which defines a radially outermost position of the seal shoe 36, or an open position of the seal (see FIG. 5). The second face 82b, 84b of each protrusion 82, 84 is configured to engage with the second shoulder 92b, 94b of the respective recess 92, 94 to form the radially inner stop, which defines a radially innermost position of the seal shoe 36 (see FIG. 2 and 6). In the open position, as shown in FIG. 5, the radially inner surface of the seal shoe 36 is positioned radially outward of the radially inner surface of the stationary component 32. In the closed position, as shown in FIG. 2 and 6, the radially inner surface of the seal shoe 36 is positioned flush with the radially inner surface of the stationary component 32, forming a smooth flow channel through the gap G between the stationary component 32 and the rotating component 34.

[0031] The described configuration of the mechanical stopper, in addition to limiting the radial displacement of the seal shoe 36, provides a sealing interface between the seal shoe 36 and the stationary component 32 in the circumferential direction. The described configuration of the mechanical stopper may also prevent liberating any part into the hot gas path and causing serious damage to the engine, in the event that the link between the seal shoe 36 and support structure 38 is broken.

[0032] FIG. 7 shows a curve 100 illustrating a variation of tip clearance with time during engine operation, in a baseline configuration without the present sealing apparatus. As shown, at start-up phase, starting from time T_0, the tip clearance typically decreases, till a pinch point 102 is reached at time T_1, in which the blade tip is closest to the surrounding stationary casing structure, where a possibility of tip rubbing exists. Thereafter, the clearance increases and after time T_2, the clearance is substantially constant over time.

[0033] In accordance with an aspect of the present invention, a method for operating a sealing apparatus 30 for active tip clearance control is provided. In accordance with the method, during a steady state operating condition (i.e., any time after time T_1, when the pinch point 102 has been avoided), the fluid flow in the supply passage 46 is controlled, for example by turning valve 48 to an “ON” state, to allow pressurized fluid into the manifold 40. The pressurized fluid in the manifold 40 acts on the actuator elements 42, causing the actuator elements 42 to exert a net inward thrust, to push the seal shoe 36 radially inward toward the rotating component 34. The radial gap G between the seal shoe 36 and the rotating component 34 is thus maintained at a minimum level during steady state operation, thereby increasing engine efficiency. In the illustrated embodiment, during this phase, the seal shoe 36 is pushed into contact with the radially inner stop 82b, 84b, to remain in a closed position, as shown in FIG. 6.

[0034] Furthermore, during a transient operating condition of the engine, for example at start-up (time T_0-T_1), the fluid flow in the supply passage 46 may be controlled, for example by turning the valve 48 to an “OFF” state, to stop a flow of pressurized fluid into the manifold 40. In the absence of a radially inward pneumatic thrust, the spring force of the spring element 44 is effective to exert a net outward force on the seal shoe 36, to push the seal shoe radially outward. In the illustrated embodiment, during this phase, the seal shoe 36 is pushed into contact with the radially outer stop 82a, 84a, to remain in an open position, as shown in FIG. 5. A safety feature realized by the above-described embodiments is that in case of loss of control, the pressurized fluid supply may be cut off, such that the seal shoe 36 returns to “open” position by the action of the spring element 44.

[0035] Embodiments of the present invention offer several technical merits. For example, the illustrated embodiments provide a robust construction with simple manufacturing and assembly. Furthermore, separating the thrust capability of the actuator element from the spring force may allow improved optimization of both components. Moreover, the closed pneumatic system realized by using bellows as the actuator elements ensures that leakage across the seal takes place only in one direction with no reversal of pressure ratio across the seal. It may thereby be ensured that leakages across the seal are driven by stage pressure ratio, independent of the supply pressure.

[0036] While specific embodiments have been described in detail, those with ordinary skill in the art will appreciate that various modifications and alternative to those details could be developed in light of the overall teachings of the disclosure. Accordingly, the particular arrangements disclosed are meant to be illustrative only and not limiting as to the scope of the invention, which is to be given the full breadth of the appended claims, and any and all equivalents thereof.

CLAIMS

1. A sealing apparatus (30) for sealing a clearance between a rotatable component (34) and a surrounding stationary component (32) in a gas turbine engine (10), comprising:

a seal shoe (36) positioned proximate to the rotatable component (34) to create a non-contact seal therewith, the seal shoe (36) being displaceable with respect to the stationary component (32) in a radial direction,

a fixed support structure (38) secured to the stationary component (32), the support structure (38) at least partially defining a manifold (40) for receiving a pressurized fluid from a fluid supply passage (46) extending through the stationary component (32), and

at least one actuator element (42) positioned between the seal shoe (36) and the support structure (38), the actuator element (42) being in fluid communication with the manifold (40) such that when pressurized fluid is supplied to the manifold (40), the actuator element (42) acts on the seal shoe (36) to displace the seal shoe (36) radially inward toward the rotating component (34), to reduce a radial gap (G) between the seal shoe (36) and the rotating component (34).

2. The sealing apparatus (30) according to claim 1, wherein the at least one actuator element (42) is configured such that the manifold (40) is fluidically isolated from a cavity (56) between the seal shoe (36) and the support structure (38).

3. The sealing apparatus (30) according to any of the preceding claims, wherein the at least one actuator element (42) is configured as a bellow having a hollow interior portion (60) in communication with the manifold (40), the bellow (42) being extendable responsive to fluid pressure in the interior portion (60).

4. The sealing apparatus (30) according to any of the preceding claims, further comprising at least one spring element (44) configured to exert a spring force on the seal shoe (36) in a radially outward direction.

5. The sealing apparatus (30) according to claim 4, wherein the spring element (44) is configured as a leaf spring,

the sealing apparatus (30) further comprising a plunger (52) connected to the seal shoe (36) and the spring element (44), the spring element (44) being configured such that the spring force of the spring element (44) acts on the plunger (52) to pull the seal shoe (36) radially outward.

6. The sealing apparatus (30) according to any of claims 4 and 5, further comprising a fluid flow controller (48) connected to the supply passage (46),

wherein the fluid flow controller (48) is operable, during a steady state operating condition of the gas turbine engine (10), to allow pressurized fluid into the manifold (40), causing the actuator element (42) to push the seal shoe (36) radially inward to a closed position,

the closed position being defined when the seal shoe (36) has reached a radially innermost position.

7. The sealing apparatus (30) according to claim 6, wherein the fluid flow controller (48) is operable, during a transient operating condition of the gas turbine engine (10), to stop a flow of pressurized fluid into the manifold (40), causing the seal shoe (36) to be pushed toward an open position by the spring element (44),

an open positioned being defined when the seal shoe (36) has reached a radially outermost position.

8. The sealing apparatus (30) according to any of the preceding claims, wherein the support structure (38) and the seal shoe (36) extend in a circumferential direction of the gas turbine engine (10), the support structure (38) forming an outer arc and the seal shoe (36) forming an inner arc.

9. The sealing apparatus (30) according to claim 8, wherein the support structure (38) extends continuously along the outer arc and the seal shoe (36) is formed of multiple discrete segments positioned circumferentially adjacent to each other along the inner arc.

10. The sealing apparatus (30) according to any of claims 8 and 9, wherein the at least one actuator element (42) comprises two or more actuator elements (42) spaced in the circumferential direction.

11. The sealing apparatus (30) according to claim 10, wherein the manifold (40) extends continuously along the support structure (38) in a circumferential direction and is in fluid communication with said two or more actuator elements (42).

12. The sealing apparatus (30) according to any of the preceding claims, further comprising a mechanical stopper (82, 84) for limiting the displacement of the seal shoe (36),

the mechanical stopper (82, 84) forming a radially outer stop (82a, 84a) that defines a radially outermost position of the seal shoe (36), and a radially inner stop (82b, 84b) that defines a radially innermost position of the seal shoe (36).

13. The sealing apparatus (30) according to claim 12, wherein the mechanical stopper (82, 84) extends along a circumferential length of the stationary component (32).

14. The sealing apparatus (30) according to any of claims 12 and 13, wherein the seal shoe (36) comprises a pair of axially extending recesses (92, 94) on axially opposite sides, which are configured to loosely receive a respective axially extending protrusion (82, 84) formed on the stationary component (32),

wherein each protrusion (82, 84) has a radially inwardly facing first face (82a, 84a) and a radially outwardly facing second face (82b, 84b),

wherein each recess (92, 94) has a radially outwardly facing first shoulder (92a, 94a) and a radially inwardly facing second shoulder (92b, 94b),

wherein the first face (82a, 84a) of each protrusion (82, 84) is configured to engage with the first shoulder (92a, 94a) of the respective recess (92, 94) to form the radially outer stop, and the second face (82b, 84b) of each protrusion (82, 84) is configured to engage with the second shoulder (92b, 94b) of the respective recess (92, 94) to form the radially inner stop.

15. A gas turbine engine (10), comprising:

a rotatable component (34) defined by a rotor blade (26),

a stationary component (32) defined by a casing structure (28) positioned radially outward of a tip of the rotor blade (26), and

a sealing apparatus (30) according to any of the preceding claims, for sealing a clearance between the tip of the rotor blade (26) and the casing structure (28).

16. A method for operating a sealing apparatus (30) for actively controlling a clearance between a rotating component (34) and a surrounding stationary component (32) in a gas turbine engine (10):

the sealing apparatus (30) comprising:

a seal shoe (36) positioned proximate to the rotating component (34) to create a non-contact seal therewith, the seal shoe (36) being displaceable with respect to the stationary component (32) in a radial direction,

a fixed support structure (38) secured to the stationary component (32), the support structure (38) at least partially defining a manifold (40) for receiving a pressurized fluid from a fluid supply passage (46) extending through the stationary component (32),

at least one actuator element (42) positioned between the seal shoe (36) and the support structure (38), the actuator element (42) being in fluid communication with the manifold (40) and being responsive to fluid pressure in the manifold (40) to actuate the seal shoe (36) in a radially inward direction,

the method comprising:

during a steady state operating condition, controlling fluid flow in the supply passage (46) to allow pressurized fluid into the manifold (40), causing the actuator element (42) to push the seal shoe (36) radially inward toward the rotating component (34), so as to reduce a radial gap (G) between the seal shoe (36) and the rotating component (34).

17. The method according to claim 17, wherein the sealing apparatus (30) further comprises at least one spring element (44) configured to exert a spring force on the seal shoe (36) in a radially outward direction.

wherein the method further comprises:

during a transient operating condition, controlling fluid flow in the supply passage (46) to stop a flow of pressurized fluid into the manifold (40), causing the seal shoe (36) to be pushed radially outward by the spring element (44).

18. The method according to claim 17, wherein the radial displacement of the seal shoe (36) is limited by a mechanical stopper (82, 84),

the mechanical stopper (82, 84) forming a radially outer stop (82a, 84a) that defines a radially outermost position of the seal shoe (36), and a radially inner stop (82b, 84b) that defines a radially innermost position of the seal shoe (36).

19. The method according to claim 18, wherein:

during the steady state operating condition, the seal shoe (36) is pushed into contact with the radially inner stop (82b, 84b), to remain in a closed position, and

during the transient operating condition, the seal shoe (36) is pushed into contact with the radially outer stop (82a, 84a), to remain in an open position.

20. The method according to any of claims 16 to 19, wherein the rotating component (34) is a rotor blade (26), and the stationary component (32) is a casing structure (28) positioned radially outward of a tip of the rotor blade (26).

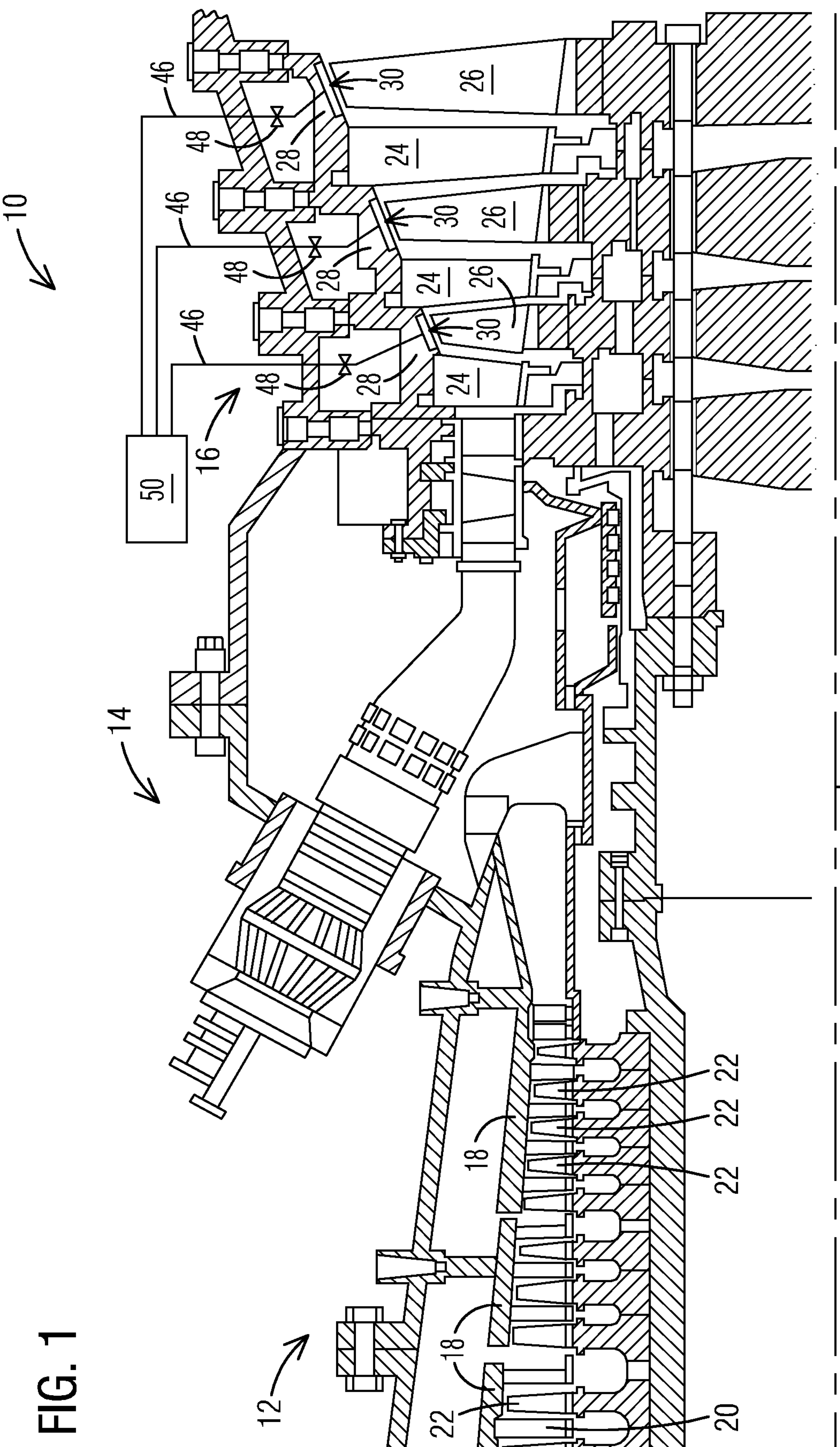
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FIG. 1

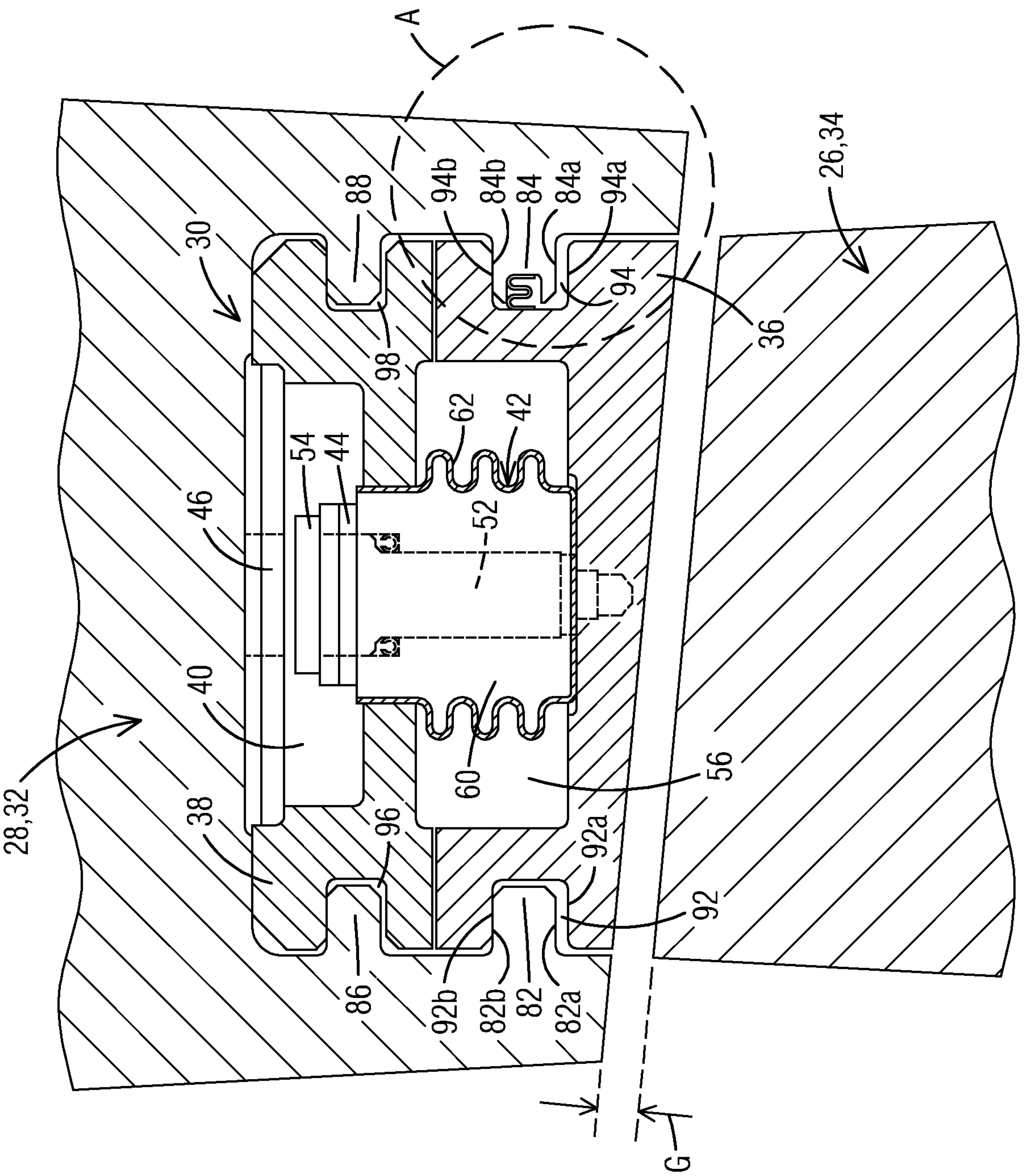
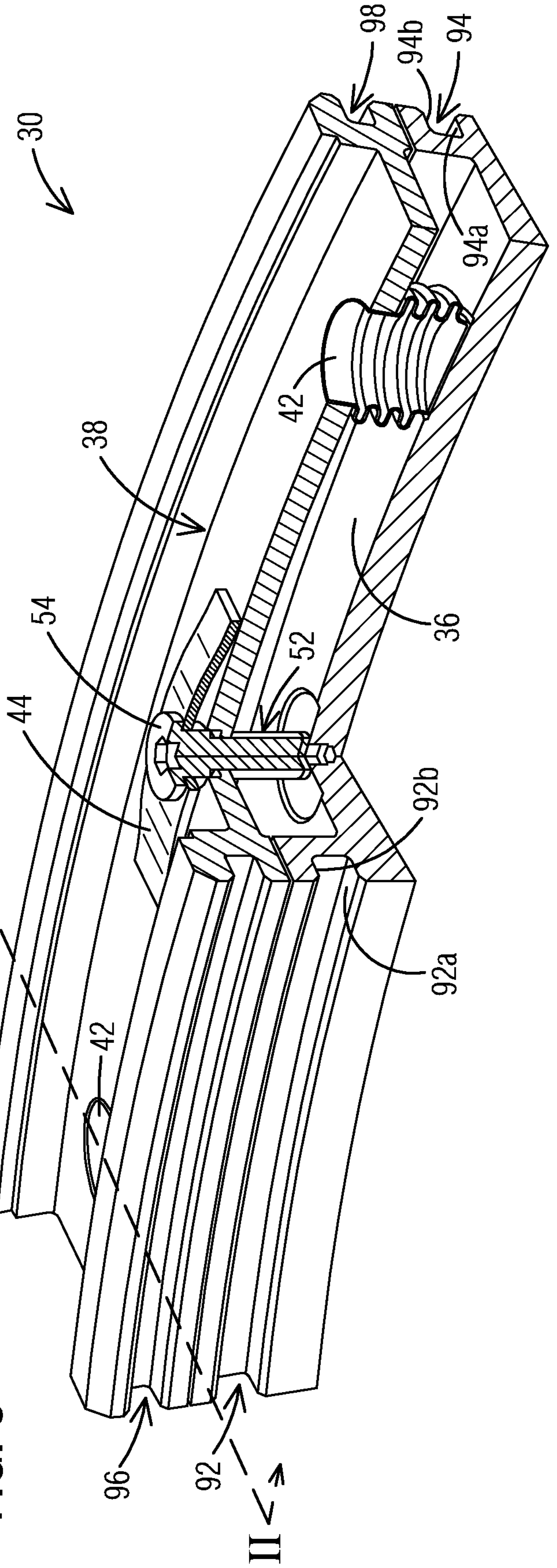


FIG. 2
View II-II



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98
94b
94
94a
42
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36
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52
44
92b
92a
II
42
96
92
II

FIG. 3

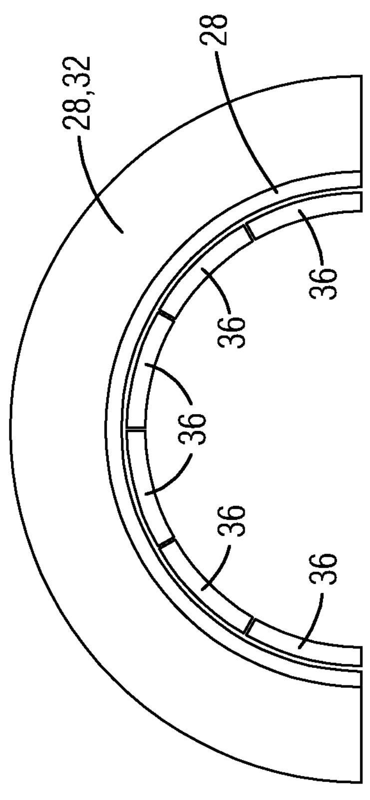

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FIG. 4

FIG. 5
View A

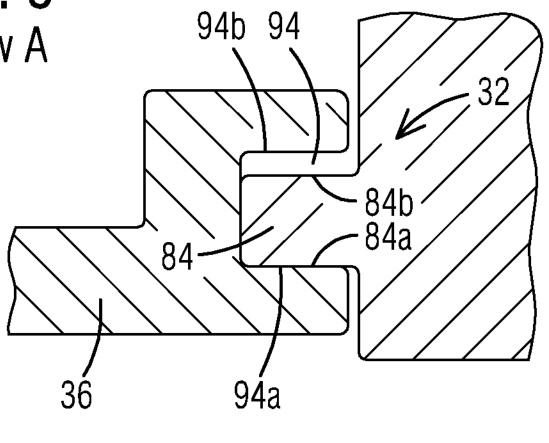


FIG. 6
View A

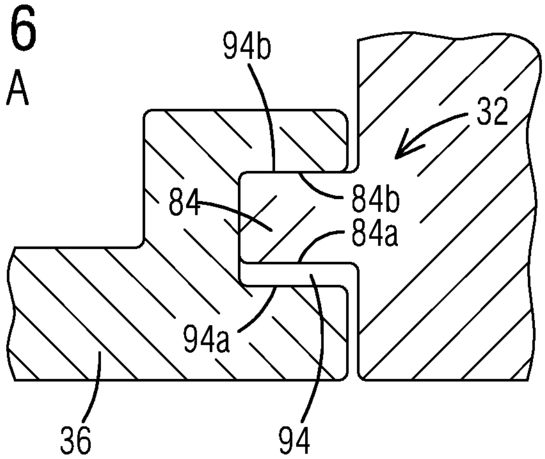
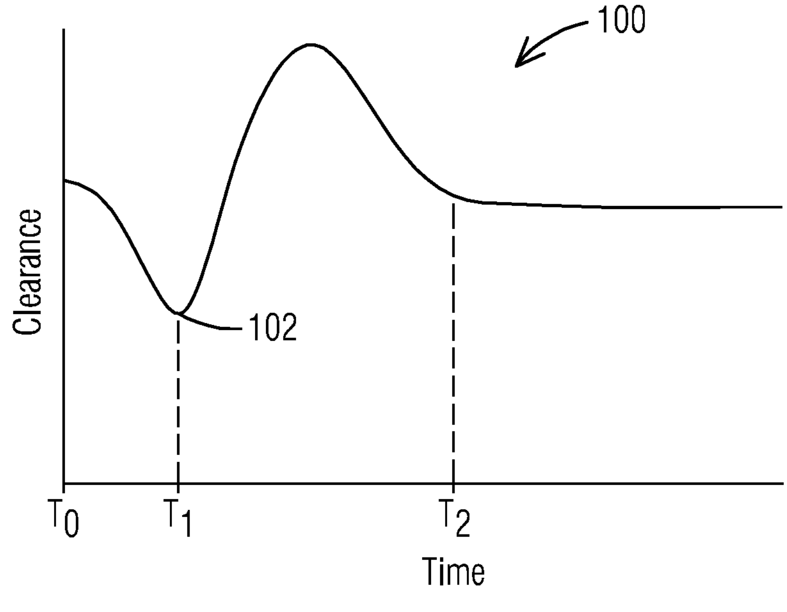


FIG. 7



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/066164

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01D11/22
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F01D

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 2017/051627 A1 (HAFNER MATTHEW TROY [US] ET AL) 23 February 2017 (2017-02-23) paragraphs [0013] - [0025] figure 1	1-3, 8-16,20 4-7, 17-19
X	JP S61 132707 A (TOSHIBA CORP) 20 June 1986 (1986-06-20) the whole document	1,3, 8-13,15, 16,20
X	JP S58 20904 A (HITACHI LTD) 7 February 1983 (1983-02-07) the whole document	1,3, 8-13,15, 16,20

-/--

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

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 August 2019	11/09/2019

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

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2017/044922 A1 (SHAPIRO JASON DAVID [US]) 16 February 2017 (2017-02-16) figures 2-6 paragraphs [0031] - [0050] -----	1,2, 8-13,15, 16

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