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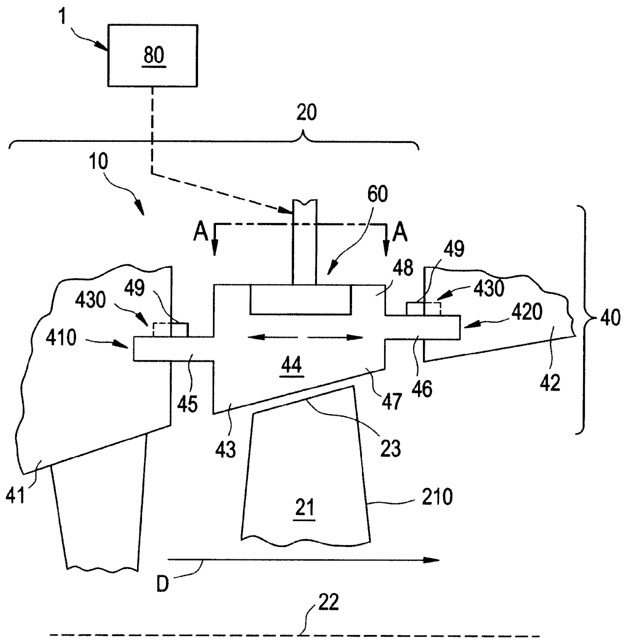
(54) Turbomachine having clearance control capability

(57) A turbomachine 10 having clearance control capability is provided and includes a turbine stage 20 including a blade 21 configured to rotate around a centerline 22, a movable portion 43 of a casing 40 circumferentially surrounding the turbine stage 20 and a rotatable cam 60 operably coupled to the movable portion and thereby configured to control an axial position of the movable portion. A radially outermost tip of the blade 21 and an interior surface of the movable portion 43 are sloped with respect to the centerline such 22 that the controlled axial position of the movable portion 43 is determinative of a clearance between the blade 21 and the movable portion 43.

FIG. 1



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Description

[0001] The subject matter disclosed herein relates generally to turbomachines and, more particularly, to turbomachines having clearance control capability.

[0002] A typical turbomachine, such as a gas turbine engine, a steam turbine engine and a compressor, includes a compressor section, a combustor section and a turbine section. The compressor section compresses inlet air and transmits the compressed inlet air to the combustor section. The combustor section combusts the compressed inlet air along with fuel to produce high energy fluids, which are transferred to the turbine section where they are expanded in power generation operations. During these power generation operations, the high energy fluids aerodynamically interact with successive stages of turbine blades, which are encompassed within a turbine casing with clearances provided between the casing and the tips of the blades.

[0003] At each stage, the high energy fluids impinge upon the turbine blades and induce rotation of the turbine blades about a rotor. Since the high energy fluids have high temperatures and pressures, the turbine blades and the casing often undergo thermal deformation (i.e., expansion or contraction) based on a type of turbine operation being conducted. Such deformation can be accounted for by setting the clearances in accordance with worst case scenarios. Under normal operating conditions, however, clearances set in accordance with worst case scenarios may be excessive and could lead to degraded performance due to leakages between the casing and the tips of the blades.

[0004] According to one aspect of the invention, a turbomachine having clearance control capability is provided and includes a turbine stage including a blade configured to rotate around a centerline, a movable portion of a casing circumferentially surrounding the turbine stage and a rotatable cam operably coupled to the movable portion and thereby configured to control an axial position of the movable portion. A radially outermost tip of the blade and an interior surface of the movable portion are sloped with respect to the centerline such that the controlled axial position of the movable portion is determinative of a clearance between the blade and the movable portion.

[0005] According to another aspect of the invention, a turbomachine having clearance control capability is provided and includes a turbine stage including a blade configured to rotate around a centerline, a casing circumferentially surrounding the turbine stage and including forward, aft and movable portions, the movable portion being axially interposed and secured between the forward and aft portions and defining a cam seat in a radially exterior surface thereof and a rotatable cam received within and operably coupled to the cam seat of the movable portion, the rotatable cam being thereby configured to control an axial position of the movable portion in accordance with rotation thereof. A radially outermost tip of the blade and an interior surface of the movable portion are sloped with respect to the centerline such that the controlled axial position of the movable portion is determinative of a clearance between the blade and the movable portion.

[0006] According to yet another aspect of the invention, a system providing a turbomachine with clearance control capability is provided and includes at least one or more turbine stages, each of the at least one or more turbine stages including a blade configured to rotate around a centerline, a movable portion of a casing circumferentially surrounding the at least one or more turbine stages, a rotatable cam operably coupled to the movable portion and thereby configured to control an axial position of the movable portion and a controller. A radially outermost tip of the blade of each of the at least one or more turbine stages and an interior surface of the movable portion are sloped with respect to the centerline such that the controlled axial position of the movable portion is determinative of a clearance between the blade of each of the at least one or more turbine stages and the movable portion. The controller is operably coupled to the rotatable cam and thereby configured to control operations of the rotatable cam.

[0007] Various advantages and features will become more apparent from the following description taken in conjunction with the drawings.

[0008] The subject matter, which is regarded as the invention, is particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The foregoing and other features, and advantages of the invention are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a side view of a portion of a turbomachine in accordance with embodiments;

FIG. 2 is a radial view of a rotatable cam and cam seat of the turbomachine portion of FIG. 1 along the line A-A;

FIG. 3 is a side view of a portion of a turbomachine in accordance with alternative embodiments;

FIG. 4 is a radial view of the turbomachine portion of FIG. 3 along the line B-B; and

FIG. 5 is a side view of a portion of a turbomachine in accordance with further embodiments.

[0009] The detailed description explains embodiments of the invention, together with advantages and features, by way of example with reference to the drawings.

[0010] With reference to FIGS. 1 and 2, a portion of a turbomachine 10 having clearance control capability is illustrated. As shown in FIG. 1, the portion of the turbomachine 10 includes a turbine stage 20 that is normally defined with a stationary blade row (i.e., nozzles) and a rotating blade row (i.e., buckets), a casing 40, a rotatable cam 60 and a controller 80. The turbine stage 20 may be any one of at least one or more of several turbine stages disposed at various axial locations along the turbomachine 10, including, but not limited to, the last turbine stage. In any case, the turbine stage 20 includes a blade 21 that is configured to rotate along with a blade row around a centerline 22. That is, the blade 21 may be provided as a plurality of blades that is arranged in a circumferential array 210 around the centerline 22. Each blade 21 has an airfoil shape such that aerodynamic interactions between the blade 21 and a working fluid flowing through the turbine stage 20 induces rotation of the blade 21 around the centerline 22. Each blade 21 also includes a sloped tip 23 at a radially outermost edge thereof.

[0011] As the turbine stage 20 may be unshrouded, the casing 40 is provided to circumferentially surround the turbine stage 20 and, in some cases, additional stages as shown in FIG. 5, which is described below. The casing 40 includes an annular forward portion 41, an annular aft portion 42 and an annular movable portion 43. The annular movable portion 43 is axially interposed and secured between the annular forward portion 41 and the annular aft portion 42 and includes an annular central body 44, a first annular flange 45, a second annular flange 46, a sloped interior facing surface 47 and a radially exterior surface 48. The annular forward portion 41 is formed to define an aft facing recess 410 and the annular aft portion 42 is similarly formed to define a forward facing recess 420.

[0012] The first annular flange 45 extends in a forward axial direction from the annular central body 44 and is movably receivable within the aft facing recess 410. The second annular flange 46 extends in an aft axial direction from the annular central body 44 and is movably receivable in the forward facing recess 420. As the annular movable portion 43 moves axially forwardly, the first annular flange 45 penetrates relatively deeply into the aft facing recess 410 while the second annular flange 46 recedes from but does not exit the forward facing recess 420. By contrast, as the annular movable portion 43 moves axially aft, the first annular flange 45 recedes from but does not exit the aft facing recess 410 while the second annular flange 46 penetrates relatively deeply into the forward facing recess 420.

[0013] Anti-rotation features, such as annularly discrete tabs 49 may be disposed on the movable portion 43 at, for example, either or both of the first annular flange 45 and the second annular flange 46. Such annularly discrete tabs 49 are receivable in secondary recesses 430 defined in the annular forward portion 41 and the annular aft portion 42. As described above, as the annular movable portion 43 moves axially forward or aft, the annularly discrete tabs 49 penetrate relatively deeply into and recede from the secondary recesses 430. While receding, the annularly discrete tabs 49 do not exit the secondary recesses 430.

[0014] The sloped interior facing surface 47 of the annular movable portion 43 is disposable radially outwardly from the sloped tip 23 of the blade 21 at a distance that is defined by the controlled clearance between the blade 21 and the annular movable portion 43. The sloped tip 23 and the sloped interior facing surface 47 may be provided substantially in parallel with one another and slope away from the centerline 22 with increasing distance in the aft axial direction, D. The sloped tip 23 provides for improved boundary layer conditions downstream from the turbine stage 20 and thereby allows for relatively aggressive exhaust diffuser performance.

[0015] The rotatable cam 60 is operably coupled to the annular movable portion 43 and is thereby configured to control an axial position of the annular movable portion 43. With the sloped tip 23 and the sloped interior facing surface 47 being mutually sloped with respect to the centerline 22, the controlled axial position of the annular movable portion 43 is determinative of a controlled amount of clearance between the blade 21 and the annular movable portion 43 or, more specifically, between the sloped tip 23 and the sloped interior facing surface 47. This control allows for improved efficiency and output for the turbine stage 20 in the unshrouded condition and could be similarly applicable and useful for shrouded turbine stages as well.

[0016] The rotatable cam 60 includes a drive shaft 61, which may be operably coupled to the controller 80 to be described in greater detail below, and a head portion 62. The head portion 62 may be generally circular, for example, and may be coupled in an off-center condition to the drive shaft 61. As the drive shaft 61 rotates about longitudinal axis 610, the head portion 62 bobs back and forth on either side of the drive shaft 61.

[0017] The radially exterior surface 48 of the annular movable portion 43 is formed to define a cam seat 90. The cam seat 90 is receptive of the head portion 62 of the rotatable cam 60 such that the drive shaft 61 appears to extend, for example, radially outwardly from the annular movable portion 43. The cam seat 90 is configured to mechanically interfere with the head portion 62 such that, as the rotatable cam 60 rotates in first or second opposite directions about the longitudinal axis 610, the annular movable portion 43 correspondingly moves in first or second opposite axial directions, respectively. To this end, in accordance with embodiments, the cam seat 90 may include a recess 91 formed in the radially exterior surface 48, which is bounded on forward and aft sides by a pair of substantially parallel circumferential wall surfaces 92.

[0018] The head portion 62 sits tightly within the recess 91 such that its sidewalls abut each of the wall surfaces 92 in opposite directions. As the rotatable cam 60 rotates about the longitudinal axis 610, the forward and aft sides of the head portion 62 impinge upon the wall surfaces 92 and, therefore, force the annular movable portion 43 to movably reciprocate in forward and aft directions.

[0019] Although the head portion 62 and the cam seat

90 are described above as being a generally circular element and as a recess 91 that is bounded by wall surfaces 92, it is to be understood that this is merely exemplary and that other embodiments exist. For example, where the head portion 62 is generally circular, the cam seat 90 may also be provided as a circular or polygonal recess defined within the radially exterior surface 48.

[0020] The controller 80 is provided as a component of a system for providing the turbomachine 10 with clearance control capability. The controller 80 is operably coupled to the rotatable cam 60 and is configured to control operations of the rotatable cam 60. That is, the controller 80 could cause the rotatable cam 60 to rotate about the longitudinal axis 610 such that, at various operational conditions such as start-up conditions, turn-down conditions, transient conditions and base-load condition, the controlled amount of clearance between the blade 21 and the annular movable portion 43 has various predefined and/or appropriate values. In addition, the controller 80 may be further configured to sense or otherwise measure current clearance amounts and, if such current clearance amounts are excessive or decreased given current operational conditions, to correct the current clearance amounts by selectively operating the rotatable cam 60 accordingly.

[0021] In accordance with embodiments, the features described above could be provided as single components or as multiple components. In the latter case, multiple rotatable cams 60 may each be operably coupled to the controller 80 and disposed circumferentially about the centerline 22. With such a configuration, each rotatable cam 60 may be jointly or separately operable based on current conditions.

[0022] With reference to FIGS. 3 and 4 and, in accordance with alternative embodiments, a turbomachine 100 is provided with clearance control capability. The turbomachine 100 includes several of the features mentioned above, which need not be described in detail again, such as the turbine stage 20, the blade 21 and the movable portion 43. In this case, a rotatable cam 101 is operably disposed at a location that is axially adjacent to the movable portion 43 and is configured to urge the movable portion 43 against a bias of elastic element 102 by rotating about drive shaft 103. The elastic element 102 may be a compression spring where the elastic element 102 is disposed on an opposite side of the movable portion 43 from the rotatable cam 101 or a tension spring in an opposite configuration. As shown in FIG. 3, an anti-rotation feature 104 may be disposed on a radially exterior surface of the movable portion 43 and a torsional spring 105 may be provided on the rotatable cam 101 to bias the movable portion 43 toward increased clearance to avoid rubbing in case of failure of control algorithms and systems.

[0023] With reference to FIG. 5 and, in accordance with further embodiments, the casing 40 and particularly the movable portion 43 may be configured to circumferentially surround at least one or more turbine stages. For example, the movable portion 43 may circumferentially surround first turbine stage 200 and second turbine stage 210. As shown in FIG. 5, the first and second turbine stages 200 and 210 may be disposed sequentially with respect to one another with the second turbine stage 210 downstream from the first turbine stage 200. The first turbine stage 200 includes a stationary blade row (i.e., nozzles) 201 and a rotating blade row (i.e., buckets) 202 and the second turbine stage 210 includes a stationary blade row (i.e., nozzles) 211 and a rotating blade row (i.e., buckets) 212.

[0024] While the invention has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the invention is not limited to such disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. Additionally, while various embodiments of the invention have been described, it is to be understood that aspects of the invention may include only some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

[0025] Various aspects and embodiments of the present invention are defined by the following numbered clauses:

1. A turbomachine having clearance control capability, comprising:

   a turbine stage including a blade configured to rotate around a centerline;
   a movable portion of a casing circumferentially surrounding the turbine stage; and
   a rotatable cam operably coupled to the movable portion and thereby configured to control an axial position of the movable portion,
   a radially outermost tip of the blade and an interior surface of the movable portion being sloped with respect to the centerline such that the controlled axial position of the movable portion is determinative of a clearance between the blade and the movable portion.

2. The turbomachine according to clause 1, wherein the blade is plural and the plurality of the blades are circumferentially arrayed around the centerline.

3. The turbomachine according to any preceding clause, wherein the tip and the interior surface are disposable substantially in parallel with one another.

4. The turbomachine according to any preceding clause, wherein the rotatable cam comprises:

   a drive shaft; and

a head portion, which is coupled off-center to the drive shaft.

5. The turbomachine according to any preceding clause, wherein the movable portion comprises a radially exterior surface defining a cam seat, which is receptive of the rotatable cam.

6. The turbomachine according to any preceding cluase, wherein the cam seat is configured to interfere with the rotatable cam such that, as the rotatable cam rotates in first or second opposite directions, the movable portion moves in first or second opposite axial directions, respectively.

7. The turbomachine according to any preceding clause, wherein the cam seat comprises a pair of substantially parallel circumferential wall surfaces.

8. The turbomachine according to any preceding clause, wherein the movable portion comprises:

a central body; and
flanges extending in forward and aft directions from the central body, respectively,
the flanges being movable in forward and aft axial directions within first and second recesses defined in forward and aft portions, respectively, the forward and aft portions being disposed forward and aft of the movable portion, respectively.

9. The turbomachine according to any preceding clause, further comprising an anti-rotation feature disposed on the movable portion.

10. The turbomachine according to any preceding clause, wherein the turbine stage comprises at least one or more turbine stages, each of which is circumferentially surrounded by the movable portion.

11. A turbomachine having clearance control capability, comprising:

a turbine stage including a blade configured to rotate around a centerline;
a casing circumferentially surrounding the turbine stage and including forward, aft and movable portions, the movable portion being axially interposed and secured between the forward and aft portions and defining a cam seat in a radially exterior surface thereof; and
a rotatable cam received within and operably coupled to the cam seat of the movable portion, the rotatable cam being thereby configured to control an axial position of the movable portion in accordance with rotation thereof,
a radially outermost tip of the blade and an interior surface of the movable portion being sloped with respect to the centerline such that the controlled axial position of the movable portion is determinative of a clearance between the blade and the movable portion.

12. The turbomachine according to any preceding clause, wherein the blade is plural and the plurality of the blades are circumferentially arrayed around the centerline.

13. The turbomachine according to any preceding clause, wherein the tip and the interior surface are disposable substantially in parallel with one another.

14. The turbomachine according to any preceding clause, wherein the rotatable cam comprises:

a drive shaft; and
a head portion, which is coupled off-center to the drive shaft.

15. The turbomachine according to any preceding clause, wherein the cam seat is configured to interfere with the head portion of the rotatable cam such that, as the rotatable cam rotates in first or second opposite directions about the drive shaft, the movable portion moves in first or second opposite axial directions, respectively.

16. The turbomachine according to any preceding clause, wherein the cam seat comprises a pair of substantially parallel circumferential wall surfaces.

17. The turbomachine according to any preceding clause, wherein the movable portion comprises:

a central body; and
flanges extending in forward and aft directions from the central body, respectively,
the flanges being movable in forward and aft axial directions within first and second recesses defined in the forward and aft portions, respectively.

18. The turbomachine according to any preceding clause, further comprising anti-rotation features disposed on the movable portion.

19. The turbomachine according to any preceding clause, wherein the turbine stage comprises at least one or more turbine stages, each of which is circumferentially surrounded by the movable portion.

20. A system providing a turbomachine with clearance control capability, comprising:

at least one or more turbine stages, each of the

at least one or more turbine stages including a blade configured to rotate around a centerline;
a movable portion of a casing circumferentially surrounding the at least one or more turbine stages;
a rotatable cam operably coupled to the movable portion and thereby configured to control an axial position of the movable portion; and
a controller,
a radially outermost tip of the blade of each of the at least one or more turbine stages and an interior surface of the movable portion being sloped with respect to the centerline such that the controlled axial position of the movable portion is determinative of a clearance between the blade of each of the at least one or more turbine stages and the movable portion, and
the controller being operably coupled to the rotatable cam and thereby configured to control operations of the rotatable cam.

Claims

1. A turbomachine (10) having clearance control capability, comprising:

    a turbine stage (20) including a blade (21) configured to rotate around a centerline (22);
    a movable portion (43) of a casing (40) circumferentially surrounding the turbine stage (20); and
    a rotatable cam (60) operably coupled to the movable portion (43) and thereby configured to control an axial position of the movable portion (43),
    a radially outermost tip of the blade (21) and an interior surface of the movable portion (43) being sloped with respect to the centerline (22) such that the controlled axial position of the movable portion (43) is determinative of a clearance between the blade (21) and the movable portion (43).

2. The turbomachine (10) according to claim 1, wherein the blade (21) is plural and the plurality of the blades are circumferentially arrayed around the centerline.

3. The turbomachine (10) according to any preceding claim, wherein the tip and the interior surface are disposable substantially in parallel with one another.

4. The turbomachine (10) according to any preceding claim, wherein the rotatable cam (60) comprises:

    a drive shaft (61); and
    a head portion (62), which is coupled off-center to the drive shaft.

5. The turbomachine (10) according to any preceding claim, wherein the movable portion (43) comprises a radially exterior surface defining a cam seat (90), which is receptive of the rotatable cam.

6. The turbomachine (10) according to claim 5, wherein the cam seat (90) is configured to interfere with the rotatable cam such that, as the rotatable cam rotates in first or second opposite directions, the movable portion moves in first or second opposite axial directions, respectively.

7. The turbomachine (10) according to claim 5 or claim 6, wherein the cam seat (90) comprises a pair of substantially parallel circumferential wall surfaces.

8. The turbomachine (10) according to any preceding claim, wherein the movable portion (43) comprises:

    a central body; and
    flanges extending in forward and aft directions from the central body, respectively,
    the flanges being movable in forward and aft axial directions within first and second recesses defined in forward and aft portions, respectively, the forward and aft portions being disposed forward and aft of the movable portion (43), respectively.

9. The turbomachine (10) according to any preceding claim, further comprising an anti-rotation feature (104) disposed on the movable portion (43).

10. The turbomachine (10) according to any preceding claim, wherein the turbine stage (20) comprises at least one or more turbine stages, each of which is circumferentially surrounded by the movable portion (43).

11. A turbomachine (10) having clearance control capability, comprising:

    a turbine stage (20) including a blade configured to rotate around a centerline;
    a casing (40) circumferentially surrounding the turbine stage and including forward, aft and movable portions (43), the movable portion being axially interposed and secured between the forward and aft portions and defining a cam seat (90) in a radially exterior surface thereof; and
    a rotatable cam (60) received within and operably coupled to the cam seat of the movable portion, the rotatable cam being thereby configured to control an axial position of the movable portion in accordance with rotation thereof,
    a radially outermost tip of the blade and an interior surface of the movable portion being sloped with respect to the centerline such that

the controlled axial position of the movable portion is determinative of a clearance between the blade and the movable portion.

12. The turbomachine (10) according to claim 11, wherein the blade is plural and the plurality of the blades are circumferentially arrayed around the centerline.

13. The turbomachine (10) according to claim 11 or claim 12, wherein the tip and the interior surface are disposable substantially in parallel with one another.

14. The turbomachine (10) according to any of claims 11 to 13, wherein the rotatable cam (60) comprises:

a drive shaft; and
a head portion, which is coupled off-center to the drive shaft.

15. The turbomachine (10) according to any of claims 11 to 14, wherein the cam seat (90) is configured to interfere with the head portion of the rotatable cam (60) such that, as the rotatable cam (60) rotates in first or second opposite directions about the drive shaft, the movable portion (43) moves in first or second opposite axial directions, respectively.

FIG. 1

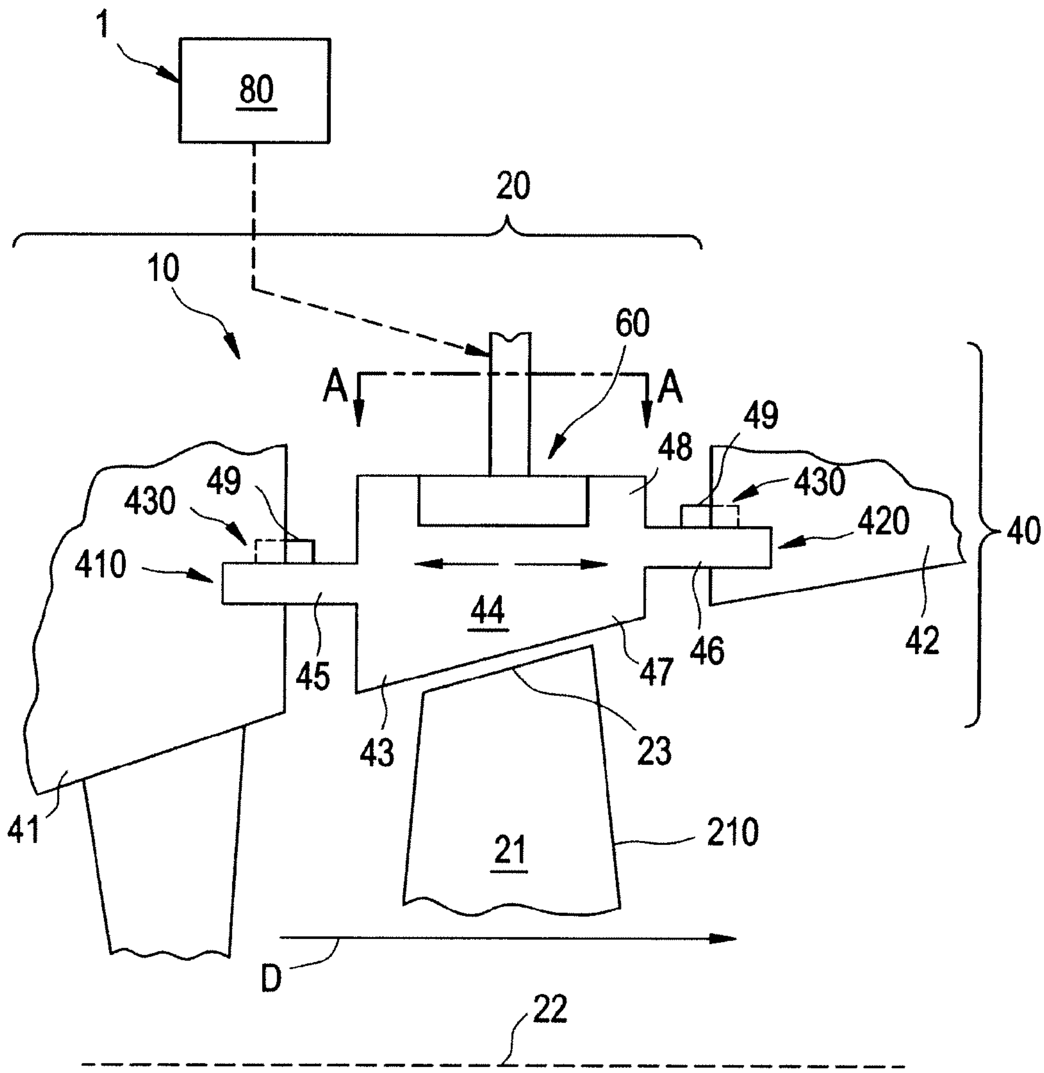
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FIG. 2

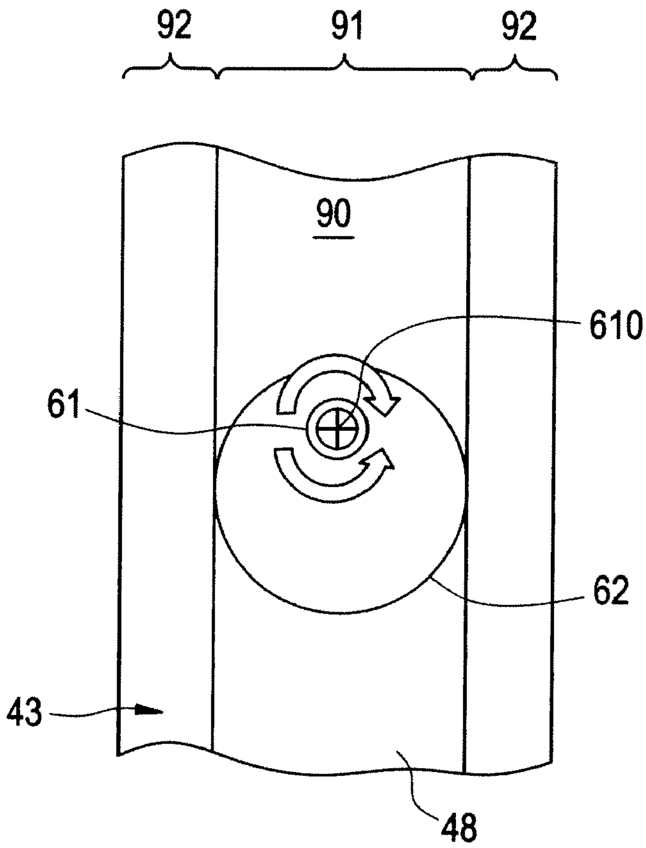


FIG. 3

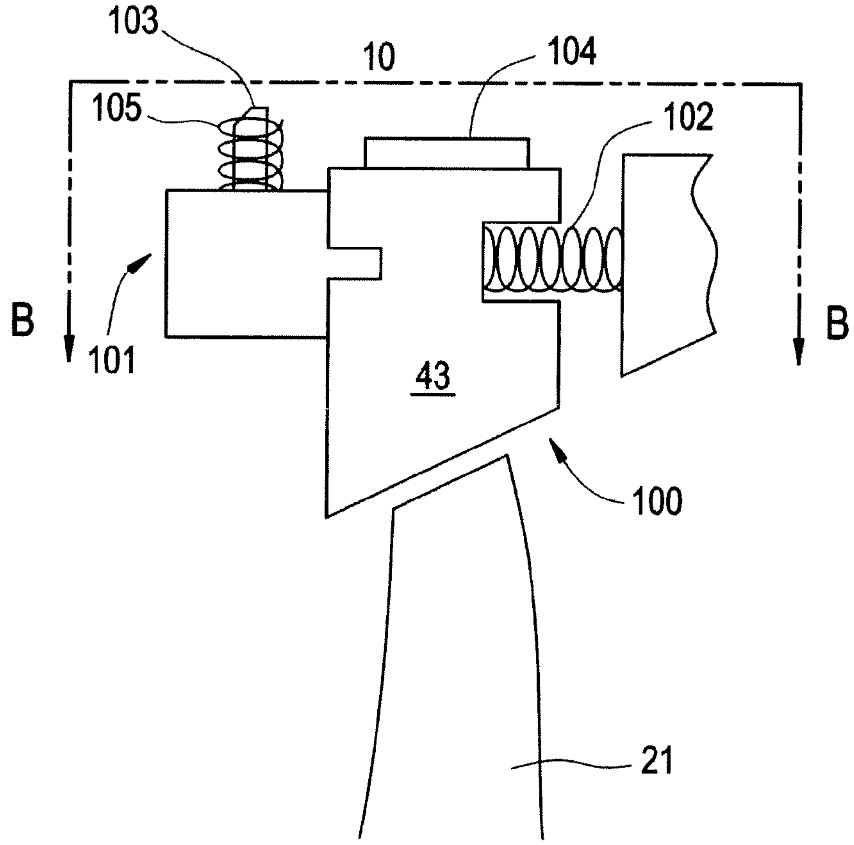


FIG. 4

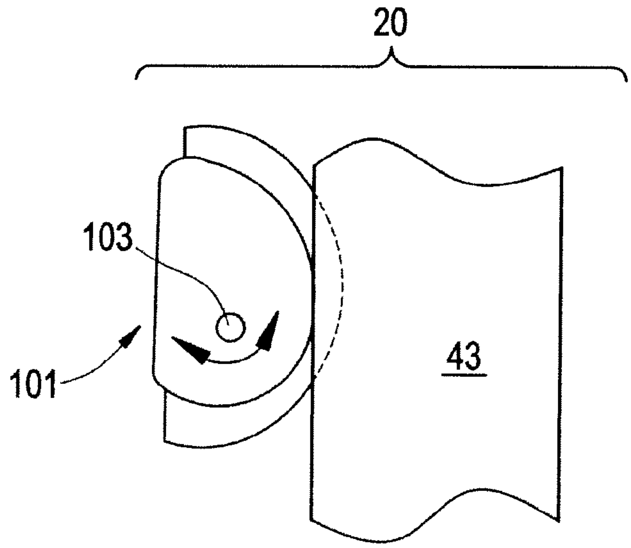
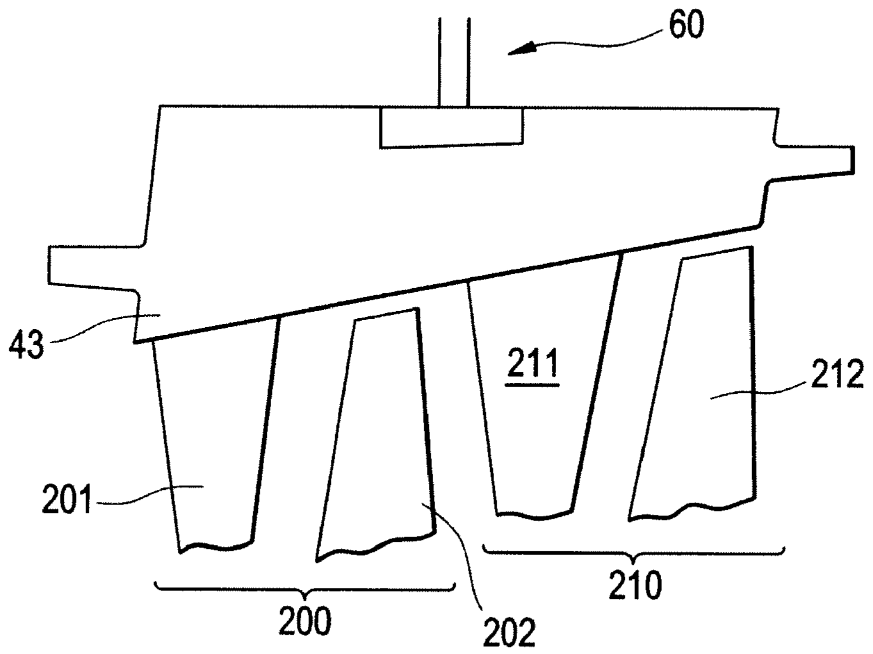


FIG. 5



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EUROPEAN SEARCH REPORT

Application Number
EP 13 16 7700

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	26 July 2013	Raspo, Fabrice

CATEGORY OF CITED DOCUMENTS

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