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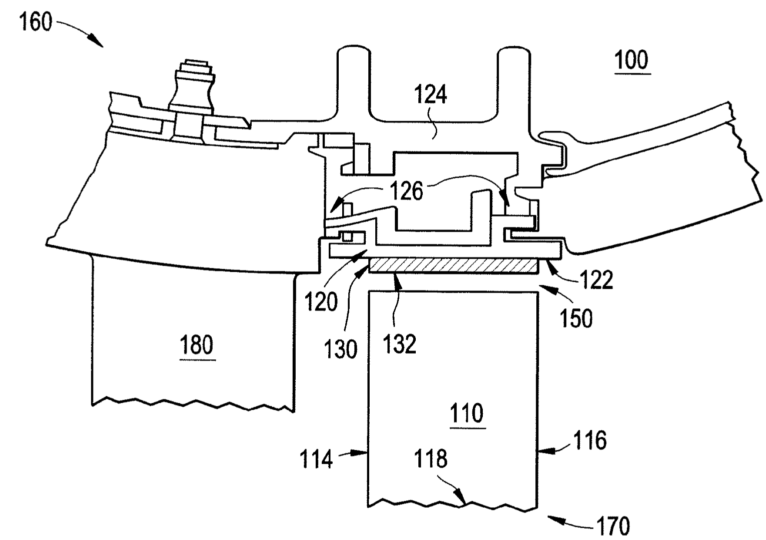
(54) **System and method for passively controlling clearance in a gas turbine engine**

(57) A system for passively controlling clearance in a turbine engine (100) comprises a static assembly (160) arranged circumferentially about an engine rotor assembly (170) and defining a gap (150) between a tip end (112) of the rotor assembly (170) and an adjacent inner surface (132) of the static assembly (160). The static assembly includes a gap control member (130) that defines the inner surface (132), is exposed to the engine working fluid, and comprises a shape memory material selected and preconditioned to deform in a preselected manner in response to a temperature of the engine working fluid. Alternatively, airfoil blades of the rotor assembly include the gap control member (230). A method for passively controlling clearance in a turbine engine (100) comprises assembling the engine so as to define an initial set of build clearances, operating the engine to observe running clearances, configuring a gap control member (130) comprising a shape memory material and re-assembling the engine with the gap control member (130).

FIG. 1



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Description

BACKGROUND OF THE INVENTION

[0001] The subject matter disclosed herein relates to clearance control systems for gas turbine engines, and more particularly, to a system and method for controlling operating clearance between a stationary shroud surface of a turbine engine and an adjacent rotating assembly.

[0002] Gas turbine engines typically include a rotating assembly housed within a static assembly. The rotating assembly typically includes sets of compressor blades (i.e., airfoils) and turbine blades. The compressor blades compress incoming air, and the turbine blades extract power from the air, usually after the addition of heat. The static assembly surrounds the rotating assembly and helps to define the flow path of the engine. Typically, a static assembly includes a series of shroud segments providing an inner surface to cooperate with outer surfaces (i.e., tips) of the blades of an adjacent rotating assembly. Efficiency of a turbine engine depends, at least in part, on the clearance or gap between the shroud surface and the adjacent rotating blades. If the clearance is excessive, a correspondingly excessive fraction of engine flow will pass through the gap rather than interacting with the rotating blades, resulting in reduced engine efficiency. If the clearance is too small, interference can occur between the rotating and stationary members of such assemblies, resulting in damage to one or more of the cooperating surfaces.

[0003] As used herein, the term axial refers to the direction of the central axis of a gas turbine engine, i.e., about which axis the turbo-machinery rotates. The term radial refers to a direction that is substantially perpendicular to the central axis, and the term circumferential refers to a set of locations and directions that do not intersect the central axis but that lie in one or more radial planes.

[0004] Complicating clearance problems in such apparatus is the well known fact that clearances between the rotor assembly and the static assembly of a turbine engine typically change with engine operating conditions such as acceleration, deceleration, or other changing thermal or centrifugal force conditions experienced by the cooperating members during engine operation. Clearance control mechanisms for such assemblies, sometimes referred to as active or passive clearance control systems, have included mechanical systems or systems based on thermal expansion and contraction characteristics of materials for the purpose of maintaining selected clearance conditions during engine operation. Such systems generally require use of substantial amounts of air for heating or cooling at the expense of such air otherwise being used in the engine operating cycle.

[0005] Accordingly, those skilled in the art seek improved means for controlling operating clearance between a stationary shroud surface of a turbine engine and an adjacent rotating assembly.

BRIEF DESCRIPTION OF THE INVENTION

[0006] According to one aspect of the invention, a system for passively controlling clearance in a gas turbine engine comprises a static assembly arranged circumferentially about an engine rotor assembly and defining a gap between a tip end of the rotor assembly and an inner surface of the static assembly adjacent to the tip end. The system includes a gap control member that defines the inner surface, is exposed to the engine working fluid, and comprises a shape memory material selected and preconditioned to deform in a pre-selected manner in response to a temperature of the engine working fluid.

[0007] The system may further comprise a rotor assembly having a plurality of airfoil blades, each blade having a tip end. The rotor assembly is surrounded by the static assembly comprising a plurality of shroud segments arranged circumferentially about the rotor assembly, each shroud segment having an inner surface adjacent to the tip end, and the inner surfaces of the shroud segments and the tip ends of the airfoil blades defining a radial gap between the tip ends and the inner surfaces. Each airfoil blade includes the gap control member that forms the tip end, the gap control member comprising a shape memory material selected and preconditioned to deform in a pre-selected manner in response to a temperature of the engine working fluid.

[0008] According to yet another aspect of the invention, a method for passively controlling clearance in a gas turbine engine comprises assembling the turbine engine so as to define an initial set of build clearances between a stationary shroud surface of the turbine engine and an adjacent rotor assembly of the turbine engine. The assembled engine is operated throughout a range of engine operating conditions, and an operating clearance is observed at one or more of the engine operating conditions. A gap control member is formulated and configured comprising a shape memory material selected and preconditioned to deform in a pre-selected manner in response to a temperature of the engine working fluid. The engine is re-assembled with the gap control member so as to define a revised set of build clearances between the stationary shroud surface and the adjacent rotor assembly.

[0009] These and other advantages and features will become more apparent from the following description taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWING

[0010] Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

FIG. 1 is a partially sectional view of a gas turbine engine including a static assembly and an adjacent blade, the view including one exemplary embodiment of a gap control member;

FIG. 2 is a partially sectional view of a gas turbine engine including a static assembly and an adjacent blade, the view including another exemplary embodiment of a gap control member with an abradable coating;

FIG. 3 is a partially sectional view of a gas turbine engine including a static assembly and an adjacent blade, the view including another exemplary embodiment of a gap control member;

FIG. 4 is an enlarged view depicting a portion of a gas turbine engine wherein an exemplary shroud with a gap control member and an abradable coating is in an open-clearance condition relative to the tip of an adjacent rotating blade;

FIG. 5 is an enlarged view depicting a portion of a gas turbine engine wherein an exemplary shroud with a gap control member and an abradable coating is in a closed-clearance condition relative to the tip of an adjacent rotating blade;

FIG. 6 is an enlarged view depicting a portion of a gas turbine engine wherein exemplary shroud segments include gap control members configured to compensate for eccentricity or other non-circularity in the assembled static structure; and

FIG. 7 is a flow chart of an exemplary method for reduced operating clearance between a stationary shroud surface of a turbine engine and an adjacent rotating assembly.

[0011] The detailed description explains embodiments of the invention, together with advantages and features, by way of example with reference to the drawings.

DETAILED DESCRIPTION OF THE INVENTION

[0012] FIG. 1 shows a portion of a gas turbine engine 100 comprising a rotating assembly 170 housed within a static assembly 160. Rotor assembly 170 carries a rotating blade 110, which has a tip end 112 and an apposing hub end 118. Rotating blade 110 also has a leading edge 114 and a trailing edge 116. As shown in FIG. 1, rotating blade is a turbine blade, but it should be appreciated that the features shown could be applied to a compressor.

[0013] Static assembly 160 includes stator 180, which guides a working fluid, such as air or steam or air mixed with fuel, toward the leading edge 114. Static assembly also includes shroud segments 120 that guide the working fluid through rotating blade 110 so that rotating blade 110 can extract energy (i.e., torque) from the fluid (or, in the case of a compressor, so that the blade can perform work on the fluid). Each shroud segment 120 has an inner shroud surface 122 on which gap control member 130 is attached. Gap control member 130 is exposed to the working fluid and has an inner controlled surface 132 facing radially inward toward tip end 112.

[0014] As rotor assembly 170 rotates about its central axis, tip end 112 travels adjacent to inner controlled surface 132, defining clearance gap 150. To reduce the size of clearance gap 150, static assembly 160 includes means for adjusting the radial position of shroud segment 120, including radial adjustment member 124, and shims 126.

[0015] Gap control member 130 comprises a shape memory material. A suitable shape memory material may comprise an alloy or a polymer or another material known in the art for providing a desired shape memory behavior characteristic. For example, a metallic shape memory alloy (SMA) is a metal alloy that changes from an initial shape to a second shape upon exposure to a transition temperature and changes back to the initial shape upon re-cooling. SMA materials that exhibit such shape changes with temperature typically undergo a solid state micro-structural phase change. This characteristic enables an article made from SMA to change from one physical shape to at least another physical shape and to return to the original shape. These changes in shape are much more dramatic than simple thermal expansion and contraction. In addition, with SMA, most or all of the changes in shape occur over a relatively small temperature range known as the transition temperature of the material. One example of a metallic SMA material is a titanium nickel alloy, also known as Nitinol alloy. Other metallic SMA materials may comprise ruthenium alloyed with niobium and/or tantalum. Transition temperatures of exemplary shape memory materials depend upon the particular composition of the material and can be configured to occur at temperatures between approximately 25 degrees C and about 1400 degrees C, with the transition temperature depending upon the specific formulation of the material.

[0016] In the manufacture (from such a metallic SMA or other shape memory material) of an article intended to change during operation from one shape to at least one other shape, the article is provided in a first shape intended for operating use at or above the transition temperature. Such first shape is developed by working and annealing an article comprising the alloy or other material at or above the transition temperature, at which the solid state micro-structural phase change occurs. However, below that critical temperature, such an alloy or other material may be malleable such that the article of the first shape can be deformed into a desired second shape, for example, to facilitate inclusion at substantially room temperature in an assembly. Thereafter, for example in service operation of the article, when the article in the second shape is heated at or above its critical temperature, it undergoes a micro-structural phase change that results in it returning to the first shape.

[0017] As noted above, gap control member 130 comprises a shape memory material and is exposed to the working fluid at its axial location in the flow-path. Therefore, while gap control member 130 may exchange some heat with shroud segment 120, the temperature of gap control member 130, under steady-state conditions, will approximate the temperature of the working fluid at its axial location. Thus, by formulating the material used to make gap control member 130, its shape can be programmed to change depending upon the flow-path temperature without requiring parasitic extraction of working fluid.

[0018] Contrariwise, radial adjustment member 124, which may also comprise shape memory material, is not typically directly exposed to the working fluid at its axial location. Instead, radial adjustment member 124 may be exposed to a mixture of fluid sources, enabling the temperature of the fluid to be actively controlled, and thereby enabling the shape of radial adjustment member 124 to be controlled. Yet, while the shape of radial adjustment member 124 may thus be controlled, doing so requires parasitic extraction of working fluid, which may mitigate performance gains that would otherwise be realized through the active clearance control scheme.

[0019] As discussed above, the size of clearance gap 150 depends upon a number of factors including initial build clearance, thermal expansion and/or contraction of static assembly 160 and rotor assembly 170, centrifugal stresses resulting from the rotational speed of the rotor assembly 170, external loads, aerodynamic loads, and other effects. These factors can cause the size of clearance gap 150 to change throughout the operational envelope of engine 100. In addition, the size of clearance gap 150 adjacent to leading edge 114 may not be equal to the size of clearance gap 150 adjacent to trailing edge 114. Moreover, as the shape of static assembly 160 may not be round, and thus the circumferential surface defined by the combination of inner controlled surfaces 132 may also not be round, the size of clearance gap 150 may vary from one shroud segment to another.

[0020] To compensate for these variations in the size of clearance gap 150, both the first shape and the second shape of gap control member 130 and the transition temperature of the shape memory material can be configured to contribute to a system for reducing the size of clearance gap 150. Other elements of an exemplary system may optionally include one or more active clearance control mechanisms such as radial adjustment member 124. Other passive elements may also be included such as shims 126. In practice, an engine may be assembled with relatively open clearances, and then operated throughout a range of operating conditions while detecting the operating clearances. Then, based on the observed data, one or more clearance adjustment mechanisms may be implemented so as to achieve a desired level of clearances.

[0021] In an exemplary embodiment, inner controlled surface 132 of gap control member 130 may exhibit a planar shape. In another embodiment, inner controlled surface 132 of gap control member 130 may exhibit a non-planar shape. In an exemplary embodiment, gap control member 130 may be configured to retain a first shape at temperatures less than 100 degrees C. In another exemplary embodiment, gap control member 130 may be configured to retain a first shape at temperatures less than 200 degrees C. In another exemplary embodiment, gap control member 130 may be configured to retain a first shape at temperatures less than 300 degrees C. Other embodiments of gap control member 130 may be formulated to change shape at temperatures of approximately 400 degrees C, 500 degrees C, 600 degrees C, 700 degrees C, 800 degrees C, or any other operating temperature where it is advantageous to change the shape of gap control member 130.

[0022] As shown in FIG. 2, static assembly 260 may include an abradable layer 240 disposed between gap control member 230 and blade 210. As systems and methods are implemented to reduce the size of clearance gap 250, risk increases that an inadvertent rub may occur between tip end 212 and any adjacent structure that is positioned radially outwardly from tip end 212. Abradable layer 240 may comprise a coating applied to a radially inward surface of gap control member 230 and may comprise a material that can deform or be abraded in the event of contact with tip end 212 without damaging tip end 212 or blade 210. Incorporation of abradable layer 240 will allow for closer clearances and offsetting the need to account for thermal expansion as well and changes in concentricity due to shock loading events.

[0023] Abradable layer 240 may be applied through thermal spraying, sintering, casting or any other suitable means known in the art. Thermal spraying involves sprayed application of melted or heated material. Sintering involves application of powdered metal followed by heating of the composite article. As shown in FIG. 3, a gap control member 330 may also be applied to a tip end 312 of blade 310.

[0024] FIG. 4 shows an enlarged view of the region of a gas turbine engine between a static assembly 420 and a rotor assembly 410. Gap control member 430 is attached to an inner shroud surface 422 of static assembly 420, and an abradable layer 440 is attached to gap control member 430 adjacent to tip end 412. As shown in FIG. 4, clearance gap 450 is relatively open, corresponding to a first shape of gap control member 430 that is relatively thin. A first shape of gap control member 430 occurs when the operating temperature of the working fluid is below the transition temperature of gap control member 430.

[0025] In juxtaposition, FIG. 5 shows an enlarged view of the same region as Fig. 4, wherein clearance gap 550 is relatively closed, corresponding to a second shape of gap control member 530 that is relatively thick. A second shape of gap control member 530 occurs when the operating temperature of the working fluid is above the transition temperature of gap control member 530.

[0026] FIG. 6 shows an enlarged view of a portion of a gas turbine engine wherein exemplary shroud segments 620 include gap control members 630 configured to compensate for eccentricity or other non-circularity in the assembled static assembly 660. As shown in Fig. 6, a relatively thin and constant clearance gap 650 is provided between blade 610 and inner shroud surface 622 by incorporation of gap control members 630. It should be noted that gap control members at 632 are relatively thin compared to gap control members at 634.

[0027] FIG. 7 is a flow chart showing an exemplary method for reduced operating clearance between a stationary shroud surface of a turbine engine and an adjacent rotating assembly. As shown in FIG. 7, an engine is assembled (step 710) comprising a static assembly and a rotor assembly. The engine is operated (step 720) throughout a range of operating conditions, and clearances are measured (step 730) at those operating conditions. Based on those measurements, a clearance control strategy is devised (step 740) considering available clearance control methods. Then, shape memory materials are formulated and configured (step 750) so as to configure customized gap control members that are capable of achieving desired shape changes at defined engine operating temperatures. The strategy is then implemented (step 760) and may comprise adjusting control schedules so as to maintain a desired level of clearances without rebuilding the engine or otherwise re-shimming or adjusting the static assembly of the engine. Once the engine has been re-assembled (step 770) with the clearance control strategy, clearances can again be evaluated (step 780) to determine the effectiveness of the implemented strategy. Finally, steps 740 through this step may be repeated (step 790) until a desirable clearance profile has been achieved.

[0028] Thus, the invention provides an improved system and method for reducing clearances and thereby improving gas turbine performance and efficiency. In accordance with the invention, shape memory materials are preconditioned to deform only upon achieving a predetermined temperature level, such as steady-state operating temperatures. As the gap control members that comprise the shape memory materials are positioned in or near to the working fluid, there is no external actuation medium required to actuate the gap control members. The invention provides a simple method for addressing eccentricity or other non-circularity in static assemblies and in operation of rotor assemblies and can be applied to compressor and turbine sections. In addition, the invention can be applied to address transient differences in dimensions of static assemblies and rotor assemblies and to address variations in manufacturing.

[0029] 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.

Claims

1. A system for passively controlling clearance in a gas turbine engine (100) comprising:

    a static assembly (160),
    the static assembly (160) being arranged circumferentially about an engine rotor assembly (170) and defining a gap (150) between a tip end (112) of the rotor assembly (170) and an inner surface (132) of the static assembly (160),
    at least one gap control member (130) defining the inner surface (132) adjacent to the tip end (112) and comprising a shape memory material selected and preconditioned to deform in a preselected manner in response to a temperature of a working fluid of the engine (100), and
    the at least one gap control member (130) being exposed to the working fluid.

2. The system of claim 1, wherein the at least one gap control member (130) comprises an abradable coating.

3. The system of claim 1 or claim 2, wherein the shape memory material comprises an alloy.

4. The system of claim 3, wherein the alloy comprises one of ruthenium, niobium or tantalum.

5. The system of any of claims 1 to 3, further comprising:

    a rotor assembly (170) comprising a plurality of airfoil blades (210), each of the airfoil blades (210) having a tip end;
    the rotor assembly (170) being surrounded by the static assembly (160) and comprising a plurality of shroud segments (120) arranged circumferentially about the rotor assembly (170);
    each shroud segment (120) having an inner surface (132) adjacent to the tip end (212);
    each of the airfoil blades (210) comprising the gap control member (230) at the tip end (212);
    the inner surfaces (132) of the shroud segments (170) and the tip ends (112) of the airfoil blades (210) defining the radial gap (250) between the tip ends (212) and the inner surfaces (132);

6. The system of claim 5, wherein the airfoil blade (210) is one of an axial compressor blade, an axial turbine

blade, a centrifugal compressor blade, or a radial turbine blade

7. A method for passively controlling clearance in a gas turbine engine (100) comprising:

assembling (710) the turbine engine (100) so as to define an initial set of build clearances (250) between a stationary shroud surface (260) of the turbine engine (100) and an adjacent rotor assembly (260) of the turbine engine (100);
operating (720) the assembled turbine engine (100) throughout a range of engine operating conditions;
observing (730) an operating clearance (250) at one or more of the engine operating conditions;
formulating and configuring (750) a gap control member (230)comprising a shape memory material selected and preconditioned to deform in a pre-selected manner in response to a temperature of an engine working fluid; and
re-assembling (770) the turbine engine (100) with the gap control member (230) so as to define a revised set of build clearances between the stationary shroud surface (260) and the adjacent rotor assembly (170).

8. The method of claim 7, further comprising, subsequently operating (790) the assembled turbine engine throughout a range of engine operating conditions and observing a revised operating clearance at one or more of the engine operating conditions.

9. The method of claim 7 or 8, further comprising formulating and configuring (790) an additional gap control member comprising a shape memory material selected and preconditioned to deform in a preselected manner in response to a temperature of the engine working fluid.

10. The method of any of claims 7 to 9, wherein the gap control member (230) comprises an abradable coating.

11. The method of any of claims 7 to 10, wherein the rotor assembly (230) is an axial compressor assembly.

12. The method of any of claims 7 to 10, wherein the rotor assembly (260) is an axial turbine assembly.

13. The method of any of claims 7 to 10, wherein the rotor assembly (260) is a centrifugal compressor assembly.

14. The method of any of claims 7 to 10, wherein the rotor assembly (260) is a radial turbine assembly.

FIG. 1

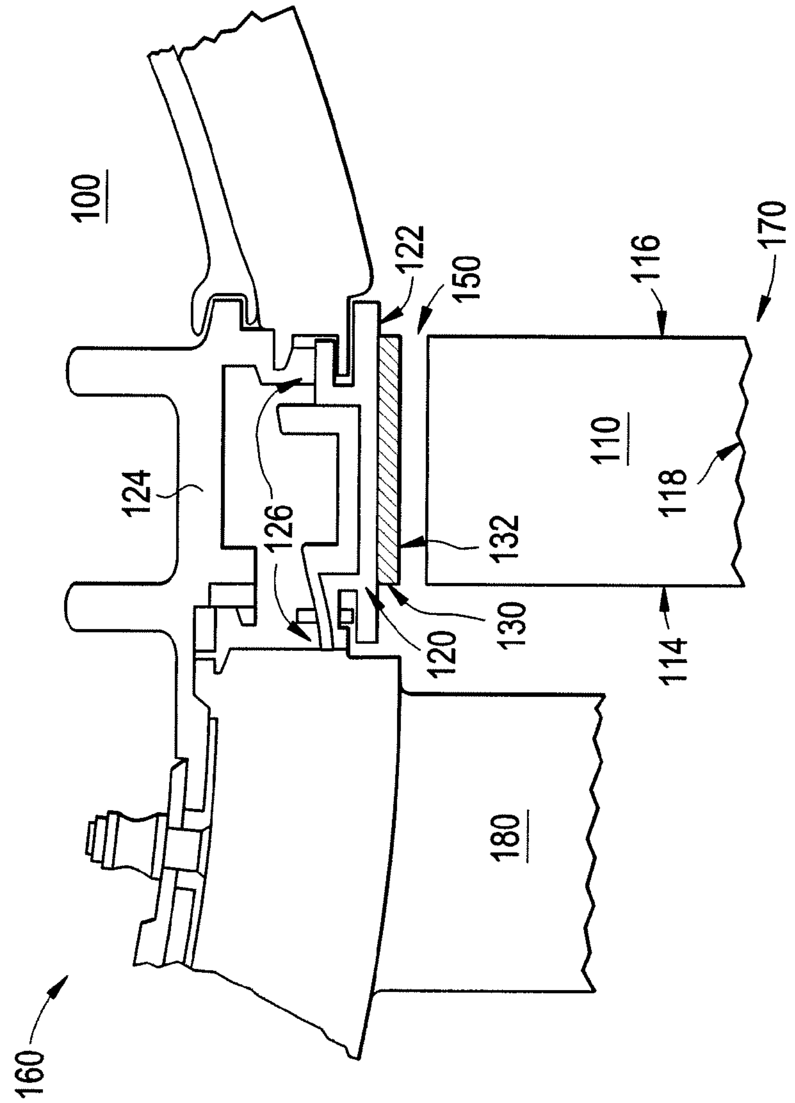


FIG. 2

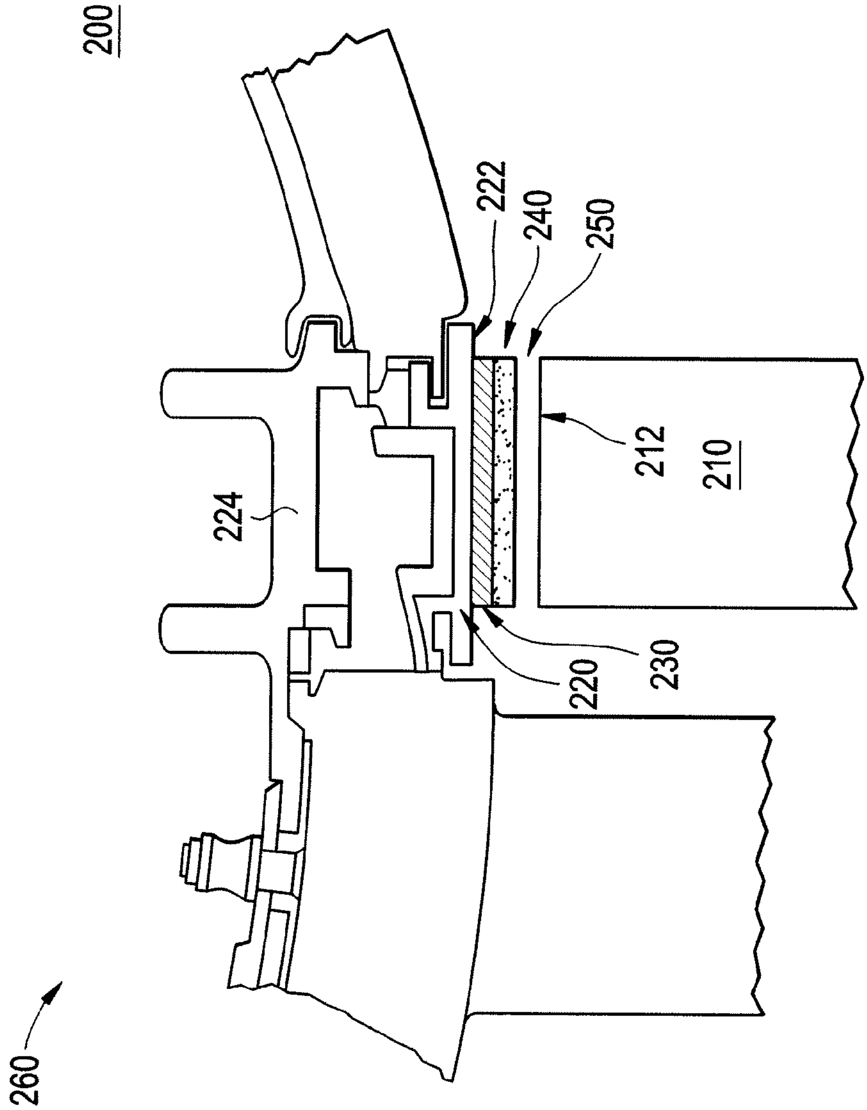


FIG. 3

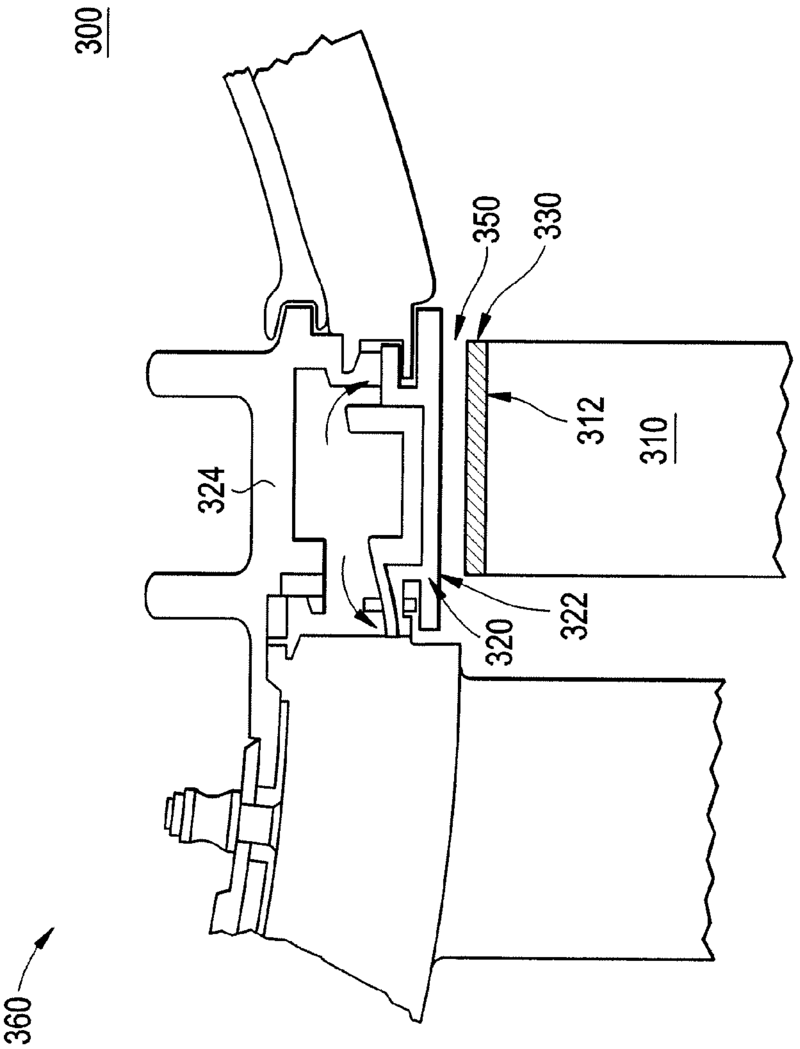


FIG. 4

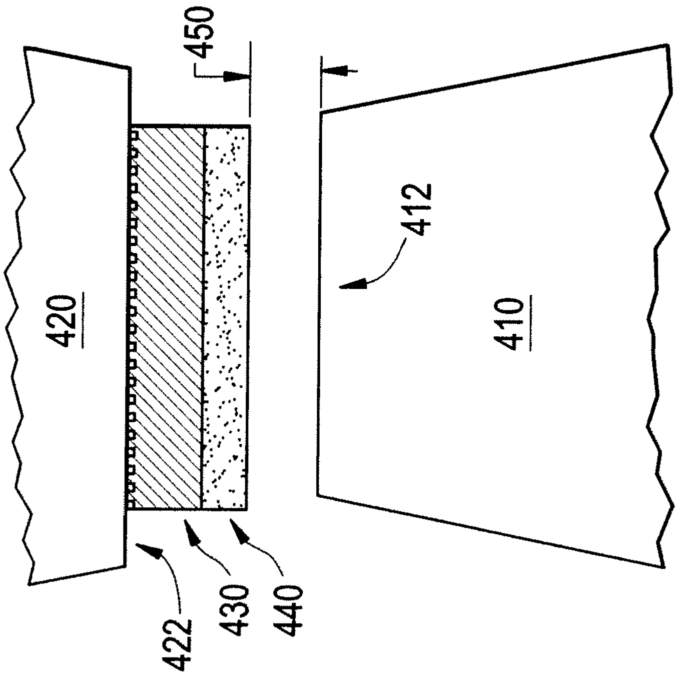


FIG. 5

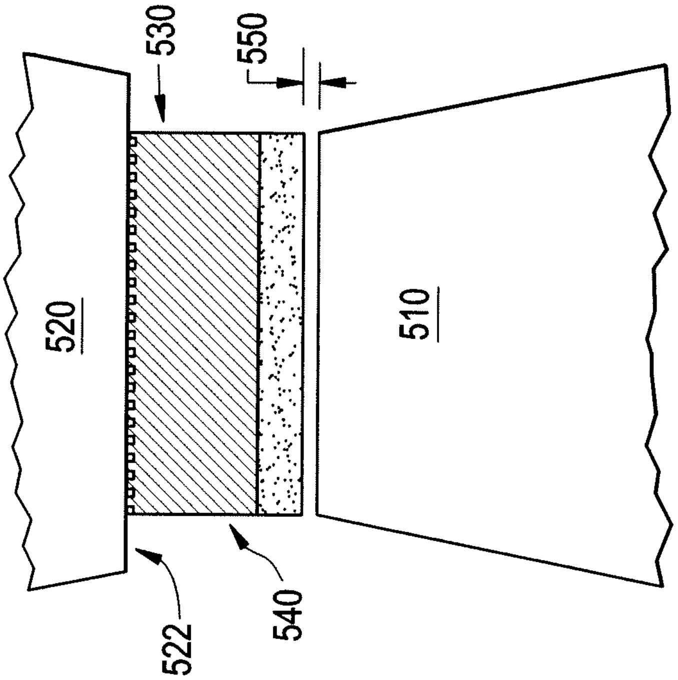


FIG. 6

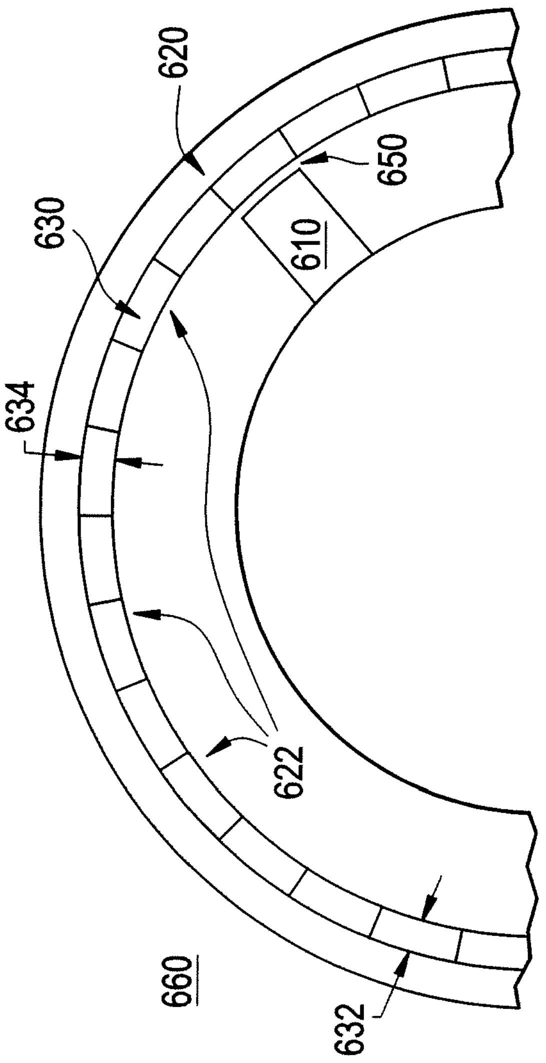
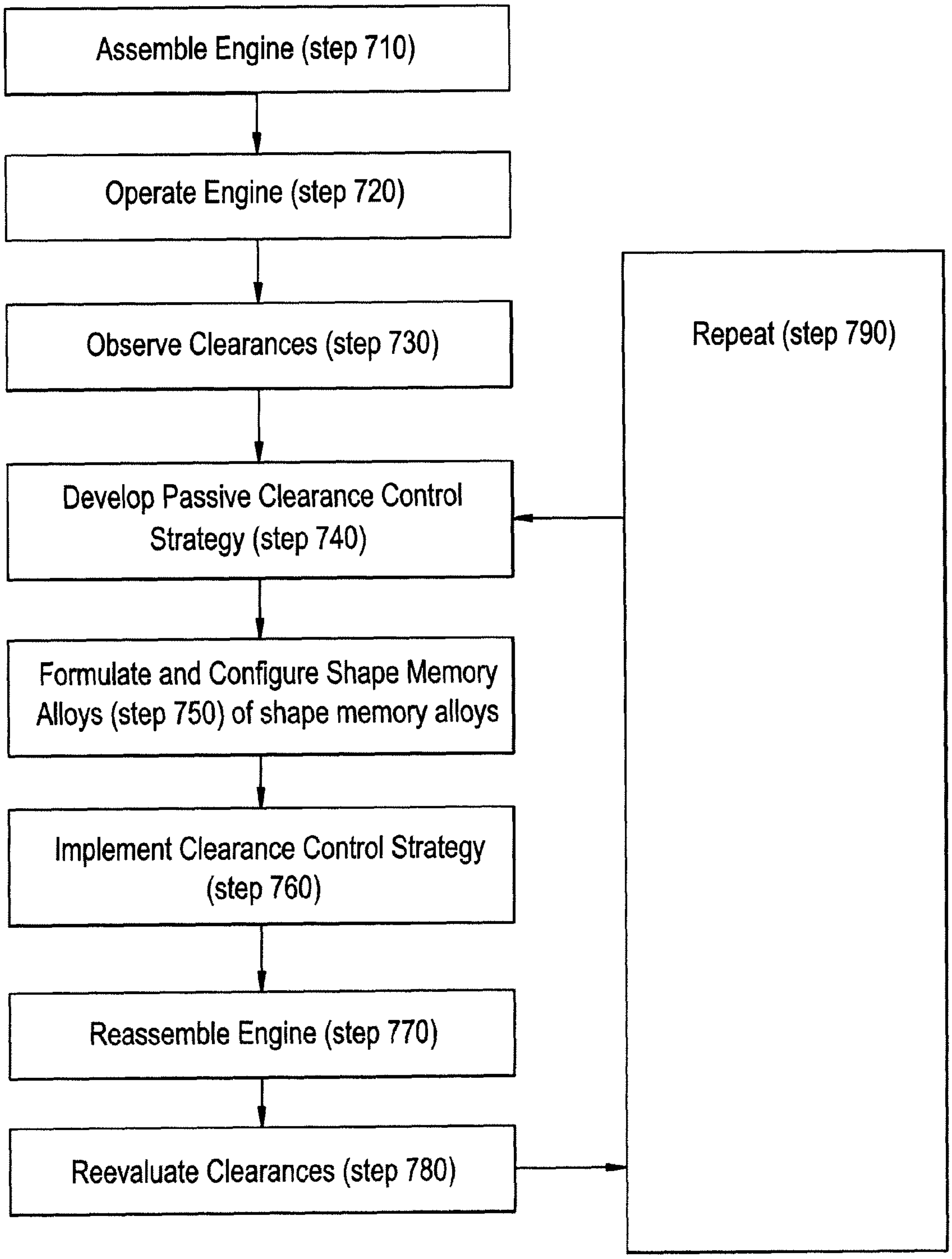


FIG. 7


Assemble Engine (step 710)
Operate Engine (step 720)
Observe Clearances (step 730)
Develop Passive Clearance Control Strategy (step 740)
Formulate and Configure Shape Memory Alloys (step 750) of shape memory alloys
Implement Clearance Control Strategy (step 760)
Reassemble Engine (step 770)
Reevaluate Clearances (step 780)
Repeat (step 790)