Fig. 6a

(57) Abstract: The disclosure describes a circumferential seal (46) applicable to turbine engines. The circumferential seal (46) includes a ceramic runner (52), an annular seal ring (49), at least one tolerance ring (70, 71), and a pair of sealing rings (68, 69). The runner (52) is circumscribed about a shaft (57) or a carrier (91) within a recess (98) along the shaft (57) and is bounded by a shoulder (55 or 92) and a clamping ring (74). At least one non-sealing spring mechanism (58 or 88) is disposed between and directly contacts the shoulder (55 or 92) and the first end (53) of the runner (52). A second end (54) of the runner (52) directly contacts the clamping ring (74). In other embodiments, at least one non-sealing spring mechanism (58 or 88) is disposed between and directly contacts the second end (54) and the clamping ring (74) and the first end (53) contacts the shoulder (55 or 92). An anti-rotation element (76, 89, or 96) is attached to the clamping ring (74), carrier (91), or shaft 57 and extends into a slot (78) or hole or slot (97) along the runner (52). The spring(s) (58 or 88) applies a biasing force (99) onto the runner (52) toward the clamping ring (74) or shoulder (55 or 92). The annular seal ring (49) is rotationally stationary and circumscribed about the runner (52). The tolerance ring(s) (70, 71) directly contacts the runner (52) and the shaft (57). The runner (52) is fixed to the shaft (57) or carrier (91) via the tolerance ring(s) (70, 71), anti-rotation element (76, 89, or 96), and spring(s) (58 or 88) so that the runner (52) rotates with the shaft (57). The sealing rings (68, 69) directly contact the runner (52) and the shaft (57) along the annular gap (72) about the tolerance ring(s) (70, 71).
Circumferential Seal with Ceramic Runner

DESCRIPTION

1. Technical Field

The invention generally relates to a sealing device for turbine engines. Specifically, the invention is directed to a circumferential seal disposed about a rotatable shaft wherein a ceramic runner is attached to the shaft adjacent to a carbon sealing ring.

2. Background Art

Seal assemblies are used in gas turbine engines to prevent or limit leakage of a fluid along the interface between a rotating shaft and an otherwise fixed element. By way of example, FIG. 1 shows a typical circumferential seal 1 including a rotating component called a seal rotor 2 and a non-rotating component called a seal stator 3. The seal rotor 2 is made of metal, is mounted to a rotatable shaft 4, and has a radially outward facing sealing surface 5. The seal stator 3 includes a ring 6 made of metal mounted to the housing 7 and a sealing ring 8. The sealing ring 8 is made of carbon and includes an inward facing sealing surface 10. The seal stator 3 and seal rotor 2 are arranged so that the inward facing sealing surface 10 circumscribes the outward facing sealing surface 5. A small radial gap 9 is maintained between the sealing ring 8 and seal rotor 2 to avoid damage to the softer sealing ring 8.

A common problem associated with circumferential seals and bushings occurs as a result of variation in the radial gap 9 between the sealing ring 8 and seal rotor 2. This variation is due in part to the mechanical growth of the seal rotor 2 due to centrifugal effects, but more significantly due to a disparity in the thermal growth between the seal rotor 2, typically composed of a material with a higher coefficient of thermal expansion, and the sealing ring 8, typically composed of a material with a lower coefficient of thermal expansion.

A variation in the radial gap 9 produces an undesirable effect when it is too wide open or too narrow. If the radial gap 9 is too large, then the flow of fluid between the sealing ring 8 and the seal rotor 2 increases so as to adversely affect pressures within the high and low pressure sections of a turbine engine, thereby reducing the performance and efficiency thereof. If the gap is too small, then contact
between the sealing ring 8 and seal rotor 2 occurs and damage results to one or both
components.

In United States Patent No. 6,322,081, Ullah et al. describes a circumferential
seal with ceramic runner to address sealing challenges associated with a seal system
incorporating materials with divergent thermal expansions.

Referring now to the FIG. 2, a section 11 of a gas turbine engine is shown
including a rotatable shaft 4 on which rotating engine components, such as the radial
compressor wheel 12, are mounted. Circumscribing the rotatable shaft 4 is a
stationary housing 7. The stationary housing 7 is mounted atop a bearing 13 having an
inner race 14 which is mounted on the rotatable shaft 4. Disposed between the
housing 7 and shaft 4 is a circumferential seal 15. The circumferential seal 15
includes a seal stator 3 having a metal ring 6 mounted to the housing 7 and a carbon
sealing ring 8 mounted to its radial inward facing surface. The carbon sealing ring 8
has a radially inward facing sealing surface 10.

The circumferential seal 15 also includes a sealing rotor 16. The rotor 16
includes a ceramic runner 17 having a radially outward facing sealing surface 5 in
rubbing contact with the radially inward facing sealing surface 10 of the sealing ring 8
to control leakage across the radial gap 9. At one axial end, the runner 17 has a
radially outward extending flange 18. At this same axial end, the runner 17 has a
radially inward extending flange 19 having axial faces adapted to receive an axial
clamping load. The sealing rotor 16 further includes two metallic annular clamping
members 20, 21 for providing this clamping load.

The first annular clamping member 21 includes a cylindrical portion 22 having
a radially inward extending flange 23 at one end and a radially outward extending lip
24 at the other end. The length and thickness of the cylindrical portion 22 are selected
to impart radial flexibility to the annular clamping member 21 so that the cylindrical
portion 22 acts as a cantilevered beam rigidly fixed at the inward extending flange 23.

The second annular clamping member 20 has a cylindrical portion 25 with a
radially inward extending flange 26 at one end and an axial face 27 at the other end.
The cylindrical portion 25 has a plurality of circumferentially extending slots (not
shown) that impart axial flexibility to the cylindrical portion 25 allowing it to
compress and expand like a coil spring. The ceramic runner 17 is flexibly clamped
between the axial face 27 and outward extending lip 24.
The circumferential seal 15 provides substantially improved sealing efficiency over metal seal rotors 2 by virtue of the ceramic runner 17. The thermal growth of the ceramic is low due to its low coefficient of thermal expansion, thus enabling the runner 17 to more closely track the sealing ring 8 resulting in a more constant radial gap 9 throughout the entire operating envelope of a turbine engine.

Alternatively, because the frictional and wear properties of the ceramic-to-carbon interface are substantially improved over those of carbon-to-metal interfaces, the ceramic runner 17 could be in rubbing contact with the carbon sealing ring 8, thus either eliminating or reducing the need for cooling of the seal rotor 16.

Unfortunately, the clamping mechanism employed by Ullah et al. and other similar mechanisms known within the art are problematic in that, when used with hard ceramic runners, the runners are susceptible to fracture induced failures.

In United States Patent No. 7,905,495, Munson describes a circumferential seal with a ceramic runner for use within a turbine engine.

Referring now to FIGS. 3-5, a seal assembly 28 is shown including carbon sealing rings 33 contacting a ceramic seal runner 38. The carbon sealing rings 33 are housed within a stator 30 between a flange 31 attached to the stator 30 at a first end and a removable locking ring 32 at a second end. The stator 30 contacts and is attached to a housing 29 along the engine. The seal runner 38 is a cylinder or sleeve-shaped element residing about a portion of the shaft 40. The shaft 40 is attached to a shaft structure 39 so that the shaft structure 39 and elements secured thereto rotate with the shaft 40. A first end of the shaft 40 includes a flange 41 projecting from the shaft 40 in FIGS. 3 and 4 or attached to a spool member 45 in FIG. 5. The spool member 45 is further attached to the shaft structure 39. The second end of the shaft 40 includes a locking ring 43 which is attached to the shaft 40 in a removable fashion in FIGS. 3 and 4 or to the spool member 45 in FIG. 5.

The seal runner 38 is fixed to the shaft 40, so as to rotate therewith, by applying a compressive force in the direction of the flange 41 when the locking ring 43 is secured to the shaft 40 or spool member 45. In FIGS. 3-5, a face seal 44 is provided between the seal runner 38 and locking ring 43 to prevent gases from bypassing the seal formed between the inward facing sealing surfaces 34 along the sealing rings 33 and the outward facing sealing surface 35 along the seal runner 38. In FIG. 3, a washer 42 is also provided between the seal runner 38 and the flange 41 to
prevent gases from bypassing the seal formed between the inward facing sealing surfaces 34 and the outward facing sealing surface 35. The face seal 44 is axially compliant so that it is deformed in response to the relative changes in the length between the seal runner 38 and the shaft 40 and shaft structure 39.

The radial position of the seal runner 38 is maintained by a pair of resilient member 36. In FIG. 3, each resilient member 36 includes a plurality of plates 37 each having deflectable, resilient fingers. In FIG. 4, each resilient member 36 is a ring with a u-shaped cross section. The resilient members 36 separately form a gas-tight seal within the cavity between the seal runner 38 and the shaft structure 39. In FIG. 5, each resilient member 36 is a ring with a u-shaped cross section attached to comprise a single structure.

The assemblies taught by Munson are problematic for several reasons. First, attachment of the seal runner 38 to the shaft 40 between the flange 41 and the compliant face seal 44 restricts or limits axial growth of the seal runner 38 and shaft 40, thereby allowing temperature-induced stress fractures to form along the seal runner 38. Second, the sealing properties of the face seal 44 are compromised by cyclic expansion and contraction of components within a turbine engine. Third, the sealing properties of the resilient members 36 are compromised by cyclic expansion and contraction of components within a turbine engine.

Accordingly, what is required is a means for attaching a ceramic runner to a rotatable metal shaft that allows the runner to be used in a circumferential seal system and avoids damage to the runner associated with cyclic expansion and contraction of components with a turbine engine.

What is also required is a means for attaching a ceramic runner within a circumferential seal system to a rotatable metal shaft that allows for sealing between the runner and shaft while avoiding damage to the sealing surface during use.

What is also required is a means for attaching a ceramic runner within a circumferential seal system which allows for axial movement of the ceramic runner while avoiding the problems of the related arts.

What is also required is a means for attaching a ceramic runner within a circumferential seal system which avoids radial expansion of the ceramic runner resulting from the radial expansion of a rotatable metal shaft and components thereon.

3. Disclosure of the Invention
An object of the invention is to provide a means for attaching a ceramic runner to a rotatable metal shaft that allows the runner to be used in a circumferential seal system and avoids damage to the runner associated with cyclic expansion and contraction of components with a turbine engine.

An object of the invention is to provide a means for attaching a ceramic runner within a circumferential seal system to a rotatable metal shaft that allows for sealing between the runner and shaft while avoiding damage to the sealing surface during use.

An object of the invention is to provide a means for attaching a ceramic runner within a circumferential seal system which allows for axial movement of the ceramic runner while avoiding the problems of the related arts.

An object of the invention is to provide a means for attaching a ceramic runner within a circumferential seal system which avoids radial expansion of the ceramic runner resulting from the radial expansion of a rotatable metal shaft and components thereon.

In accordance with embodiments of the invention, the circumferential seal includes a ceramic runner, an annular seal ring, at least one tolerance ring, and a pair of sealing rings. The ceramic runner is circumscribed about a shaft within a recess along the shaft. The recess is bounded by a shoulder and a clamping ring. A first annular gap is disposed between a first end of the ceramic runner and the shoulder. A second end of the ceramic runner directly contacts the clamping ring. An anti-rotation pin is attached to the clamping ring and extends into a slot along the ceramic runner.

At least one non-sealing spring mechanism is disposed between and directly contacts the shoulder and the first end along the first annular gap. The non-sealing spring mechanism applies a biasing force onto the ceramic runner toward the clamping ring.

The annular seal ring is circumscribed about the ceramic runner and disposed within a seal housing so that the annular seal ring is stationary. The tolerance ring(s) directly contacts the ceramic runner and the shaft along a second annular gap between the ceramic runner and the shaft. The ceramic runner is fixed to the shaft via the tolerance ring(s), anti-rotation pin, and non-sealing spring mechanism so that the ceramic runner rotates with the shaft. The non-sealing spring mechanism expands and contracts in response to expansion and contraction of the ceramic runner. The pair of sealing rings directly contacts the ceramic runner and the shaft along the second annular gap. The tolerance ring(s) is disposed between the pair of sealing rings.
In accordance with other embodiments of the invention, the non-sealing spring mechanism is a wave spring or a compression spring.

In accordance with other embodiments of the invention, the non-sealing spring mechanism is compression springs separately disposed about the first annular gap and attached to the shoulder along the shaft.

In accordance with other embodiments of the invention, each tolerance ring and each sealing ring is separately disposed within an equal number of annular grooves along the ceramic runner.

In accordance with other embodiments of the invention, the sealing ring is an O-ring, a spring-energized seal, or a high-temperature metallic seal ring.

In accordance with embodiments of the invention, the circumferential seal includes a ceramic runner, an annular seal ring, at least one tolerance ring, and a pair of sealing rings. The ceramic runner is circumscribed about a recess along a shaft. The recess is bounded by a shoulder and a clamping ring. A first annular gap is disposed between a second end of the ceramic runner and the clamping ring. A first end of the ceramic runner directly contacts the shoulder along the shaft. An anti-rotation pin is attached to the shoulder and extends into a slot along the ceramic runner. At least one non-sealing spring mechanism is disposed between and directly contacts the clamping ring and the second end along the first annular gap. At least one non-sealing spring mechanism applies a biasing force onto the ceramic runner toward the shoulder. The annular seal ring is circumscribed about the ceramic runner and disposed within a seal housing so that the annular seal ring is stationary. The tolerance ring(s) directly contacts the ceramic runner and the shaft along a second annular gap between the ceramic runner and the shaft. The ceramic runner is fixed to the shaft via the tolerance ring(s), anti-rotation pin, and non-sealing spring mechanism so that the ceramic runner rotates with the shaft. The non-sealing spring mechanism expands and contracts in response to expansion and contraction of the ceramic runner. The pair of sealing rings directly contacts the ceramic runner and the shaft along the second
annular gap. The tolerance ring(s) is disposed between the pair of sealing rings.

In accordance with other embodiments of the invention, the non-sealing spring mechanism is a wave spring or a compression spring.

In accordance with other embodiments of the invention, the non-sealing spring mechanism is compression springs separately disposed about the first annular gap and attached to the clamping ring.

In accordance with other embodiments of the invention, each tolerance ring and each sealing ring is separately disposed within an equal number of annular grooves along the ceramic runner.

In accordance with other embodiments of the invention, the sealing ring is an O-ring, a spring-energized seal, or a high-temperature metallic seal ring.

In accordance with embodiments of the invention, the circumferential seal includes a carrier, a ceramic runner, an annular seal ring, at least one tolerance ring, and a pair of sealing rings. The carrier is disposed about and directly contacts a shaft within a recess along the shaft. The carrier is rotatable with the shaft. The carrier has a shoulder at one end. The ceramic runner is circumscribed about the carrier and disposed between the shoulder and a clamping ring. A first annular gap is disposed between a first end of the ceramic runner and the shoulder. A second end of the ceramic runner directly contacts the clamping ring. An anti-rotation key is attached to the clamping ring and extends into a slot along the ceramic runner. At least one non-sealing spring mechanism directly contacts the shoulder and the first end along the first annular gap. The non-sealing spring mechanism applies a biasing force onto the ceramic runner toward the clamping ring. The annular seal ring is circumscribed about the ceramic runner and disposed within a seal housing so that the annular seal ring is stationary. The tolerance ring(s) directly contacts the ceramic runner and the carrier along a second annular gap between the ceramic runner and the carrier. The ceramic runner is fixed to the carrier via the tolerance ring(s), anti-rotation key, and non-sealing spring mechanism so that the ceramic runner rotates with the carrier. The
non-sealing spring mechanism expands and contracts in response to expansion and
contraction of the ceramic runner. The pair of sealing rings directly contacts the
ceramic runner and the carrier along the second annular gap. The tolerance ring(s) is
disposed between the pair of sealing rings.

In accordance with other embodiments of the invention, the non-sealing spring
mechanism is a wave spring or a compression spring.

In accordance with other embodiments of the invention, the non-sealing spring
mechanism is compression springs separately disposed about the first annular gap and
attached to the shoulder.

In accordance with other embodiments of the invention, each tolerance ring
and each sealing ring is separately disposed within an annular groove along the
carrier.

In accordance with other embodiments of the invention, each tolerance ring
and each sealing ring is separately disposed within an annular groove along the
ceramic runner.

In accordance with other embodiments of the invention, the annular seal ring
forms a contact seal or a non-contact seal about the ceramic runner.

In accordance with other embodiments of the invention, the sealing ring is an
O-ring, a spring-energized seal, or a high-temperature metallic seal ring.

In accordance with embodiments of the invention, the circumferential seal
includes a carrier, a ceramic runner, an annular seal ring, at least one tolerance ring,
and a pair of sealing rings. The carrier is disposed about and directly contacts a shaft
within a recess along the shaft. The carrier is rotatable with the shaft. The carrier has a
shoulder at one end. The ceramic runner is circumscribed about the carrier and
disposed between the shoulder and a clamping ring. A first annular gap is disposed
between a second end of the ceramic runner and the clamping ring. A first end of the
ceramic runner directly contacts the shoulder. An anti-rotation key is attached to the
shoulder and extends into a slot along the ceramic runner. At least one non-sealing
spring mechanism directly contacts the clamping ring and the second end along the
first annular gap. The non-sealing spring mechanism applies a biasing force onto the
ceramic runner toward the shoulder. The annular seal ring is circumscribed about the
ceramic runner and disposed within a seal housing so that the annular seal ring is
stationary. The tolerance ring(s) directly contacts the ceramic runner and the carrier
along a second annular gap between the ceramic runner and the carrier. The ceramic runner is fixed to the carrier via the tolerance ring(s), anti-rotation key, and non-sealing spring mechanism so that the ceramic runner rotates with the carrier. The non-sealing spring mechanism expands and contracts in response to expansion and contraction of the ceramic runner. The pair of sealing rings directly contacts the ceramic runner and the carrier along the second annular gap. The tolerance ring(s) is disposed between the pair of sealing rings.

In accordance with other embodiments of the invention, the non-sealing spring mechanism is a wave spring or a compression spring.

In accordance with other embodiments of the invention, the non-sealing spring mechanism is compression springs separately disposed about the first annular gap and attached to the clamping ring.

In accordance with other embodiments of the invention, each tolerance ring and each sealing ring is separately disposed within an annular groove along the carrier.

In accordance with other embodiments of the invention, the annular seal ring forms a contact seal or a non-contact seal about the ceramic runner.

In accordance with other embodiments of the invention, the sealing ring is an O-ring, a spring-energized seal, or a high-temperature metallic seal ring.

In accordance with embodiments of the invention, the circumferential seal includes a carrier, a ceramic runner, an annular seal ring, at least one tolerance ring, and a pair of sealing rings. The carrier is disposed about and directly contacts a shaft within a recess along the shaft. The carrier is rotatable with the shaft. The carrier has a shoulder at one end. The ceramic runner is circumscribed about the carrier and disposed between the shoulder and a clamping ring. A first annular gap is disposed between a first end of the ceramic runner and the shoulder. A second end of the ceramic runner directly contacts the clamping ring. An anti-rotation screw is attached to the carrier and extends into a hole along the ceramic runner. At least one non-sealing spring mechanism directly contacts the shoulder and the first end along the first annular gap. The non-sealing spring mechanism applies a biasing force onto the
ceramic runner toward the clamping ring. The annular seal ring is circumscribed about the ceramic runner and disposed within a seal housing so that the annular seal ring is stationary. The tolerance ring(s) directly contacts the ceramic runner and the carrier along a second annular gap between the ceramic runner and the carrier. The ceramic runner is fixed to the carrier via the tolerance ring(s), anti-rotation screw, and non-sealing spring mechanism so that the ceramic runner is rotatable with the carrier. The non-sealing spring mechanism expands and contracts in response to expansion and contraction of the ceramic runner. At least one sealing ring directly contacts the ceramic runner and the carrier along the second annular gap. The tolerance ring(s) and anti-rotation screw are disposed between the pair of sealing rings.

In accordance with other embodiments of the invention, the non-sealing spring mechanism is a wave spring or a compression spring.

In accordance with other embodiments of the invention, the non-sealing spring mechanism is compression springs separately disposed about the first annular gap and attached to the shoulder.

In accordance with other embodiments of the invention, each tolerance ring and one sealing ring is separately disposed within an annular groove along the carrier and another sealing ring is disposed within another annular groove along the clamping ring.

In accordance with other embodiments of the invention, each tolerance ring and one sealing ring is separately disposed within an annular groove along the ceramic runner and another sealing ring is disposed within another annular groove along the clamping ring.

In accordance with other embodiments of the invention, the annular seal ring forms a contact seal or a non-contact seal about the ceramic runner.

In accordance with other embodiments of the invention, the sealing ring is an O-ring, a spring-energized seal, or a high-temperature metallic seal ring.

In accordance with embodiments of the invention, the circumferential seal includes a carrier, a ceramic runner, an annular seal ring, at least one tolerance ring, and a pair of sealing rings. The carrier is disposed about and directly contacts a shaft within a recess along the shaft. The carrier is rotatable with the shaft. The carrier has a shoulder at one end. A ceramic runner is circumscribed about the carrier and disposed between the shoulder and a clamping ring. A first annular gap is disposed between a
second end of the ceramic runner and the clamping ring. A first end of the ceramic runner directly contacts the shoulder. An anti-rotation screw is attached to the carrier and extends into a hole along the ceramic runner. At least one non-sealing spring mechanism directly contacts the clamping ring and the second end along the first annular gap. The non-sealing spring mechanism applies a biasing force onto the ceramic runner toward the shoulder. The annular seal ring is circumscribed about the ceramic runner and disposed within a seal housing so that the annular seal ring is stationary. The tolerance ring(s) directly contacts the ceramic runner and the carrier along a second annular gap between the ceramic runner and the carrier. The ceramic runner is fixed to the carrier via the tolerance ring(s), anti-rotation screw, and non-sealing spring mechanism so that the ceramic runner is rotatable with the carrier. The non-sealing spring mechanism expands and contracts in response to expansion and contraction of the ceramic runner. At least one sealing ring directly contacts the ceramic runner and the carrier along the second annular gap. The tolerance ring(s) and anti-rotation screw are disposed between the pair of sealing rings.

In accordance with other embodiments of the invention, the non-sealing spring mechanism is a wave spring or a compression spring.

In accordance with other embodiments of the invention, the non-sealing spring mechanism is compression springs separately disposed about the first annular gap and attached to the clamping ring.

In accordance with other embodiments of the invention, each tolerance ring and one sealing ring is separately disposed within an annular groove along the carrier and another sealing ring is disposed within another annular groove along the clamping ring.

In accordance with other embodiments of the invention, each tolerance ring and one sealing ring is separately disposed within an annular groove along the ceramic runner and another sealing ring is disposed within another annular groove along the clamping ring.

In accordance with other embodiments of the invention, the annular seal ring forms a contact seal or a non-contact seal about the ceramic runner.

In accordance with other embodiments of the invention, the sealing ring is an O-ring, a spring-energized seal, or a high-temperature metallic seal ring.
During operation of a turbine engine, the shaft rotates with respect to the annular seal ring. The ceramic runner is configured to rotate with the shaft via the non-sealing spring mechanism, anti-rotation element, and tolerance ring(s). The non-sealing spring mechanism applies an axial load onto the ceramic runner biasing the runner against the clamping ring attached to the shaft. Friction between the ceramic runner and clamping ring resists relative rotational motion between the runner and shaft. Relative motion is further avoided by the anti-rotation element fixed to and movable with the shaft. The anti-rotation element contacts the ceramic runner thereby arresting rotation between runner and shaft. Contact by the tolerance rings between the ceramic runner and shaft or a carrier along the shaft further resists relative rotational motion between the runner and shaft.

In one of its aspects, the invention utilizes a spring mechanism which deflects or compresses axially along the length of the shaft to accommodate thermal expansion axially along the ceramic runner during operation of the turbine engine so as to minimize stresses within the ceramic runner thereby minimizing the possibility of stress induced failures.

In another of its aspects, the invention utilizes a spring mechanism which allows the ceramic runner to expand independently relative to the shaft and/or carrier so as to minimize stresses within the ceramic runner thereby minimizing the possibility of stress induced failures.

In yet another of its aspects, the invention utilizes sealing rings between the ceramic runner and shaft or a carrier along the shaft which prevent oil leakage under the ceramic runner thereby minimizing oil coking under the runner.

In yet another of its aspects, the invention utilizes sealing rings between the ceramic runner and shaft or a carrier along the shaft about the tolerance ring which prevent oil from contacting the tolerance ring(s) thereby avoiding slippage between the runner and shaft or carrier.

In yet another of its aspects, the invention utilizes one or more sealing rings between the ceramic runner and shaft or a carrier along the shaft to radially deflect and accommodate changes in the clearance between the runner and shaft or carrier as the shaft and/or carrier expands thereby avoiding radial expansion by and damage to the runner.
In other of its aspects, the invention utilizes one or more gapped tolerance rings between the ceramic runner and shaft or carrier which expands circumferentially so as to accommodate changes in the clearance between the runner and shaft or carrier as the shaft and/or carrier expands thereby avoiding radial expansion by and damage to the runner.

In other of its aspects, the invention separates axial functionality of the spring mechanism from sealing function of the sealing rings thereby minimizing degradation of the sealing rings by thermally induced expansion and contraction cycles within a gas turbine engine.

In other of its aspects, the invention separates radial functionality of the tolerance ring(s) from sealing function of the sealing rings thereby minimizing degradation of the sealing rings by thermally induced expansion and contraction cycles within a gas turbine engine.

The above and other objectives, features, and advantages of the embodiments of the invention will become apparent from the following description read in connection with the accompanying drawings, in which like reference numerals designate the same or similar elements.

4. Brief Description of the Drawings

Additional aspects, features, and advantages of the invention will be understood and will become more readily apparent when the invention is considered in the light of the following description made in conjunction with the accompanying drawings, in which:

FIG. 1 is a cross-sectional view illustrating a circumferential seal with metal rotor as described by Ullah et al. in United States Patent No. 6,322,081;

FIG. 2 is a cross-sectional view illustrating a circumferential seal with ceramic rotor as described by Ullah et al. in United States Patent No. 6,322,081;

FIG. 3 is a cross-section view illustrating a circumferential seal with a ceramic runner attached compressively along a shaft between a flange and a locking ring and radially supported along the shaft via a pair of resilient members each having a plurality of plates as described by Munson in United States Patent No. 7,905,395;

FIG. 4 is a cross-section view illustrating a circumferential seal with a ceramic runner attached compressively along a shaft between a flange and a locking ring and radially supported along the shaft via a pair of resilient members each being a ring
with u-shaped cross section as described by Munson in United States Patent No. 7,905,395;

FIG. 5 is a cross-section view illustrating a circumferential seal with a ceramic runner attached compressively along a spool member between a flange and a locking ring and radially supported along the spool member via a pair of resilient members each being a ring with u-shaped cross section which form a single structure as described by Munson in United States Patent No. 7,905,395;

FIG. 6a is a cross-section view illustrating a circumferential seal with a ceramic runner recessed along a rotatable shaft and attached thereto via at least one anti-rotation pin and an annular spring wherein sealing and tolerance rings are disposed between the runner and shaft within annular grooves along the runner in accordance with an embodiment of the invention;

FIG. 6b is a cross-section view illustrating the anti-rotation pin in FIG. 6a within a slot or hole along the ceramic runner in accordance with an embodiment of the invention;

FIG. 6c is a side view illustrating the tolerance ring in FIG. 6a with a gap in accordance with an embodiment of the invention;

FIG. 6d is a cross-section view illustrating a circumferential seal with a ceramic runner recessed along a rotatable shaft and attached thereto via at least one anti-rotation pin and an annular spring wherein the spring mechanism is provided between the ceramic runner and a clamping ring in accordance with an embodiment of the invention;

FIG. 7a is a cross-section view illustrating a circumferential seal with a ceramic runner recessed along a rotatable shaft and attached thereto via at least one anti-rotation pin and an annular spring wherein sealing and tolerance rings are disposed between the runner and shaft within annular grooves along the shaft in accordance with an embodiment of the invention;

FIG. 7b is a cross-section view illustrating a compression spring disposed between the ceramic runner and shaft in FIG. 7a in accordance with an embodiment of the invention;

FIG. 7c is a cross-section view illustrating several compression springs each within a hole along a portion of the shaft in accordance with an embodiment of the invention;
FIG. 8a is a cross-section view illustrating a circumferential seal with a ceramic runner disposed along a carrier recessed along a rotatable shaft and attached to the carrier via at least one key and a plurality of compression springs wherein sealing and tolerance rings are disposed between the runner and shaft within annular grooves along the carrier in accordance with an embodiment of the invention;

FIG. 8b is a cross-section view illustrating the key in FIG. 8a within a slot along the ceramic runner in accordance with an embodiment of the invention;

FIG. 8c is a cross-section view illustrating several compression springs each within a hole along a portion of the carrier in accordance with an embodiment of the invention;

FIG. 8d is a cross-section view illustrating an annular spring disposed between the ceramic runner and carrier in FIG. 8a in accordance with an embodiment of the invention;

FIG. 8e is a cross-section view illustrating a circumferential seal with a ceramic runner disposed along a carrier recessed along a rotatable shaft wherein the spring mechanism is disposed between the ceramic runner and a clamping ring in accordance with an embodiment of the invention;

FIG. 9a is a cross-section view illustrating a circumferential seal with a ceramic runner disposed along a carrier recessed along a rotatable shaft and attached to the carrier via at least one anti-rotation screw and a plurality of compression springs wherein a first sealing ring and tolerance ring are disposed between the runner and shaft within annular grooves along the shaft and a second sealing ring is disposed between the runner and a clamping ring along a groove within the clamping ring in accordance with an embodiment of the invention;

FIG. 9b is a cross-section view illustrating the anti-rotation screw in FIG. 9a disposed within a hole along the carrier in accordance with an embodiment of the invention;

FIG. 9c is a cross-section view illustrating the anti-rotation screw in FIG. 9a disposed within a hole along the ceramic runner in accordance with an embodiment of the invention;

FIG. 9d is a cross-section view illustrating a circumferential seal with a ceramic runner disposed along a carrier recessed along a rotatable shaft and attached to the carrier via at least one anti-rotation screw and a plurality of compression
springs wherein a first sealing ring and tolerance ring are disposed between the runner and shaft within annular grooves along the shaft and a second sealing ring is disposed between the runner and the carrier along a groove within the carrier in accordance with an embodiment of the invention; and

FIG. 9e is a cross-section view illustrating a circumferential seal with a ceramic runner disposed along a carrier recessed along a rotatable shaft wherein a spring mechanism is disposed between the ceramic runner and a clamping ring in accordance with an embodiment of the invention.

5. Modes for Carrying out the Invention

Reference will now be made in detail to several embodiments of the invention that are illustrated in the accompanying drawings. Wherever possible, same or similar reference numerals are used in the drawings and the description to refer to the same or like parts. The drawings are in simplified form and are not to precise scale.

While features of various embodiments are separately described throughout this document, it is understood that such features could be combined to form a single embodiment.

Referring now to FIGS. 6a and 7a, the circumferential seal 46 is illustrated for descriptive purposes along an upper half of an exemplary shaft 57 rotatable about a centerline 67 along a turbine engine. While the shaft 57 is generally represented as a cylindrical-shaped element, other configurations are possible.

The outer diameter 100 of the shaft 57 is shown including a recess 98. The recess 98 could include one or more regions along the shaft 57 each having a diameter smaller than the outer diameter 100 of the shaft 57. The exemplary shafts 57 in FIGS. 6a and 7a have a recess 98 which includes three sections arranged end-to-end in a stepwise fashion, whereby the first section accommodates a ceramic runner 52, the second section accommodates a clamping ring 74, and the third section accommodates a locking ring 75. The clamping ring 74 and locking ring 75 are composed of materials suitable for use within a turbine engine. Materials should be wear, failure, and temperature resistant. Exemplary compositions include metals, preferably compositions of steel. The locking ring 75 secures the various components described herein to the shaft 57 about the recess 98. It is understood that the recess 98 could include one or more sections as well as other shapes and designs which
facilitate attachment of elements required to provide circumferential sealing along a
shaft 57.

The interface between the outer diameter 100 of the shaft 57 and the outer
diameter 62 of the recess 98 is defined by a first shoulder 55. The recess 98 could
include additional shoulders depending on the profile of the recess 98, although such
features are optional and design dependent. For example, the recess 98 in FIGS. 6a
and 7a is shown with a second shoulder 56 at the interface between the regions for the
ceramic runner 52 and clamping ring 74 formed at the discontinuity of the outer
diameters 62, 79. The second shoulder 56 acts as a mechanical stop which fixes the
clamping ring 74 at a prescribed distance from the first shoulder 55. A clearance fit
could be provided between the outer diameter 79 of the shaft 57 and inner diameter 83
along the clamping ring 74 so that the clamping ring 74 is slidable with respect to the
shaft 57. The clamping ring 74 is secured to the shaft 57 via the locking ring 75 which
could include threads along its inner diameter 84 which engage a complementary
thread arrangement along the outer diameter 80 of the shaft 57. In another example,
the recess 98 at the interface between the regions for the clamping ring 74 and locking
ring 75 is shown without a shoulder because these regions include outer diameters 79,
80 which are approximately equal.

The ceramic runner 52 is a cylindrically-shaped or sleeve-shaped element
which is slid onto the shaft 57 during assembly so as to circumscribe the shaft 57
about the recess 98. The ceramic runner 52 is composed of a ceramic composition
suitable for use within a turbine engine. In preferred embodiments, the ceramic
composition should be wear, failure, and temperature resistant. Exemplary, non-
limiting compositions include silicon nitride and silicon carbide.

The ceramic runner 52 has an inner diameter 61 which is larger than the outer
diameter 62 of the shaft 57 along the recess 98 resulting in a second annular gap 72
which avoids direct contact between the ceramic runner 52 and shaft 57. The distance
between a first end 53 and a second end 54 of the ceramic runner 52 is less than the
axial distance between the first shoulder 55 and second shoulder 56. The first end 53
is positioned adjacent to the first shoulder 55 so that a first annular gap 73 separates
the first end 53 from the first shoulder 55. The axial length of the first annular gap 73
is sized to accommodate a spring mechanism. The spring mechanism provides no
sealing functionality. Although spring mechanisms are described herein, it is
understood that such mechanisms could include other non-sealing devices which at least resist compression and are resilient. The second end 54 directly contacts the clamping ring 74 so that the second end 54 is generally aligned with the second shoulder 56.

In some embodiments, the spring mechanism could be a single annular spring 58, as represented in FIGS. 6a and 7a. Exemplary annular springs 58 include a wave spring or a compression spring or the like which circumscribe the shaft 57 within the first annular gap 73. The length of the annular spring 58 in its uncompressed state requires the annular spring 58 to be partially compressed when assembled between the ceramic runner 52 and shaft 57. The annular spring 58 is compressed by contact with the first shoulder 55 at one end of the annular spring 58 and the first end 53 at another end of the annular spring 58. In its partially compressed state, the annular spring 58 communicates a biasing force 99 axially onto the ceramic runner 52 thereby pressing the ceramic runner 52 onto the clamping ring 74. The biasing force 99 is preferred to maintain contact between the second end 54 of the ceramic runner 52 and the clamping ring 74 during operation of a turbine engine, thereby avoiding axial separation between the ceramic runner 52 and clamping ring 74 which could occur because of thermally induced expansion and contraction of components within the engine. The biasing force 99 also resists rotational sliding motion between the ceramic runner 52 and clamping ring 74 at the second end 54. The annular spring 58 is partially compressed at or below ambient conditions so as to allow for further compression of the annular spring 58 during operation of a turbine engine. This feature allows the annular spring 58 to expand and contract with axial expansion and contraction of the ceramic runner 52 as the ceramic runner 52 and other components heat and cool.

In other embodiments, the spring mechanism could include a plurality of compression springs 88 or the like, as represented in FIGS. 7b and 7c. Each compression spring 88 is axially aligned along the direction of the shaft 57 as shown in FIG. 7b. The compression springs 88 are further separately disposed about the diameter of the shaft 57 along the first shoulder 55 as generally shown in FIG. 7c, so as to communicate a biasing force 99 symmetrically about the ceramic runner 52 in the axial direction. One end of each compression spring 88 could reside within a complementary shaped hole 94 so that a portion of the compression spring 88 extends
into the first annular gap 73 with sufficient length to contact the first end 53 along the ceramic runner 52. The compression spring 88 could be mechanically fixed to the hole 94 via an interference fit or freely movable within the hole 94. The compression springs 88 are preferred to be sufficiently long so that each is partially compressed when assembled between the shaft 57 and ceramic runner 52. Partial compression of the compression spring 88 maintains a biasing force 99 onto the ceramic runner 52 so that the second end 54 of the ceramic runner 52 is biased toward and contacts the clamping ring 74. The biasing force 99 maintains contact between the second end 54 of the ceramic runner 52 and the clamping ring 74 during operation of a turbine engine, thereby avoiding axial separation thereof because of thermally induced expansion and contraction of ceramic runner 52 and other components within the engine. The biasing force 99 also resists rotational sliding motion between the ceramic runner 52 and clamping ring 74 at the second end 54. The compression springs 88 are partially compressed at or below ambient conditions so as to allow for further compression of the compression springs 88 during operation of a turbine engine. This feature allows the compression springs 88 to expand and contract with expansion and contraction of the ceramic runner 52 as the ceramic runner 52 and other components heat and cool.

In other embodiments, the first end 53 could directly contact the first shoulder 55 and the spring mechanism, either the annular spring 58 or the compression springs 88, is disposed between the second end 54 and clamping ring 74, as generally represented in FIG. 6d. The first annular gap 73 now resides between the second end 54 and clamping ring 74. The biasing force 99 is directed toward the shoulder 55. The anti-rotation pin 76 partially resides within a hole 77 and is attached to the shaft 57 along the first shoulder 55 so as to extend toward the ceramic runner 52. Another portion of the anti-rotation pin 76 resides within a slot 78 along the first side 53. The spring mechanisms could be attached to the clamping ring 74 in a similar manner as otherwise described herein for attachment to the shaft 57.

Referring again to FIGS. 6a and 7a, the second annular gap 72 between the inner diameter 61 of the ceramic runner 52 and outer diameter 62 of the shaft 57 is shown with a pair of tolerance rings 70, 71. Although two tolerance rings 70, 71 are shown and described, it is understood that the second annular gap 72 could include one or more such rings. The tolerance rings 70, 71 are generally described as a ring-
shaped element with corrugations along an inward face or an outward face and with a gap 87, the latter feature represented in FIG. 6c (corrugated structure not shown). Tolerance rings 70, 71 provide no sealing functionality. When attached between the inner diameter 61 and outer diameter 62 along the gap 72, the tolerance rings 70, 71 conform to the bore and are self-retaining thereby resisting rotational slippage between the ceramic runner 52 and shaft 57. The tolerance rings 70, 71 could allow for axial slippage so as to avoid stresses within the ceramic runner 52. Exemplary tolerance rings 70, 71 are the BN Series devices sold by USA Tolerance Rings of Pennington, New Jersey (United States). The tolerance rings 70, 71 maintain proper fit between the ceramic runner 52 and shaft 57 by expanding circumferentially to the radial clearance between the inner diameter 61 and outer diameter 62 by closing the gap 87. This functionality avoids radial expansion of the ceramic runner 52 which could damage the runner 52. Each tolerance ring 70, 71 resides within an annular groove 63, 65, respectively. The annular grooves 63, 65 are disposed along the inner diameter 61 of the ceramic runner 52 as shown in FIG. 6a or along the outer diameter 52 of the shaft 57 as shown in FIG. 7a. The depth of each annular groove 63, 65 should allow assembly of the ceramic runner 52 onto the shaft 57 and proper placement of the tolerance rings 70, 71 along the shaft 57 while ensuring sufficient contact between the tolerance rings 70, 71 and inner and outer diameters 61, 62 for proper function of the tolerance rings 70, 71. The annular grooves 63, 65 should be at least as wide as the tolerance rings 70, 71, preferably providing a tolerance fit which allows each tolerance ring 70, 71 to be secured within the respective annular groove 63, 65.

Referring again to FIGS. 6a and 7a, the second annular gap 72 between the inner diameter 61 of the ceramic runner 52 and outer diameter 62 of the shaft 57 is shown with a pair of sealing rings 68, 69. Sealing rings 68, 69 could include devices known within the art, examples including, but not limited to, multi-directional O-rings, unidirectional spring-energized seals, high-temperature metallic seal rings, or other comparable devices sold by the Parker Hannifin Corporation located in North Haven, Connecticut (United States) or other suppliers. Other exemplary seals include those sold under the Trademark OMNISEAL® by Saint-Gobain Performance Plastics Corporation of Aurora, Ohio (United States). When assembled between the inner diameter 61 and outer diameter 62 about the second annular gap 72, the sealing rings...
68, 69 conform to the bore thereby further resisting rotational slippage between the
ceramic runner 52 and shaft 57. The seal rings 68, 69 could allow for axial slippage so
as to avoid stresses within the ceramic runner 52. Each sealing ring 68, 69 resides
within an annular groove 64, 66, respectively. The annular grooves 64, 66 are
disposed along the inner diameter 61 of the ceramic runner 52 as shown in FIG. 6a or
along the outer diameter 52 of the shaft 57 as shown in FIG. 7a. The depth of each
annular groove 64, 66 should be sufficiently deep so as to allow assembly of the
ceramic runner 52 onto the shaft 57 and proper placement of the sealing rings 68, 69
along the shaft 57 while ensuring sufficient contact between the sealing rings 68, 69
and inner and outer diameters 61, 62 for proper function of the sealing rings 68, 69.
The grooves 64, 66 should be at least as wide as the sealing rings 68, 69, preferably
with a tolerance fit allowing each sealing ring 68, 69 to be secured within the
respective annular groove 64, 66.

The sealing rings 68, 69 are disposed about the tolerance rings 70, 71, as
represented in FIGS. 6a and 7a. The sealing rings 68, 69 are oriented along the second
annular gap 72 so that the sealing direction 101 of the sealing rings 68, 69 avoids or at
least minimizes oil and other contaminants within the higher and/or lower pressure
sides 81, 82 from entering the second annular gap 72 and interacting with the
tolerance rings 70, 71. This feature minimizes degradation to the performance of the
tolerance rings 70, 71 caused by oil and other contaminants and further minimizes oil
coking under the ceramic runner 52.

The clamping ring 74 further includes at least one anti-rotation pin 76. The
anti-rotation pin 76 could reside within a complementary shaped hole 77 along the
clamping ring 74 so that a portion of the anti-rotation pin 76 extends toward the
ceramic runner 52. The anti-rotation pin 76 could be mechanically fixed to the hole 77
via an interference fit or slidable therein via a clearance fit. The portion of the anti-
rotation pin 76 extending from the clamping ring 74 could reside within a slot 78
along the ceramic runner 52. The slot 78 could extend from the inner diameter 61 of
the ceramic runner 52 and partially traverse the thickness of the ceramic runner 52 in
the direction of the outward facing sealing surface 60, as represented in FIG. 6b. The
slot 78 is dimensioned to avoid contact with the end and sides of the anti-rotation pin
76, see FIGS. 6a and 6b, respectively. The anti-rotation pin 76 could contact a side
wall 102, the latter shown in FIG. 6b, along the slot 78 when the ceramic runner 52
rotates relative to the clamping ring 74. The degree of rotation before contact between
the anti-rotation pin 76 and side wall 102 is determined by the clearance
therebetween, which is design dependent.

An annular seal ring 49 is circumferentially disposed about the outward facing
sealing surface 60 of the ceramic runner 52. The annular seal ring 49 includes an
inward facing sealing surface 59 which interacts with the outward facing sealing
surface 60 to form the circumferential sealing of the present invention. The annular
seal ring 49 is a ring-shaped element with or without segmentation. In some
embodiments, the inward facing sealing surface 59 could physically contact the
outward facing sealing surface 60 during rotation of the ceramic runner 52 and shaft
57 to provide a contact seal. In other embodiments, the inward facing sealing surface
59 and outward facing sealing surface 60 could be separated by a gap to form a non-
contact seal. In yet other embodiments, the outward facing sealing surface 60 could
include hydrodynamic pockets which form a thin-film between inward and outward
facing sealing surfaces 59, 60 during rotation of the ceramic runner 52.

The annular seal ring 49 resides within a seal housing 47 and is secured
thereto via a support ring 50 and a retaining ring 51 or other like elements via
methods and designs known within the art. The annular seal ring 49 is stationary
rotationally with respect to the seal housing 47. As such, the annular seal ring 49 does
not rotate with respect to the seal housing 47. The annular seal ring 49 could move
radially inward and outward to track radial excursions of the ceramic runner 52. The
seal housing 47 is secured to a housing 48 comprising a turbine engine. Both seal
housing 47 and housing 48 are shown in a generalized form for descriptive purposes
only and are not intended to limit the scope of the claimed invention. Arrangement of
the annular seal ring 49, seal housing 47, and housing 48 about the ceramic runner 52
and shaft 57 generally defines a higher pressure side 81 and a lower pressure side 82.
The higher pressure side 81 could define the air or gas side within a turbine engine.
The lower pressure side 82 could define the bearing or oil side within a turbine
engine.

Referring again to FIGS 6a and 7a, the outward facing sealing surface 60
along the ceramic runner 52 is shown approximately radially aligned with the outer
diameter 100 of the shaft 57. However, it is understood that outward facing sealing
surface 60 could extend above or be depressed below the outer diameter 100 in other
embodiments of the invention. In yet other embodiments, it is possible for the
outward facing sealing surface 60 to move radially inward and outward with respect
to the outer diameter 100 during operation of a turbine engine.

Referring now to FIG. 8a, the circumferential seal 46 is illustrated for
descriptive purposes along an upper half of an exemplary shaft 57 along a turbine
engine rotatable about a centerline 67. In this embodiment, a ceramic runner 52 is
attached to a carrier 91 to form a cartridge 90. The cartridge 90 facilitates assembly of
components comprising the circumferential seal 46 prior to attachment to a shaft 57.
This approach simplifies assembly and repair of a turbine engine.

The outer diameter 100 of the shaft 57 is shown including a recess 98. The
recess 98 could include one or more regions along the shaft 57 each having a diameter
smaller than the outer diameter 100. The exemplary shaft 57 has a recess 98 which
includes a single section to accommodate a locking ring 75 and a carrier 91, the latter
supporting a ceramic runner 52 and a clamping ring 74. The clamping ring 74 and
locking ring 75 are composed of materials suitable for use within a turbine engine.
Materials should be wear, failure, and temperature resistant. Exemplary compositions
include metals, preferably compositions of steel. The locking ring 75 secures the
carrier 91 with the various components described herein to the shaft 57 about the
recess 98. It is understood that the recess 98 could include one or more sections as
well as other shapes and designs which facilitate attachment of elements required to
provide circumferential sealing along a shaft 57.

The interface between the outer diameter 100 of the shaft 57 and the outer
diameter 62 of the recess 98 defines a first shoulder 55. The recess 98 could include
additional shoulders depending on the profile of the recess 98, although such features
are optional and design dependent. For example, the recess 98 could include other
shoulders each defined by a discontinuity where two outer diameters differ.

The carrier 91 is a ring-shaped element with a flange 104 which extends
perpendicular from one end of an annular ring 105. In some embodiments, a clearance
fit is provided for assembly purposes between the outer diameter 62 of the shaft 57
and inner diameter 85 of the carrier 91 so that the carrier 91 is slidable with respect to
the shaft 57. In other embodiments, an interference fit is provided between the outer
diameter 62 and the inner diameter 85 and the carrier 91 is heated to open the inner
diameter 85 prior to sliding the carrier 91 onto the shaft 57. The carrier 91 is then
cooled to fix the carrier 91 to the shaft 57. The flange 104 should contact the shoulder 55 in addition to the annular ring 105 contacting the surface of the shaft 57. The carrier 91 is composed of materials suitable for use within a turbine engine. Materials should be wear, failure, and temperature resistant. Exemplary compositions include metals, preferably compositions of steel with a coefficient of thermal expansion comparable to that of the shaft 57 so that carrier 91 tracks the expansion and contraction of the shaft 57.

The carrier 91 could likewise include one or more shoulders along the surface of the annular ring 105. The interface between the annular surface 107 along the carrier 91 and the outer diameter 106 of the carrier 91 defines a first shoulder 92. The carrier 91 could also include a first segment with an outer diameter 106 and a second segment with an outer diameter 86. The outer diameter 106 could be larger than the other outer diameter 86 so that a second shoulder 103 is provided at the discontinuity between the two outer surfaces. A clearance fit could be provided between the outer diameter 86 of the carrier 91 and inner diameter 83 along the clamping ring 74 so that the clamping ring 74 is slidable with respect to the carrier 91. The carrier 91 and clamping ring 74 are secured to the shaft 57 via the locking ring 75. The locking ring 75 contacts both the clamping ring 74 and the end 93 of the carrier 91 as illustrate in FIG. 8a. The locking ring 75 includes threads along its inner diameter 84 which engage a complementary thread arrangement along the outer diameter 80 of the shaft 57. The force applied by the locking ring 75 onto the carrier 91 and clamping ring 74 should be sufficient to prevent relative motion with respect to the shaft 57.

The ceramic runner 52 is a cylindically-shaped or sleeve-shaped element which is slid onto the shaft 57 during assembly so as to circumscribe the carrier 91. The ceramic runner 52 is composed of a ceramic composition suitable for use within a turbine engine. In preferred embodiments, the ceramic composition should be wear, failure, and temperature resistant. Exemplary, non-limiting compositions include silicon nitride and silicon carbide.

The ceramic runner 52 has an inner diameter 61 which is larger than the outer diameter 106 of the carrier 91 resulting in a second annular gap 72 which avoids direct contact between the ceramic runner 52 and carrier 91. The distance between a first end 53 and a second end 54 of the ceramic runner 52 is less than the axial distance between the first shoulder 92 and second shoulder 103. The first end 53 is
positioned adjacent to the first shoulder 92 so that a first annular gap 73 separates the
first end 53 from the first shoulder 92. The axial length of the first annular gap 73 is
sized to accommodate a spring mechanism. The spring mechanism provides no
sealing functionality. Although spring mechanisms are described herein, it is
understood that such mechanisms could include other non-sealing devices which at
least resist compression and are resilient. The second end 54 directly contacts the
clamping ring 74 so that the second end 54 is generally aligned with the second
shoulder 103.

In some embodiments, the spring mechanism could include a plurality of
compression springs 88 as represented in FIG. 8a and generally described in FIGS. 7b
and 7c. Each compression spring 88 is axially aligned along the direction of the shaft
57. The compression springs 88 are further separately disposed about the shaft 57
along the flange 104 of the carrier 91, as generally shown in FIG. 8c, so as to
communicate a biasing force 99 symmetrically about the ceramic runner 52 in the
axial direction. One end of each compression spring 88 could reside within a
complementary shaped hole 94 within the flange 104 so that a portion of the
compression spring 88 extends into the first annular gap 73 with sufficient length to
contact the first end 53 along the ceramic runner 52. The compression spring 88 could
be mechanically fixed to the hole 94 via an interference fit or freely movable within
the hole 94. The compression springs 88 are preferred to be sufficiently long so that
each is partially compressed when assembled between the carrier 91 and ceramic
runner 52. Partial compression of the compression spring 88 maintains a biasing force
99 onto the ceramic runner 52 so that the second end 54 of the ceramic runner 52 is
biased toward and contacts the clamping ring 74. The biasing force 99 maintains
contact between the second end 54 of the ceramic runner 52 and the clamping ring 74
during operation of a turbine engine, thereby avoiding separation thereof because of
thermally induced expansion and contraction of ceramic runner 52 and other
components within the engine. The biasing force 99 also resists rotational sliding
motion between the ceramic runner 52 and clamping ring 74 at the second end 54.
The compression springs 88 are partially compressed at or below ambient conditions
so as to allow for further compression of the compression springs 88 during operation
of a turbine engine. This feature allows the compression springs 88 to expand and

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contract with expansion and contraction of the ceramic runner 52 as the ceramic runner 52 and other components heat and cool.

In other embodiments, the spring mechanism could be a single annular spring 58, as represented in FIG. 8d. Exemplary annular springs 58 include a wave spring or a compression spring or the like which circumscribe the shaft 57 within the first annular gap 73 between the first end 53 of the ceramic runner 52 and first shoulder 92 along the carrier 91. The length of the annular spring 58 in its uncompressed state requires the annular spring 58 to be partially compressed when assembled between the ceramic runner 52 and carrier 91. The annular spring 58 is compressed by contact with the first shoulder 92 at one side of the annular spring 58 and the first end 53 at another side of the annular spring 58. In its partially compressed state, the annular spring 58 communicates a biasing force 99 axially onto the ceramic runner 52 thereby pressing the ceramic runner 52 onto the clamping ring 74. The biasing force 99 is preferred to maintain contact between the second end 54 of the ceramic runner 52 and the clamping ring 74 during operation of a turbine engine, thereby avoiding separation between the ceramic runner 52 and clamping ring 74 which could occur because of thermally induced expansion and contraction of components within the engine. The biasing force 99 also resists rotational sliding motion between the ceramic runner 52 and the clamping ring 74 at the second end 54. The annular spring 58 is partially compressed at or below ambient conditions so as to allow for further compression of the annular spring 58 during operation of a turbine engine. This feature allows the annular spring 58 to expand and contract with axial expansion and contraction of the ceramic runner 52 as the ceramic runner 52 and other components heat and cool.

In other embodiments, the first end 53 could directly contact the first shoulder 92 and the spring mechanism, either an annular spring 58 or compression springs 88, is disposed between the second end 54 and clamping ring 74, as generally represented in FIG. 8e. The biasing force 99 is directed toward the flange 104. The anti-rotation key 89 is attached to the flange 104 along the carrier 91 so as to extend toward the ceramic runner 52. A portion of the anti-rotation key 89 resides within a slot 78 along the first side 53. The spring mechanisms could be attached to the clamping ring 74 as described in FIG. 8a. For example, each compression spring 88 could partially reside within a hole 94 so as to extend across the first annular gap 73 and contact the second end 54.
Referring again to FIG. 8a, the second annular gap 72 between the inner
diameter 61 of the ceramic runner 52 and outer diameter 106 of the carrier 91 is
shown with a pair of tolerance rings 70, 71. Although two tolerance rings 70, 71 are
shown and described, it is understood that the second annular gap 72 could include
one or more such rings. The tolerance rings 70, 71 are generally described as a ring-
shaped element with corrugations along an inward face or an outward face and with a
gap 87, the latter feature represented in FIG. 6c. Tolerance rings 70, 71 provide no
sealing functionality. When attached between the inner diameter 61 and outer
diameter 106 along the gap 72, the tolerance rings 70, 71 conform to the bore and are
self-retaining thereby resisting rotational slippage between the ceramic runner 52 and
carrier 91. The tolerance rings 70, 71 could allow for axial slippage so as to avoid
stresses within the ceramic runner 52. Exemplary tolerance rings 70, 71 are the BN
Series devices sold by USA Tolerance Rings of Pennington, New Jersey (United
States). The tolerance rings 70, 71 maintain proper fit between the ceramic runner 52
and carrier 91 by expanding circumferentially to the radial clearance between the
inner diameter 61 and outer diameter 106 by closing the gap 87. This functionality
avoids radial expansion of the ceramic runner 52 which could damage the runner 52.
Each tolerance ring 70, 71 resides within an annular groove 63, 65, respectively. The
annular grooves 63, 65 could be disposed along the inner diameter 61 of the ceramic
runner 52 in an arrangement similar to that shown in FIG. 6a or along the outer
diameter 106 of the carrier 91 as shown in FIG. 8a. The depth of each annular groove
63, 65 should allow assembly of the ceramic runner 52 onto the carrier 91 and proper
placement of the tolerance rings 70, 71 along the carrier 91 while ensuring sufficient
contact between the tolerance rings 70, 71 and inner and outer diameters 61, 106 for
proper function of the tolerance rings 70, 71. The annular grooves 63, 65 should be at
least as wide as the tolerance rings 70, 71, preferably providing a tolerance fit which
allows each tolerance ring 70, 71 to be secured within the respective annular groove
63, 65.

Referring again to FIG. 8a, the second annular gap 72 between the inner
diameter 61 of the ceramic runner 52 and outer diameter 106 of the carrier 91 is
shown with a pair of sealing rings 68, 69. Sealing rings 68, 69 could include devices
known within the art, examples including, but not limited to, multi-directional O-
rings, unidirectional spring-energized seals, high-temperature metallic seal rings, or
other comparable devices sold by the Parker Hannifin Corporation located in North
Haven, Connecticut (United States) or other suppliers. Other exemplary seals include
those sold under the Trademark OMNISEAL® by Saint-Gobain Performance Plastics
Corporation of Aurora, Ohio (United States). When assembled between the inner
diameter 61 and outer diameter 106 along the second annular gap 72, the sealing rings
68, 69 conform to the bore thereby further resisting rotational slip between the
ceramic runner 52 and carrier 91. The sealing rings 68, 69 could allow for axial
slippage so as to avoid stresses within the ceramic runner 52. Each sealing ring 68, 69
resides within an annular groove 64, 66, respectively. The annular grooves 64, 66 are
disposed along the inner diameter 61 of the ceramic runner 52 in an arrangement
similar to that shown in FIG. 6a or along the outer diameter 106 of the carrier 91 as
shown in FIG. 8a. The depth of each annular groove 64, 66 should be sufficiently
deep so as to allow assembly of the ceramic runner 52 onto the carrier 91 and proper
placement of the sealing rings 68, 69 along the carrier 91 while ensuring sufficient
contact between the sealing rings 68, 69 and inner and outer diameters 61, 106 for
proper function of the sealing rings 68, 69. The grooves 64, 66 should be at least as
wide as the sealing rings 68, 69, preferably with a tolerance fit allowing each sealing
ring 68, 69 to be secured within the respective annular groove 64, 66.

The sealing rings 68, 69 are disposed about the tolerance rings 70, 71, as
represented in FIG. 8a. The sealing rings 68, 69 are oriented along the second annular
gap 72 so that the sealing direction 101 of the sealing rings 68, 69 avoids or at least
minimizes oil and other contaminants within the higher and/or lower pressure sides
81, 82 from entering the second annular gap 72 and interacting with the tolerance
rings 70, 71. This feature minimizes degradation to the performance of the tolerance
rings 70, 71 caused by oil and other contaminants and further minimizes oil coking
under the ceramic runner 52.

The clamping ring 74 further includes at least one anti-rotation key 89. The
anti-rotation key 89 is attached or fixed to one side of the clamping ring 74 via
techniques understood in the art so that a portion of the anti-rotation key 89 extends
toward the ceramic runner 52. The portion of the anti-rotation key 89 extending from
the clamping ring 74 could reside within a slot 78 along the ceramic runner 52. The
slot 78 could extend from the inner diameter 61 of the ceramic runner 52 and partially
traverse the thickness of the ceramic runner 52 in the direction of the outward facing
sealing surface 60, as represented in FIG. 8b. The anti-rotation key 89 could include a circular head as shown in FIG. 8b or a substantially rectangular head. The slot 78 is dimensioned to avoid contact with the end and sides of the anti-rotation key 89, see FIGS. 8a and 8b, respectively. The anti-rotation key 89 could contact a side wall 102, the latter shown in FIG. 8b, along the slot 78 when the ceramic runner 52 rotates relative to the clamping ring 74. The degree of rotation before contact between the anti-rotation key 89 and side wall 102 is determined by the clearance therebetween, which is design dependent.

An annular seal ring 49 is circumferentially disposed about the outward facing sealing surface 60 of the ceramic runner 52. The annular seal ring 49 includes an inward facing sealing surface 59 which interacts with the outward facing sealing surface 60 to form the circumferential sealing of the present invention. The annular seal ring 49 is a ring-shaped element with or without segmentation. In some embodiments, the inward facing sealing surface 59 could physically contact the outward facing sealing surface 60 during rotation of the ceramic runner 52 and shaft 57 to provide a contact seal. In other embodiments, the inward facing sealing surface 59 and outward facing sealing surface 60 could be separated by a gap to form a non-contact seal. In yet other embodiments, the outward facing sealing surface 60 could include hydrodynamic pockets which form a thin-film between inward and outward facing sealing surfaces 59, 60 during rotation of the ceramic runner 52.

The annular seal ring 49 resides within a seal housing 47 and is secured thereto via a support ring 50 and a retaining ring 51 or other like elements via methods and designs known within the art. The annular seal ring 49 is rotationally stationary with respect to the seal housing 47. As such, the annular seal ring 49 does not rotate with respect to the seal housing 47. The annular seal ring 49 could move radially inward and outward to track radial excursions of the ceramic runner 52. The seal housing 47 is secured to a housing 48 comprising a turbine engine. Both seal housing 47 and housing 48 are shown in a generalized form for descriptive purposes only and are not intended to limit the scope of the claimed invention. Arrangement of the annular seal ring 49, seal housing 47, and housing 48 about the ceramic runner 52 and shaft 57 generally defines a higher pressure side 81 and a lower pressure side 82. The higher pressure side 81 could define the air or gas side within a turbine engine.
The lower pressure side 82 could define the bearing or oil side within a turbine engine.

Referring again to FIGS. 8a, the outward facing sealing surface 60 along the ceramic runner 52 and annular surface 107 of the carrier 91 are shown approximately radially aligned with the outer diameter 100 of the shaft 57. However, it is understood that outward facing sealing surface 60 and annular surface 107 could extend above or be depressed below the outer diameter 100 in other embodiments of the invention. In yet other embodiments, it is possible for the outward facing sealing surface 60 and annular surface 107 to move radially inward and outward with respect to the outer diameter 100 during operation of a turbine engine.

Referring now to FIG. 9a, the circumferential seal 46 is illustrated for descriptive purposes along an upper half of an exemplary shaft 57 along a turbine engine rotatable about a centerline 67. In this embodiment, a ceramic runner 52 is attached to a carrier 91 to form a cartridge 90. The cartridge 90 facilitates assembly of components comprising the circumferential seal 46 prior to attachment to a shaft 57. This approach simplifies assembly and repair of a turbine engine.

The outer diameter 100 of the shaft 57 is shown including a recess 98. The recess 98 could include one or more regions along the shaft 57 each having a diameter smaller than the outer diameter 100. The exemplary shaft 57 has a recess 98 which includes a single section to accommodate a locking ring 75 and a carrier 91, the latter supporting a ceramic runner 52 and a clamping ring 74. The clamping ring 74 and locking ring 75 are composed of materials suitable for use within a turbine engine. Materials should be wear, failure, and temperature resistant. Exemplary compositions include metals, preferably compositions of steel. The locking ring 75 secures the carrier 91 with the various components described herein to the shaft 57 about the recess 98. It is understood that the recess 98 could include one or more sections as well as other shapes and designs which facilitate attachment of elements required to provide circumferential sealing along a shaft 57.

The interface between the outer diameter 100 of the shaft 57 and the outer diameter 62 of the recess 98 defines a first shoulder 55. The recess 98 could include additional shoulders depending on the profile of the recess 98, although such features are optional and design dependent. For example, the recess 98 could include other shoulders each defined by a discontinuity where two outer diameters differ.
The carrier 91 is a ring-shaped element with a flange 104 which extends perpendicular from one end an annular ring 105. In some embodiments, a clearance fit is provided for assembly purposes between the outer diameter 62 of the shaft 57 and inner diameter 85 of the carrier 91 so that the carrier 91 is slidable with respect to the shaft 57. In other embodiments, an interference fit is provided between the outer diameter 62 and the inner diameter 85 and the carrier 91 is heated to open the inner diameter 85 prior to sliding the carrier 91 onto the shaft 57. The carrier 91 is then cooled to fix the carrier 91 to the shaft 57. The flange 104 should contact the shoulder 55 in addition to the annular ring 105 contacting the surface of the shaft 57. The carrier 91 is composed of materials suitable for use within a turbine engine. Materials should be wear, failure, and temperature resistant. Exemplary compositions include metals, preferably compositions of steel with a coefficient of thermal expansion comparable to that of the shaft 57 so that carrier 91 tracks the expansion and contraction of the shaft 57.

The carrier 91 could likewise include one or more shoulders along the annular ring 105. The interface between the annular surface 107 along the carrier 91 and the outer diameter 106 of the carrier 91 defines a first shoulder 92. The carrier 91 could also include a first segment with an outer diameter 106 and a second segment with an outer diameter 86. The outer diameter 106 could be larger than the other outer diameter 86 so that a second shoulder 103 is provided at the discontinuity between the two outer surfaces. A clearance fit could be provided between the outer diameter 86 of the carrier 91 and inner diameter 83 along the clamping ring 74 so that the clamping ring 74 is slidable with respect to the carrier 91. The carrier 91 and clamping ring 74 are secured to the shaft 57 via the locking ring 75. The locking ring 75 contacts both the clamping ring 74 and the end 93 of the carrier 91 as illustrate in FIG. 9a. The locking ring 75 includes threads along its inner diameter 84 which engage a complementary thread arrangement along the outer diameter 80 of the shaft 57. The force applied by the locking ring 75 onto the carrier 91 and clamping ring 74 should be sufficient to prevent relative motion with respect to the shaft 57.

The ceramic runner 52 is a cylindrically-shaped or sleeve-shaped element which is slid onto the shaft 57 during assembly so as to circumscribe the carrier 91. The ceramic runner 52 is composed of a ceramic composition suitable for use within a turbine engine. In preferred embodiments, the ceramic composition should be wear,
failure, and temperature resistant. Exemplary, non-limiting compositions include silicon nitride and silicon carbide.

The ceramic runner 52 has an inner diameter 61 which is larger than the outer diameter 106 of the carrier 91 resulting in a second annular gap 72 which avoids direct contact between the ceramic runner 52 and carrier 91. The distance between a first end 53 and a second end 54 of the ceramic runner 52 is less than the axial distance between the first shoulder 92 and second shoulder 103. The first end 53 is positioned adjacent to the first shoulder 92 so that a first annular gap 73 separates the first end 53 from the first shoulder 92. The axial length of the first annular gap 73 is sized to accommodate a spring mechanism. The spring mechanism provides no sealing functionality. Although spring mechanisms are described herein, it is understood that such mechanisms could include other non-sealing devices which at least resist compression and are resilient. The second end 54 directly contacts the clamping ring 74 so that the second end 54 is generally aligned with the second shoulder 103.

In some embodiments, the spring mechanism could include a plurality of compression springs 88 as represented in FIG. 9a and generally described in FIGS. 7b and 7c. Each compression spring 88 is axially aligned along the direction of the shaft 57. The compression springs 88 are further separately disposed about the shaft 57 along the flange 104 of the carrier 91, as generally shown in FIG. 8c, so as to communicate a biasing force 99 symmetrically about the ceramic runner 52 in the axial direction. One end of each compression spring 88 could reside within a complementary shaped hole 94 within the flange 104 so that a portion of the compression spring 88 extends into the first annular gap 73 with sufficient length to contact the first end 53 along the ceramic runner 52. The compression spring 88 could be mechanically fixed to the hole 94 via an interference fit or freely movable within the hole 94. The compression springs 88 are preferred to be sufficiently long so that each is partially compressed when assembled between the carrier 91 and ceramic runner 52. Partial compression of the compression spring 88 maintains a biasing force 99 onto the ceramic runner 52 so that the second end 54 of the ceramic runner 52 is biased toward and contacts the clamping ring 74. The biasing force 99 maintains contact between the second end 54 of the ceramic runner 52 and the clamping ring 74 during operation of a turbine engine, thereby avoiding separation thereof because of
thermally induced expansion and contraction of ceramic runner 52 and other
components within the engine. The biasing force 99 is also resists rotational sliding
between the ceramic runner 52 and clamping ring 74 at the second end 54. The
compression springs 88 are partially compressed at or below ambient conditions so as
to allow for further compression of the compression springs 88 during operation of a
turbine engine. This feature allows the compression springs 88 to expand and contract
with expansion and contraction of the ceramic runner 52 as the ceramic runner 52 and
other components heat and cool.

In other embodiments, the spring mechanism could be a single annular spring
58, as represented in FIG. 8d. Exemplary annular springs 58 include a wave spring or
a compression spring or the like which circumscribe the shaft 57 within the first
annular gap 73 between the first end 53 of the ceramic runner 52 and first shoulder 92
along the carrier 91. The length of the annular spring 58 in its uncompressed state
requires the annular spring 58 to be partially compressed when assembled between the
ceramic runner 52 and carrier 91. The annular spring 58 is compressed by contact
with the first shoulder 92 at one side of the annular spring 58 and the first end 53 at
another side of the annular spring 58. In its partially compressed state, the annular
spring 58 communicates a biasing force 99 axially onto the ceramic runner 52 thereby
pressing the ceramic runner 52 onto the clamping ring 74. The biasing force 99 is
preferred to maintain contact between the second end 54 of the ceramic runner 52 and
the clamping ring 74 during operation of a turbine engine, thereby avoiding separation
between the ceramic runner 52 and clamping ring 74 which could occur because of
thermally induced expansion and contraction of components within the engine. The
biasing force 99 also resists rotational sliding motion between the ceramic runner 52
and the clamping ring 74 at the second end 54. The annular spring 58 is partially
compressed at or below ambient conditions so as to allow for further compression of
the annular spring 58 during operation of a turbine engine. This feature allows the
annular spring 58 to expand and contract with axial expansion and contraction of the
ceramic runner 52 as the ceramic runner 52 and other components heat and cool.

In other embodiments, the first end 53 could directly contact the first shoulder
92 and the spring mechanism, either the annular spring 58 or the compression springs
88, is disposed between the second end 54 and clamping ring 74, as shown in FIG. 9e.
The biasing force 99 is directed toward the flange 104. The spring mechanisms could
be attached to the clamping ring 74 via in a similar manner as the attachment to the
flange 104 as described in FIG. 9a. The first annular gap 73 is now disposed between
the clamping ring 74 and second end 54.

Referring again to FIG. 9a, the second annular gap 72 between the inner
diameter 61 of the ceramic runner 52 and outer diameter 106 of the carrier 91 is
shown with a tolerance ring 70. Although one tolerance ring 70 is shown and
described, it is understood that the second annular gap 72 could include one or more
such rings. The tolerance ring 70 is generally described as a ring-shaped element with
corrugations along an inward face or an outward face and with a gap 87, the latter
feature represented in FIG. 6c. The tolerance ring 70 provides no sealing
functionality. When attached between the inner diameter 61 and outer diameter 106
along the gap 72, the tolerance ring 70 conforms to the bore and is self-retaining
thereby resisting rotational slip between the ceramic runner 52 and carrier 91. The
tolerance ring 70 could allow for axial slippage so as to avoid stresses within the
ceramic runner 52. An exemplary tolerance ring 70 is the BN Series devices sold by
USA Tolerance Rings of Pennington, New Jersey (United States). The tolerance ring
70 maintains proper fit between the ceramic runner 52 and carrier 91 by expanding
circumferentially to the radial clearance between the inner diameter 61 and outer
diameter 106 by closing the gap 87. This functionality avoids radial expansion of the
ceramic runner 52, which could damage the runner 52. The tolerance ring 70 resides
within an annular groove 63. The annular groove 63 could be disposed along the inner
diameter 61 of the ceramic runner 52 in an arrangement similar to that shown in FIG.
6a or along the outer diameter 106 of the carrier 91 as shown in FIG. 9a. The depth of
the annular groove 63 should allow assembly of the ceramic runner 52 onto the carrier
91 and proper placement of the tolerance ring 70 along the carrier 91 while ensuring
sufficient contact between the tolerance ring 70 and inner and outer diameters 61, 106
for proper function of the tolerance ring 70. The annular groove 63 should be at least
as wide as the tolerance ring 70, preferably providing a tolerance fit allowing the
tolerance ring 70 to be secured within the annular groove 63.

Referring again to FIG. 9a, the second annular gap 72 between the inner
diameter 61 of the ceramic runner 52 and outer diameter 106 of the carrier 91 is
shown with a sealing ring 68. The clamping ring 74 also includes a sealing ring 69
disposed along the vertical surface at the interface with the ceramic runner 52. In
other embodiments, the seal ring 69 could be disposed within an annular groove 66
between the carrier 91 and the ceramic runner 52 along the second annular gap 72
further between the clamping ring 74 and anti-rotation screw 96, as shown in FIG. 9d.
Sealing rings 68, 69 could include devices known within the art, examples including,
but not limited to, multi-directional O-rings, unidirectional spring-energized seals,
high-temperature metallic seal rings, or other comparable devices sold by the Parker
Hannifin Corporation located in North Haven, Connecticut (United States) or other
suppliers. Other exemplary seals include those sold under the Trademark
OMNISEAL® by Saint-Gobain Performance Plastics Corporation of Aurora, Ohio
(United States). When assembled between the inner diameter 61 and outer diameter
106 along the second annular gap 72, the sealing ring 68 conforms to the bore thereby
further resisting rotational slip between the ceramic runner 52 and carrier 91. The
sealing ring 68 could allow for axial slippage so as to avoid stresses within the
ceramic runner 52. The sealing ring 69 conforms to the ring-shaped surfaces to further
resist rotational slip when assembled between the clamping ring 74 and the ceramic
runner 52. Each sealing ring 68, 69 resides within an annular groove 64, 66,
respectively. The annular groove 64 could be disposed along the inner diameter 61 of
the ceramic runner 52 in an arrangement similar to that shown in FIG. 6a or along the
outer diameter 106 of the carrier 91 as shown in FIG. 9a. The depth of each annular
groove 64, 66 should be sufficiently deep so as to allow assembly of the ceramic
runner 52 onto the carrier 91 and proper placement of the sealing rings 68, 69 along
the carrier 91 while ensuring sufficient contact between the sealing ring 68 and inner
and outer diameters 61, 106, as well as the sealing ring 69 and the ceramic runner 52
and clamping ring 74, for proper function of the sealing rings 68, 69. The grooves 64,
66 should be at least as wide as the sealing rings 68, 69, preferably with a tolerance fit
allowing each sealing ring 68, 69 to be secured within the respective annular groove
64, 66.

The sealing rings 68, 69 are disposed about the tolerance ring 70, as
represented in FIG. 9a. The sealing rings 68, 69 are oriented so that the sealing
direction 101 avoids or at least minimizes oil and other contaminants within the
higher and/or lower pressure sides 81, 82 from entering the second annular gap 72 and
interacting with the tolerance ring 70. This feature minimizes degradation to the
performance of the tolerance rings 70 caused by oil and other contaminants and
further minimizes oil coking under the ceramic runner 52.

Referring again to FIG. 9a, the carrier 91 further includes at least one anti-
rotation screw 96. The anti-rotation screw 96 is attached or fixed to a threaded hole 95
along the carrier 91, as represented in FIG. 9b, via techniques understood in the art so
that a portion of the anti-rotation screw 96 extends toward the ceramic runner 52. The
end of the anti-rotation screw 96 extending from the carrier 91 could reside within a
hole or slot 97 along the ceramic runner 52. The hole or slot 97 could extend from the
inner diameter 61 of the ceramic runner 52 and partially traverse the thickness of the
ceramic runner 52 in the direction of the outward facing sealing surface 60. The hole
or slot 97 is dimensioned to avoid contact with the end and side of the anti-rotation
screw 96, see FIGS. 9a and 9c, respectively. The anti-rotation screw 96 could contact
a side of the hole or slot 97 when the ceramic runner 52 rotates relative to the carrier
91. The degree of rotation before contact between the anti-rotation screw 96 and side
of the threaded hole 95 is determined by the clearance therebetween which is design
dependent.

An annular seal ring 49 is circumferentially disposed about the outward facing
sealing surface 60 of the ceramic runner 52. The annular seal ring 49 includes an
inward facing sealing surface 59 which interacts with the outward facing sealing
surface 60 to form the circumferential sealing of the present invention. The annular
seal ring 49 is a ring-shaped element with or without segmentation. In some
embodiments, the inward facing sealing surface 59 could physically contact the
outward facing sealing surface 60 during rotation of the ceramic runner 52 and shaft
57 to provide a contact seal. In other embodiments, the inward facing sealing surface
59 and outward facing sealing surface 60 could be separated by a gap to form a non-
contact seal. In yet other embodiments, the outward facing sealing surface 60 could
include hydrodynamic pockets which form a thin-film between inward and outward
facing sealing surfaces 59, 60 during rotation of the ceramic runner 52.

The annular seal ring 49 resides within a seal housing 47 and is secured
thereto via a support ring 50 and a retaining ring 51 or other like elements via
methods and designs known within the art. The annular seal ring 49 is rotationally
stationary with respect to the seal housing 47. As such, the annular seal ring 49 does
not rotate with respect to the seal housing 47. The annular seal ring 49 could move
radially inward and outward to track radial excursions of the ceramic runner 52. The
seal housing 47 is secured to a housing 48 comprising a turbine engine. Both seal
housing 47 and housing 48 are shown in a generalized form for descriptive purposes
only and are not intended to limit the scope of the claimed invention. Arrangement of
the annular seal ring 49, seal housing 47, and housing 48 about the ceramic runner 52
and shaft 57 generally defines a higher pressure side 81 and a lower pressure side 82.
The higher pressure side 81 could define the air or gas side within a turbine engine.
The lower pressure side 82 could define the bearing or oil side within a turbine
engine.

Referring again to FIGS. 9a, the outward facing sealing surface 60 along the
ceramic runner 52 and annular surface 107 of the carrier 91 are shown approximately
radially aligned with the outer diameter 100 of the shaft 57. However, it is understood
that outward facing sealing surface 60 and annular surface 107 could extend above or
be depressed below the outer diameter 100 in other embodiments of the invention. In
yet other embodiments, it is possible for the outward facing sealing surface 60 and
annular surface 107 to move radially inward and outward with respect to the outer
diameter 100 during operation of a turbine engine.

The description above indicates that a great degree of flexibility is offered in
terms of the present invention. Although various embodiments have been described in
considerable detail with reference to certain preferred versions thereof, other versions
are possible. Therefore, the spirit and scope of the appended claims should not be
limited to the description of the preferred versions contained herein.

6. Industrial Applicability

The invention is applicable for use within a variety of applications wherein
sealing is required about a rotatable element. One specific non-limiting example is a
turbine engine including a circumferential seal formed between a stationary annular
seal and a rotatable runner.
What is claimed is:

1. A circumferential seal comprising:
   (a) a ceramic runner circumscribed about a recess along a shaft, said recess bounded by a shoulder and a clamping ring, a first annular gap disposed between a first end of said ceramic runner and said shoulder, a second end of said ceramic runner directly contacts said clamping ring, an anti-rotation pin attached to said clamping ring and extends into a slot along said ceramic runner, at least one non-sealing spring mechanism disposed between and directly contacts said shoulder and said first end along said first annular gap, said at least one non-sealing spring mechanism applies a biasing force onto said ceramic runner toward said clamping ring;
   (b) an annular seal ring circumscribed about said ceramic runner and disposed within a seal housing so that said annular seal ring is rotationally stationary;
   (c) at least one tolerance ring directly contacts said ceramic runner and said shaft along a second annular gap between said ceramic runner and said shaft, said ceramic runner fixed to said shaft via said at least one tolerance ring, said anti-rotation pin, and said at least one non-sealing spring mechanism so that said ceramic runner rotates with said shaft, said at least one non-sealing spring mechanism expands and contracts in response to expansion and contraction of said ceramic runner; and
   (d) a pair of sealing rings directly contacts said ceramic runner and said shaft along said second annular gap, said at least one tolerance ring disposed between said pair of sealing rings.

2. The circumferential seal of claim 1, wherein said at least one non-sealing spring mechanism is a wave spring.

3. The circumferential seal of claim 1, wherein said at least one non-sealing spring mechanism is a compression spring.

4. The circumferential seal of claim 1, wherein said at least one non-sealing spring mechanism is a plurality of compression springs separately disposed about said first annular gap, each said compression spring separately attaches to said shoulder.

5. The circumferential seal of claim 1, wherein each said tolerance ring and each said
sealing ring separately disposed within an equal number of annular grooves along said ceramic runner.

6. The circumferential seal of claim 1, wherein each said tolerance ring and each said sealing ring separately disposed within an equal number of annular grooves along said shaft.

7. The circumferential seal of claim 1, wherein said annular seal ring forms a contact seal about said ceramic runner.

8. The circumferential seal of claim 1, wherein said annular seal ring forms a non-contact seal about said ceramic runner.

9. The circumferential seal of claim 1, wherein at least one said sealing ring is an O-ring, a spring-energized seal, or a high-temperature metallic seal ring.

10. A circumferential seal comprising:

(a) a ceramic runner circumscribed about a recess along a shaft, said recess bounded by a shoulder and a clamping ring, a first annular gap disposed between a second end of said ceramic runner and said clamping ring, a first end of said ceramic runner directly contacts said shoulder along said shaft, an anti-rotation pin attached to said shoulder and extends into a slot along said ceramic runner, at least one non-sealing spring mechanism disposed between and directly contacts said clamping ring and said second end along said first annular gap, said at least one non-sealing spring mechanism applies a biasing force onto said ceramic runner toward said shoulder;

(b) an annular seal ring circumscribed about said ceramic runner and disposed within a seal housing so that said annular seal ring is rotationally stationary;

(c) at least one tolerance ring directly contacts said ceramic runner and said shaft along a second annular gap between said ceramic runner and said shaft, said ceramic runner fixed to said shaft via said at least one tolerance ring, said anti-rotation pin, and said at least one non-sealing spring mechanism so that said ceramic runner rotates with said shaft, said at least one non-sealing spring mechanism expands and contracts in response to expansion and contraction of said ceramic runner; and

(d) a pair of sealing rings directly contacts said ceramic runner and said shaft
along said second annular gap, said at least one tolerance ring disposed
between said pair of sealing rings.

11. The circumferential seal of claim 10, wherein said at least one non-sealing spring
mechanism is a wave spring.

12. The circumferential seal of claim 10, wherein said at least one non-sealing spring
mechanism is a compression spring.

13. The circumferential seal of claim 10, wherein said at least one non-sealing spring
mechanism is a plurality of compression springs separately disposed about said first
annular gap, each said compression spring separately attached to said clamping ring.

14. The circumferential seal of claim 10, wherein each said tolerance ring and each
said sealing ring separately disposed within an equal number of annular grooves along
said ceramic runner.

15. The circumferential seal of claim 10, wherein each said tolerance ring and each
said sealing ring separately disposed within an equal number of annular grooves along
said shaft.

16. The circumferential seal of claim 10, wherein said annular seal ring forms a
contact seal about said ceramic runner.

17. The circumferential seal of claim 10, wherein said annular seal ring forms a non-
contact seal about said ceramic runner.

18. The circumferential seal of claim 10, wherein at least one said sealing ring is an
O-ring, a spring-energized seal, or a high-temperature metallic seal ring.

19. A circumferential seal comprising:

(a) a carrier disposed about and directly contacts a shaft within a recess along
said shaft, said carrier rotatable with said shaft, said carrier having a
shoulder at one end;

(b) a ceramic runner circumscribed about said carrier, said ceramic runner
disposed between said shoulder and a clamping ring, a first annular gap
disposed between a first end of said ceramic runner and said shoulder, a
second end of said ceramic runner directly contacts said clamping ring, an
anti-rotation key attached to said clamping ring and extends into a slot
along said ceramic runner, at least one non-sealing spring mechanism
directly contacts said shoulder and said first end along said first annular
gap, said at least one non-sealing spring mechanism applies a biasing force
onto said ceramic runner toward said clamping ring;

(c) an annular seal ring circumscribed about said ceramic runner and disposed
within a seal housing so that said annular seal ring is rotationally
stationary;

(d) at least one tolerance ring directly contacts said ceramic runner and said
carrier along a second annular gap between said ceramic runner and said
carrier, said ceramic runner fixed to said carrier via said at least one
tolerance ring, said anti-rotation key, and said at least one non-sealing
spring mechanism so that said ceramic runner rotates with said carrier, said
at least one non-sealing spring mechanism expands and contracts in
response to expansion and contraction of said ceramic runner; and

(e) a pair of sealing rings directly contacts said ceramic runner and said carrier
along said second annular gap, said at least one tolerance ring disposed
between said pair of sealing rings.

20. The circumferential seal of claim 19, wherein said at least one non-sealing spring
mechanism is a wave spring.

21. The circumferential seal of claim 19, wherein said at least one non-sealing spring
mechanism is a compression spring.

22. The circumferential seal of claim 19, wherein said at least one non-sealing spring
mechanism is a plurality of compression springs separately disposed about said first
annular gap, each said compression spring separately attached to said shoulder.

23. The circumferential seal of claim 19, wherein each said tolerance ring and each
said sealing ring separately disposed within an equal number of annular grooves along
said carrier.

24. The circumferential seal of claim 19, wherein each said tolerance ring and each
said sealing ring separately disposed within an equal number of annular grooves along
said ceramic runner.

25. The circumferential seal of claim 19, wherein said annular seal ring forms a
contact seal about said ceramic runner.

26. The circumferential seal of claim 19, wherein said annular seal ring forms a non-
contact seal about said ceramic runner.

27. The circumferential seal of claim 19, wherein at least one said sealing ring is an
O-ring, a spring-energized seal, or a high-temperature metallic seal ring.
28. A circumferential seal comprising:
   (a) a carrier disposed about and directly contacts a shaft within a recess along said shaft, said carrier rotatable with said shaft, said carrier having a shoulder at one end;
   (b) a ceramic runner circumscribed about said carrier, said ceramic runner disposed between said shoulder and a clamping ring, a first annular gap disposed between a second end of said ceramic runner and said clamping ring, a first end of said ceramic runner directly contacts said shoulder, an anti-rotation key attached to said shoulder and extends into a slot along said ceramic runner, at least one non-sealing spring mechanism directly contacts said clamping ring and said second end along said first annular gap, said at least one non-sealing spring mechanism applies a biasing force onto said ceramic runner toward said shoulder;
   (c) an annular seal ring circumscribed about said ceramic runner and disposed within a seal housing so that said annular seal ring is rotationally stationary;
   (d) at least one tolerance ring directly contacts said ceramic runner and said carrier along a second annular gap between said ceramic runner and said carrier, said ceramic runner fixed to said carrier via said at least one tolerance ring, said anti-rotation key, and said at least one non-sealing spring mechanism so that said ceramic runner rotates with said carrier, said at least one non-sealing spring mechanism expands and contracts in response to expansion and contraction of said ceramic runner; and
   (e) a pair of sealing rings directly contacts said ceramic runner and said carrier along said second annular gap, said at least one tolerance ring disposed between said pair of sealing rings.

29. The circumferential seal of claim 28, wherein said at least one non-sealing spring mechanism is a wave spring.

30. The circumferential seal of claim 28, wherein said at least one non-sealing spring mechanism is a compression spring.

31. The circumferential seal of claim 28, wherein said at least one non-sealing spring mechanism is a plurality of compression springs separately disposed about said first annular gap, each said compression spring separately attached to said clamping ring.
32. The circumferential seal of claim 28, wherein each said tolerance ring and each
said sealing ring separately disposed within an equal number of annular grooves along
said carrier.
33. The circumferential seal of claim 28, wherein each said tolerance ring and each
said sealing ring separately disposed within an equal number of annular grooves along
ceramic runner.
34. The circumferential seal of claim 28, wherein said annular seal ring forms a
contact seal about said ceramic runner.
35. The circumferential seal of claim 28, wherein said annular seal ring forms a non-
contact seal about said ceramic runner.
36. The circumferential seal of claim 28, wherein at least one said sealing ring is an
O-ring, a spring-energized seal, or a high-temperature metallic seal ring.
37. A circumferential seal comprising:
   (a) a carrier disposed about and directly contacts a shaft within a recess along
       said shaft, said carrier rotatable with said shaft, said carrier having a
       shoulder at one end;
   (b) a ceramic runner circumscribed about said carrier, said ceramic runner
       disposed between said shoulder and a clamping ring, a first annular gap
       disposed between a first end of said ceramic runner and said shoulder, a
       second end of said ceramic runner directly contacts said clamping ring, an
       anti-rotation screw attached to said carrier and extends into a hole along
       said ceramic runner, at least one non-sealing spring mechanism directly
       contacts said shoulder and said first end along said first annular gap, said
       at least one non-sealing spring mechanism applies a biasing force onto said
       ceramic runner toward said clamping ring;
   (c) an annular seal ring circumscribed about said ceramic runner and disposed
       within a seal housing so that said annular seal ring is rotationally
       stationary;
   (d) at least one tolerance ring directly contacts said ceramic runner and said
       carrier along a second annular gap between said ceramic runner and said
       carrier, said ceramic runner fixed to said carrier via said at least one
       tolerance ring, said anti-rotation screw, and said at least one non-sealing
       spring mechanism so that said ceramic runner is rotatable with said carrier,
said at least one non-sealing spring mechanism expands and contracts in
response to expansion and contraction of said ceramic runner; and
(e) a pair of sealing rings, at least one said sealing ring directly contacts said
ceramic runner and said carrier along said second annular gap, said at least
one tolerance ring and said anti-rotation screw disposed between said pair
of sealing rings.
38. The circumferential seal of claim 37, wherein said at least one non-sealing spring
mechanism is a wave spring.
39. The circumferential seal of claim 37, wherein said at least one non-sealing spring
mechanism is a compression spring.
40. The circumferential seal of claim 37, wherein said at least one non-sealing spring
mechanism is a plurality of compression springs separately disposed about said first
annular gap, each said compression spring separately attached to said shoulder.
41. The circumferential seal of claim 37, wherein each said tolerance ring and one
said sealing ring separately disposed within an equal number of annular grooves along
said carrier and another said sealing ring disposed within another said annular groove
along said clamping ring.
42. The circumferential seal of claim 37, wherein each said tolerance ring and one
said sealing ring separately disposed within an equal number of annular grooves along
said ceramic runner and another said sealing ring disposed within another said annular
groove along said clamping ring.
43. The circumferential seal of claim 37, wherein said annular seal ring forms a
contact seal about said ceramic runner.
44. The circumferential seal of claim 37, wherein said annular seal ring forms a non-
contact seal about said ceramic runner.
45. The circumferential seal of claim 37, wherein at least one said sealing ring is an
O-ring, a spring-energized seal, or a high-temperature metallic seal ring.
46. A circumferential seal comprising:
   (a) a carrier disposed about and directly contacts a shaft within a recess along
       said shaft, said carrier rotatable with said shaft, said carrier having a
       shoulder at one end;
   (b) a ceramic runner circumscribed about said carrier, said ceramic runner
disposed between said shoulder and a clamping ring, a first annular gap
disposed between a second end of said ceramic runner and said clamping ring, a first end of said ceramic runner directly contacts said shoulder, an anti-rotation screw attached to said carrier and extends into a hole along said ceramic runner, at least one non-sealing spring mechanism directly contacts said clamping ring and said second end along said first annular gap, said at least one non-sealing spring mechanism applies a biasing force onto said ceramic runner toward said shoulder;

(c) an annular seal ring circumscribed about said ceramic runner and disposed within a seal housing so that said annular seal ring is rotationally stationary;

(d) at least one tolerance ring directly contacts said ceramic runner and said carrier along a second annular gap between said ceramic runner and said carrier, said ceramic runner fixed to said carrier via said at least one tolerance ring, said anti-rotation screw, and said at least one non-sealing spring mechanism so that said ceramic runner is rotatable with said carrier, said at least one non-sealing spring mechanism expands and contracts in response to expansion and contraction of said ceramic runner; and

(e) a pair of sealing rings, at least on said sealing ring directly contacts said ceramic runner and said carrier along said second annular gap, said at least one tolerance ring and said anti-rotation screw disposed between said pair of sealing rings.

47. The circumferential seal of claim 46, wherein said at least one non-sealing spring mechanism is a wave spring.

48. The circumferential seal of claim 46, wherein said at least one non-sealing spring mechanism is a compression spring.

49. The circumferential seal of claim 46, wherein said at least one non-sealing spring mechanism is a plurality of compression springs separately disposed about said first annular gap, each said compression spring separately attached to said clamping ring.

50. The circumferential seal of claim 46, wherein each said tolerance ring and one said sealing ring separately disposed within an equal number of annular grooves along said carrier and another said sealing ring disposed within another said annular groove along said clamping ring.

51. The circumferential seal of claim 46, wherein each said tolerance ring and one
said sealing ring separately disposed within an equal number of annular grooves along said ceramic runner and another said sealing ring disposed within another said annular groove along said clamping ring.

52. The circumferential seal of claim 46, wherein said annular seal ring forms a contact seal about said ceramic runner.

53. The circumferential seal of claim 46, wherein said annular seal ring forms a non-contact seal about said ceramic runner.

54. The circumferential seal of claim 46, wherein at least one said sealing ring is an O-ring, a spring-energized seal, or a high-temperature metallic seal ring.
Fig. 2
(Prior Art)
Fig. 3
(Prior Art)
Fig. 4
(Prior Art)
Fig. 5
(Prior Art)
**INTERNATIONAL SEARCH REPORT**

**PCT/US2013/040812**

**A. CLASSIFICATION OF SUBJECT MATTER**
F01D II/00(2006.01)i, F02C 7/28(2006.01)i, F01D II/02(2006.01)i

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 II/00(2006.01)i, F02C 7/28(2006.01)i, F01D II/02(2006.01)i

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic database consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS/KIPO internal & Keywords: turbine, shaft, recess, groove, runner, clamp, spring, elastic, biasing force, seal, anti-rotation, lock

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>US 2009-0142180 A1 (MUNSON, JOHN) 4 June 2009</td>
<td>1-54</td>
</tr>
<tr>
<td></td>
<td>See paragraphs [0017]-[0028]; figure 1.</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>US 6,145,840 A (POPE, ADAM NELSON) 14 November 2000</td>
<td>1-54</td>
</tr>
<tr>
<td></td>
<td>See column 2, line 61 - column 4, line 53; figures 1A,1B.</td>
<td></td>
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<td>US 5,593,165 A (MURRAY et al.) 14 January 1997</td>
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<td></td>
<td>See column 3, line 32 - column 4, line 56; figure 3.</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>US 5,301,957 A (HWANG et al.) 12 April 1994</td>
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<tr>
<td></td>
<td>See column 4, line 24 - column 5, line 28; figures 3-5.</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>US 5,813,830 A (SMITH et al.) 29 September 1998</td>
<td>1-54</td>
</tr>
<tr>
<td></td>
<td>See column 4, line 45 - column 5, line 41; figure 3.</td>
<td></td>
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</table>

Further documents are listed in the continuation of Box C.  

See patent family annex.

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Date of the actual completion of the international search
17 October 2013 (17.10.2013)

Date of mailing of the international search report
18 October 2013 (18.10.2013)

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