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(54) **LEAKAGE FLOW MINIMIZATION SYSTEM FOR A TURBINE ENGINE**

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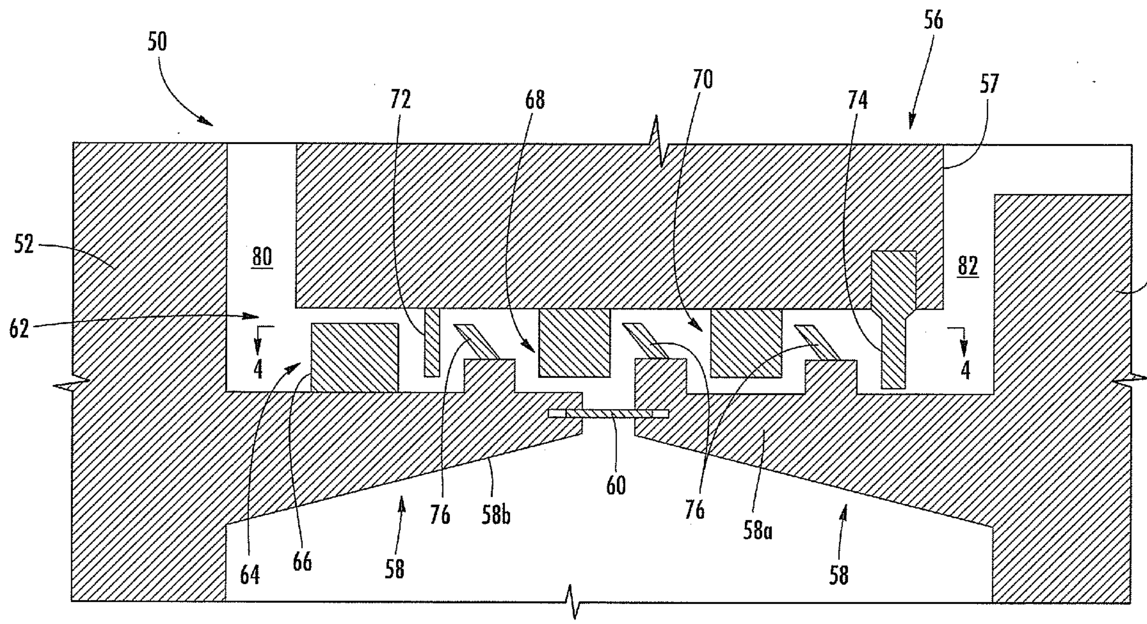
(57) **ABSTRACT**

A sealing system is applied to the interface between a stator and a rotor in a turbine engine to minimize fluid leakage across the interface. One interface can be defined between portions of neighboring rotor disks and a stator. The sealing system includes one or more rows of flow guides, such as airfoils, provided on the rotor disk near the upstream end of the interface. These flow guides can impart tangential velocity on the leakage flow. One or more undulating seal structures can be connected to the stator downstream of the flow guides. These undulating seals can have a periodic waveform conformation. The undulating seals can create unsteadiness in the flow and recirculation of the leakage flow, which causes losses. The sealing system can also include other types of seals, such as labyrinth seals and brush seals, to further create a tortuous path for any leakage flow.



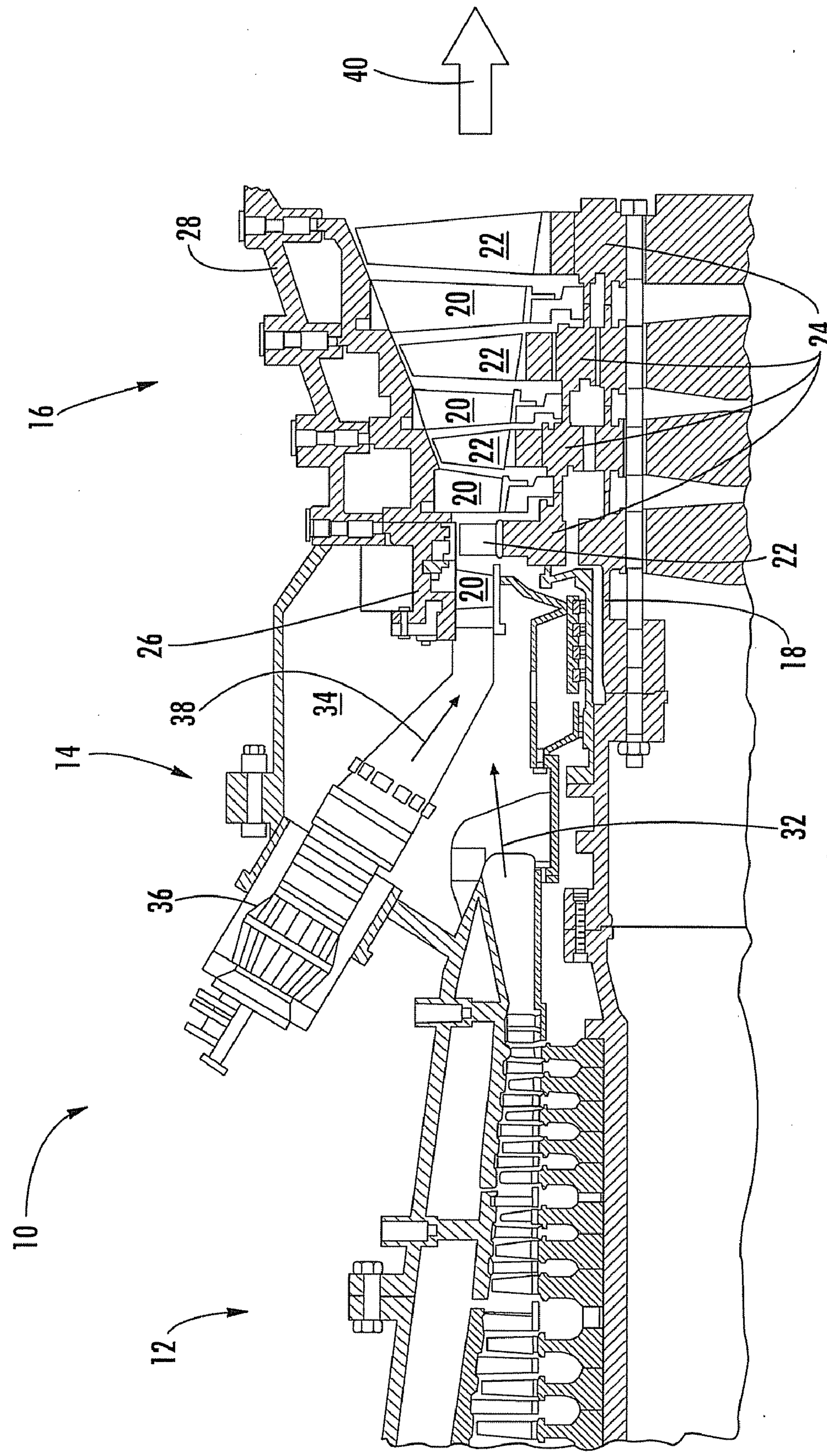


FIG. 1
(PRIOR ART)

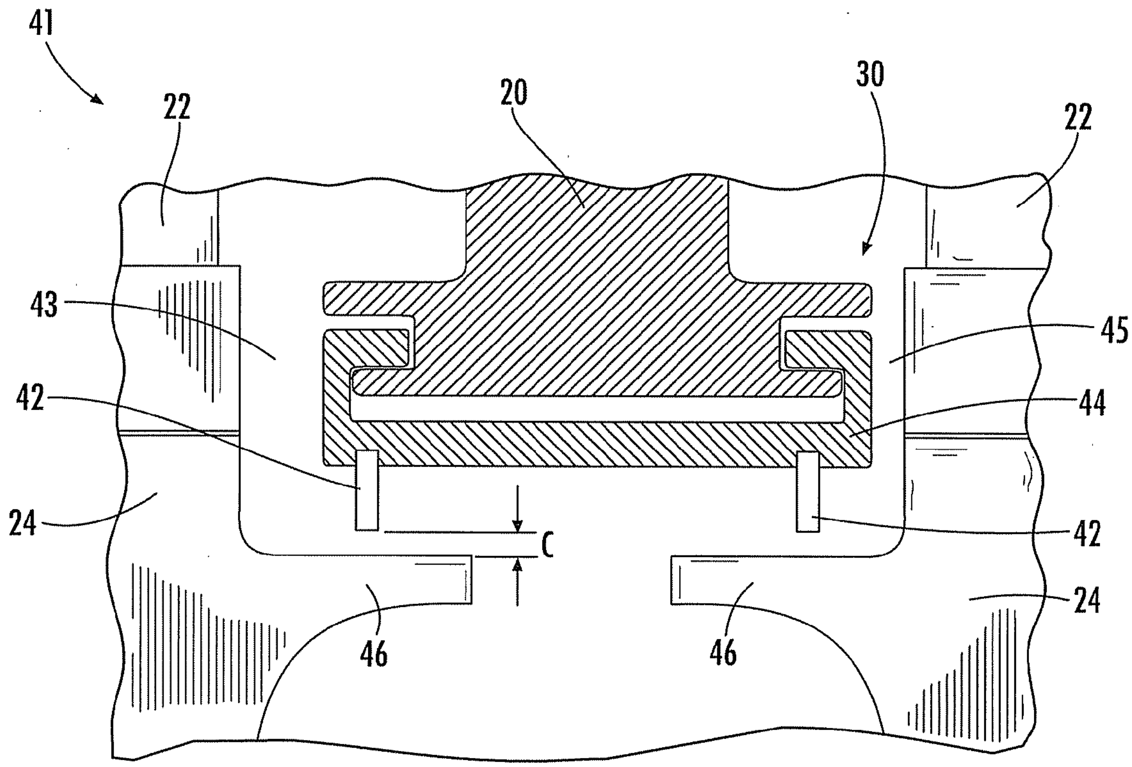


FIG. 2
(PRIOR ART)

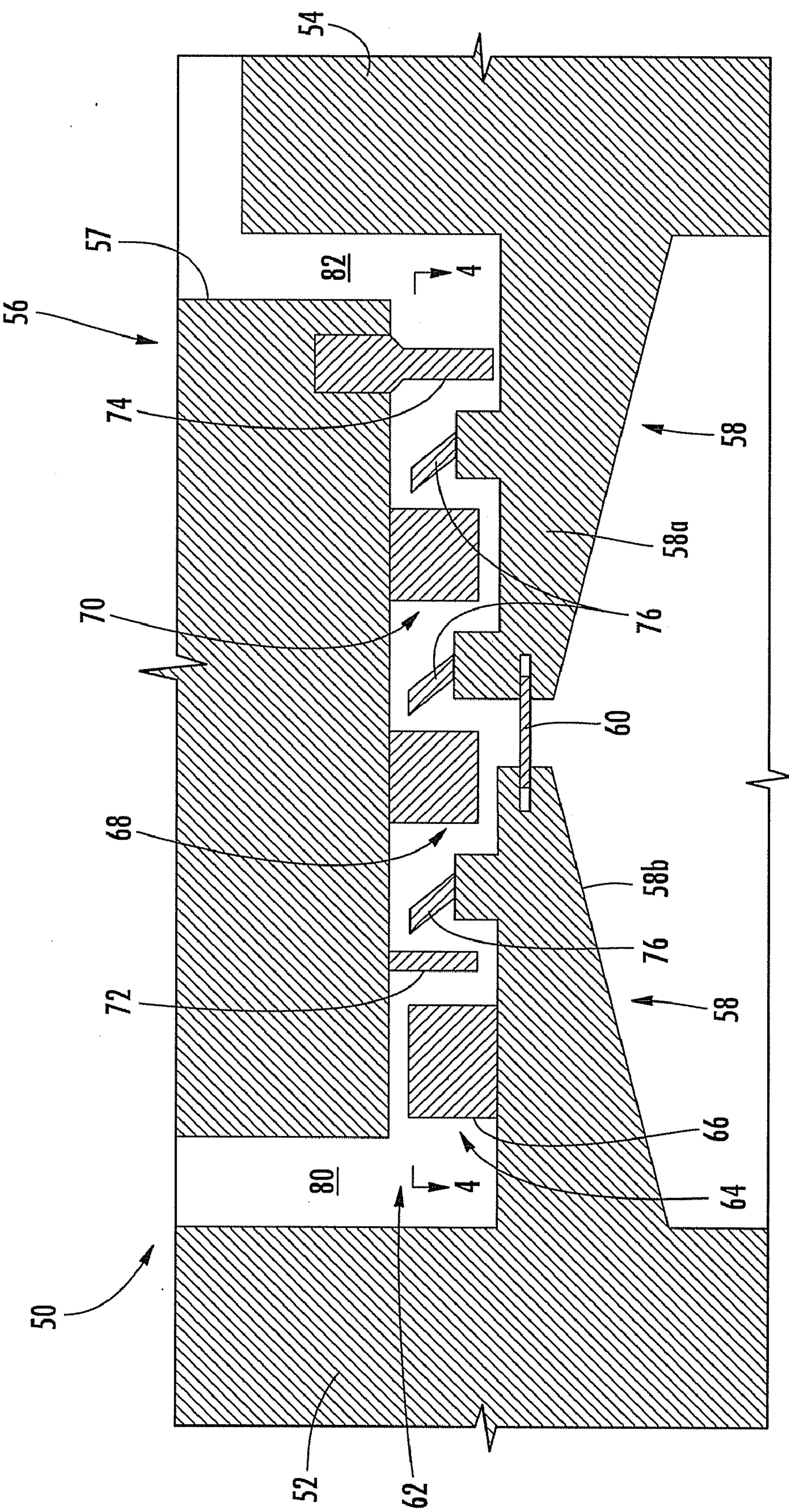


FIG. 3

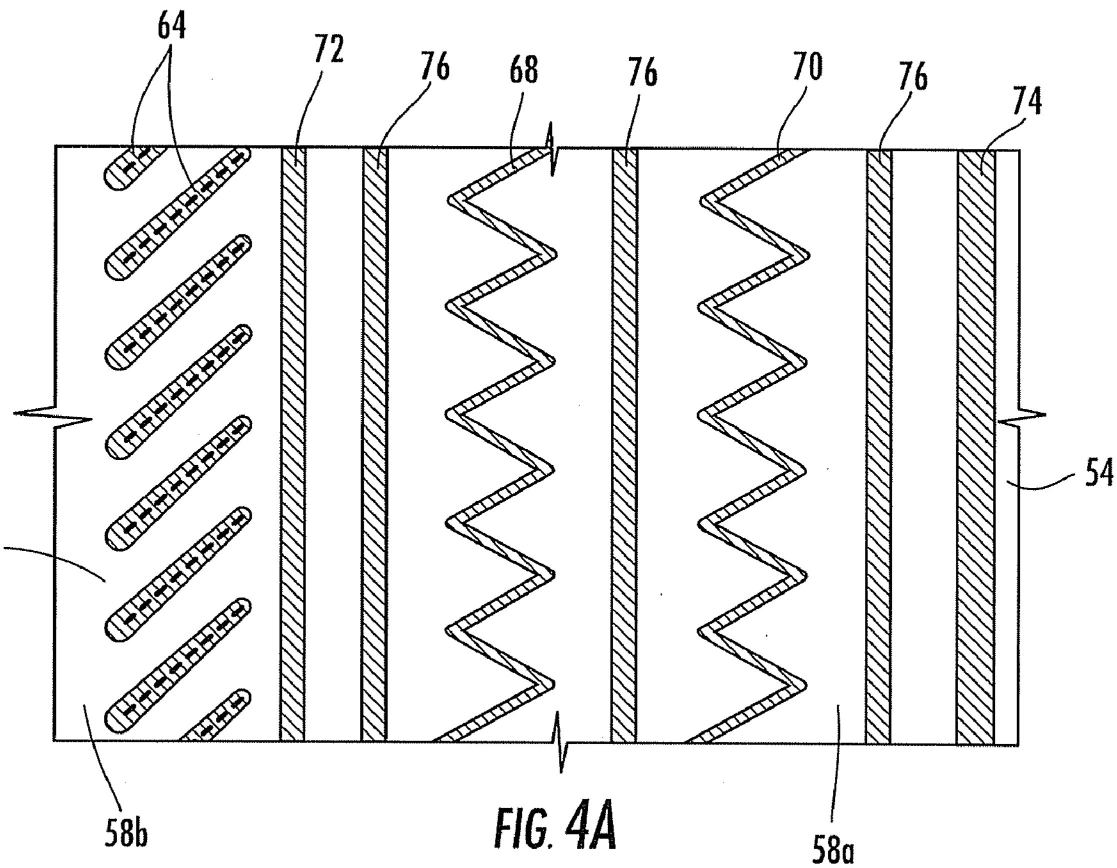


FIG. 4A

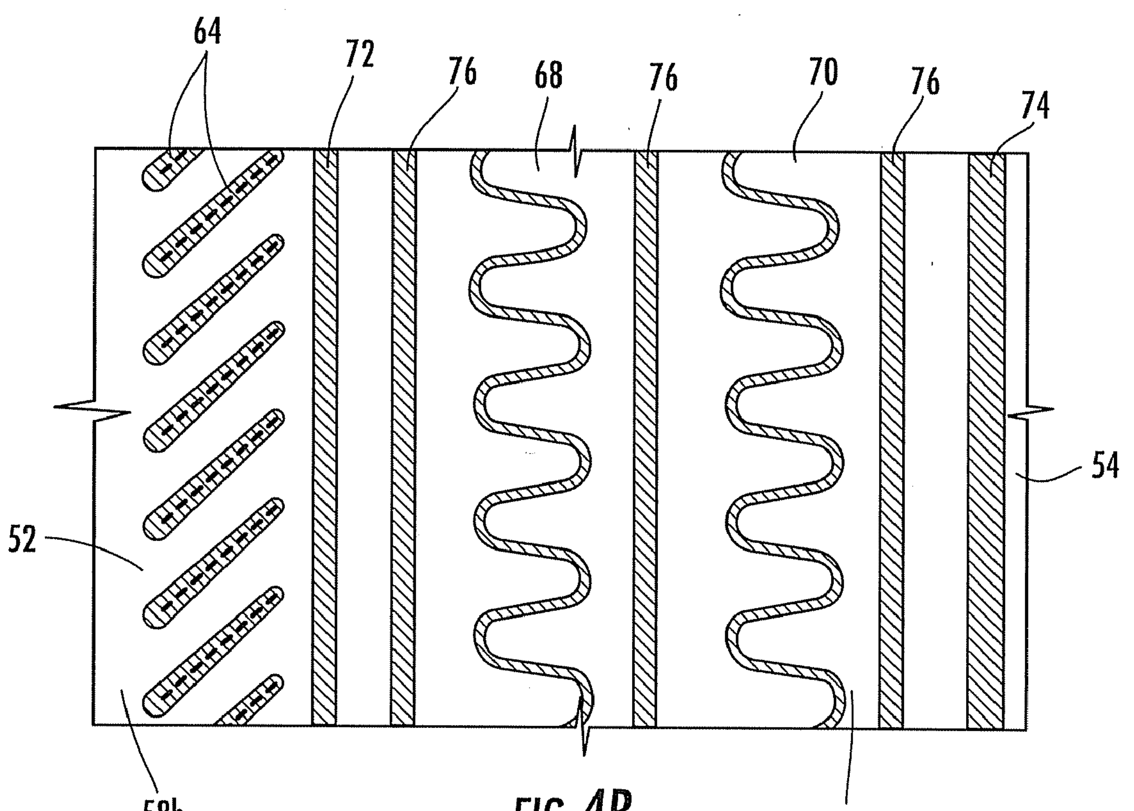


FIG. 4B

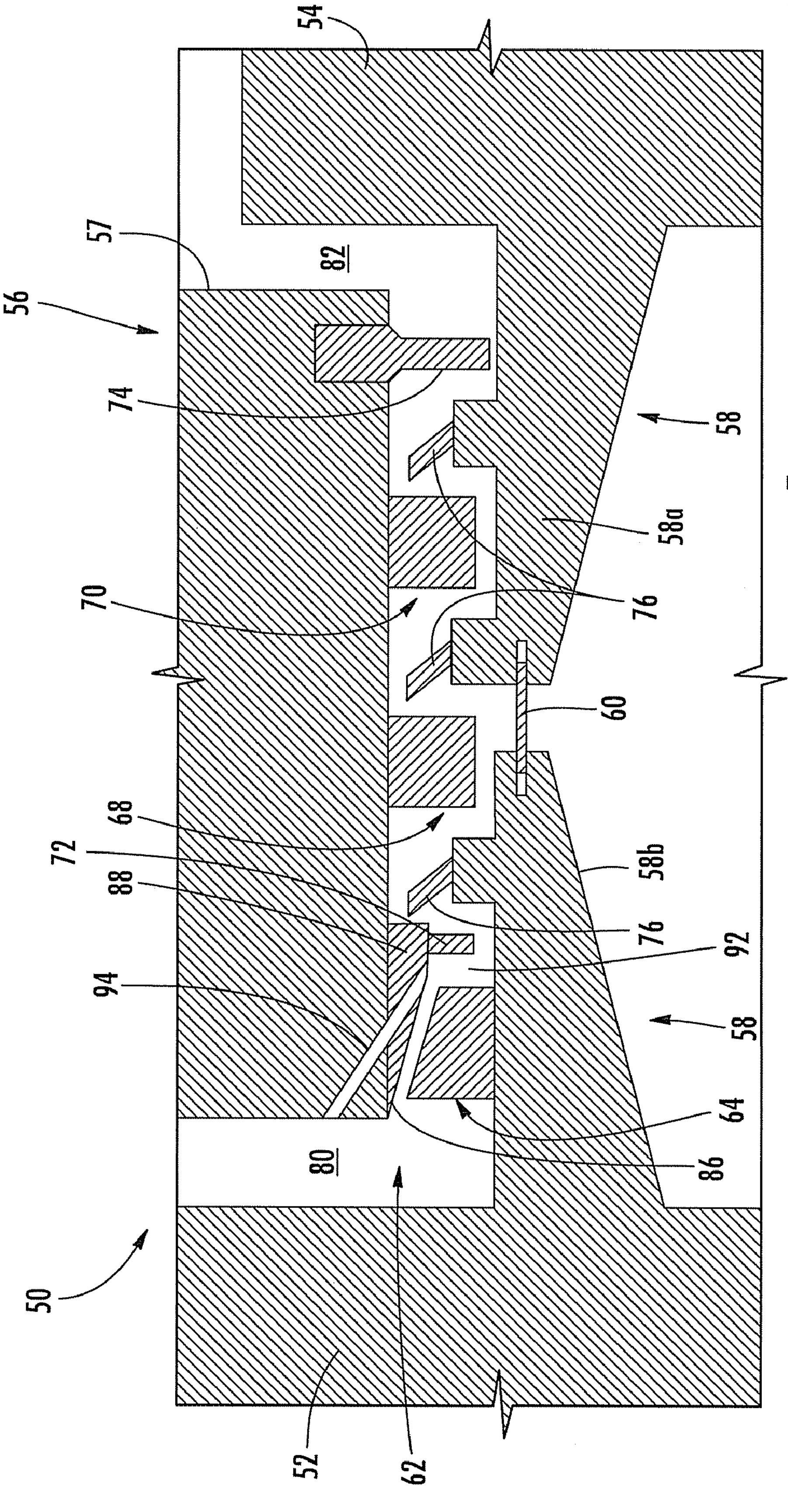

54
57
56
82
74
58
58a
70
76
60
68
72
88
58b
76
92
94
58
64
86
80
50
52
62

FIG. 5

LEAKAGE FLOW MINIMIZATION SYSTEM FOR A TURBINE ENGINE

FIELD OF THE INVENTION

[0001] The invention relates in general to turbine engines and, more particularly, to a system for minimizing leakage flow in a turbine engine.

BACKGROUND OF THE INVENTION

[0002] FIG. **1** shows a cross-section through a portion of a turbine engine **10**. The turbine engine **10** can generally include a compressor section **12**, a combustor section **14** and a turbine section **16**. A centrally disposed rotor **18** can extend through the three sections.

[0003] The turbine section **16** can include alternating rows of stationary vanes **20** and rotating blades **22**. Each row of blades can include a plurality of airfoils **22** attached to a disk **24** provided on the rotor **18**. The rotor **18** can include a plurality of axially-spaced disks **24**. The blades **22** can extend radially outward from the disks **24**.

[0004] Each row of vanes can be formed by attaching a plurality of airfoils **20** to the stationary support structure in the turbine section **16**. For instance, the airfoils **20** can be hosted by a vane carrier **26** that is attached to an outer casing **28**. The vanes **20** can extend radially inward from the vane carrier **26** or other stationary support structure to which they are attached.

[0005] In operation, the compressor section **12** can induct ambient air and can compress it. The compressed air **32** from the compressor section **12** can enter a chamber **34** enclosing the combustor section **12**. The compressed air **32** can then be distributed to each of the combustors **36** (only one of which is shown). In each combustor **36**, the compressed air **32** can be mixed with the fuel. The air-fuel mixture can be burned to form a hot working gas **38**. The hot gas **38** can be routed to the turbine section **16**. As it travels through the rows of vanes **20** and blades **22**, the gas **38** can expand and generate power that can drive the rotor **18**. The expanded gas **40** can then be exhausted from the turbine **16**.

[0006] However, there are several places in the turbine section **16** in which fluid leakage can occur. Such leakage can result in measurable decreases in engine power and efficiency. One area in which such leakage can occur is at interface **41** between the vanes **20** and the neighboring rotating structure, as is shown in FIG. **2**. This interface **41** includes a forward cavity **43** and an aft cavity **45**. During engine operation, cooling and leakage air are dumped into the forward cavity **43**. In addition, hot gas **38** can be ingested in this cavity **43** due to asymmetric circumferential pressure distribution in the gas path. Leakage of these fluid occurs axially across the interface **41** from the forward cavity **43** to the aft cavity **45**, which is at a lower pressure than the forward cavity **43**.

[0007] Known systems for impeding such leakage flow across the interface **41** include labyrinth seals, with or without honeycombs, and/or brush seals. An example of a brush seal system is generally shown in FIG. **2**. One or more brush seals **42** can be attached to the vane **20** directly or indirectly by a seal housing **44** attached to a tip region **30** of the vane **20**. The seals **42** can extend radially inward from the seal housing **44**. The seals **42** can be in close proximity to the neighboring rotating components, such as axially extending portions **46** of the disks **24**. A clearance C can be defined between the seals **42** and the axially extending portions **46** of the disks **24**.

[0008] However, the rotating and stationary components of the turbine section **16** radially expand and contract at different rates when the engine is operating under transient conditions. As a result, the clearance C can reduce to zero or less in some circumstances. As a result, the seals **42** can rub against the disk extensions **46**. Though the seals **42** can withstand such rubbing contact, extensive wearing of the seals **42** can occur such that the seals **42** become shorter. Consequently, the clearance C may become overly large when the engine reaches steady state operation such that leakage flow through the interface **41** increases. High leakage flows have a detrimental impact on engine performance and efficiency because the fluid cannot be used to extract work from the turbine. Thus, there is a need for a system that can minimize such concerns.

SUMMARY OF THE INVENTION

[0009] In one respect, aspects of the invention are directed to a leakage flow control system for a turbine engine. The system includes a turbine stator, such as a seal housing or stationary turbine component. The system can also include a turbine component rotatable about an axis of rotation.

[0010] A plurality of flow guides are provided on the rotatable turbine component. The flow guides can be airfoils. The flow guides are circumferentially arrayed about the rotatable turbine component. The flow guides are angled relative to the axis of rotation. The flow guides extend from the rotatable turbine component in a radially outward direction. Thus, the flow guides can increase tangential velocity on a leakage flow across an interface defined between the stator and the rotatable turbine component. A portion of the stator can surrounds the flow guides. In one embodiment, this portion of the stator can include a conical passage.

[0011] The system also includes an undulating seal operatively connected to stator and extends radially inward from the stator. The undulating seal extends circumferentially about the stator so as to circumferentially surround at least a portion of the rotatable turbine component. The undulating seal is located axially downstream of the plurality of flow guides. The undulating seal can create imbalances and recirculation in the leakage flow. The undulating seal can have a generally triangular waveform conformation or a generally sinusoidal conformation. The undulating seal can have a substantially periodic waveform conformation.

[0012] The system also includes a second undulating seal operatively connected to the stator and extends radially inward from the stator, wherein the second undulating seal extends circumferentially about the stator, wherein the second undulating seal is located axially downstream of the first undulating seal, whereby the undulating seal creates imbalances and recirculation in the leakage flow. The undulating seal and the second undulating seal can be substantially identical.

[0013] The system can further include a forward cavity defined between the stator and the rotatable turbine engine component upstream of the flow guides as well as a cavity immediately downstream of the flow guides defined between the stator and the rotatable turbine engine component. A passage can extend through the stator so as to connect in fluid communication the forward cavity and the cavity downstream of the flow guides. In one embodiment, a labyrinth seal and/or a brush seal can be operatively connected to the stator.

[0014] In another respect, aspects of the invention are directed to a leakage flow control system for a turbine engine.

The system includes a first rotor disk having a generally axially downstream extending protrusion. The first rotor disk is rotatable about an axis of rotation.

[0015] The system further includes a seal housing that is spaced radially outward from the axially downstream extending protrusion of the rotor disk.

[0016] A plurality of flow guides are provided on the axially downstream extending protrusion and are circumferentially arrayed about the protrusion. The flow guides are angled relative to the axis of rotation. The flow guides extend from the axially downstream extending protrusion in a radially outward direction. Thus, the flow guides increase tangential velocity on a leakage flow across an interface defined between the rotor disk and the seal housing. In one embodiment, the flow guides are airfoils.

[0017] The system can further include a first undulating seal operatively connected to seal housing and extending radially inward from the seal housing. The first undulating seal can extend circumferentially about the seal housing so as to circumferentially surround at least a portion of the axially downstream extending protrusion. The first undulating seal can be located axially downstream of the plurality of flow guides. Thus, the first undulating seal can create imbalances and recirculation in the leakage flow across the interface. The first undulating seal can have a substantially periodic waveform conformation.

[0018] The system can further include a second undulating seal operatively connected to seal housing. The second undulating seal can extend radially inward from the seal housing. The second undulating seal can extend circumferentially about the seal housing. The second undulating seal can be located axially downstream of the first undulating seal. Thus, the second undulating seal can create imbalances and recirculation in the leakage flow across the interface. The second undulating seal can have a substantially periodic waveform conformation.

[0019] The system can further include a second rotor disk having a generally axially upstream extending protrusion. The second rotor disk can be rotatable about an axis of rotation. The second undulating seal circumferentially surrounds at least a portion of the axially upstream extending protrusion. A first seal can be operatively connected to the axially upstream extending protrusion of the second rotor disk in a region that is upstream of the second undulating seal. A second seal can be operatively connected to the axially upstream extending protrusion of the second rotor disk in a region that is downstream of the second undulating seal.

[0020] A portion of the seal housing can surround the flow guides. This portion of the seal housing can at least partially define a conical passage. Thus, the cross-sectional area of the interface can decrease in the axial direction.

[0021] The system can further include a forward cavity defined between the seal housing and the first rotor disk upstream of the flow guides and a cavity immediately downstream of the flow guides defined between the seal housing and the first rotor disk. A passage can extend through the seal housing so as to connect in fluid communication the forward cavity and the cavity downstream of the flow guides.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] FIG. **1** is a cross-sectional view through a portion of a known turbine engine.

[0023] FIG. **2** is a close-up cross-sectional view of a portion of a known turbine engine, showing an interface between a ID shroud region of a turbine vane and the neighboring rotor disks.

[0024] FIG. **3** is a cross-sectional view of an interface between a stator and the neighboring rotating turbine components, showing a first sealing arrangement according to aspects of the invention.

[0025] FIG. **4**A is a top plan cross-sectional view of the first sealing arrangement according to aspects of the invention, taken along line **4-4** in FIG. **3**.

[0026] FIG. **4**B is a top plan cross-sectional view of the first sealing arrangement according to aspects of the invention, taken along line **4-4** in FIG. **3**, and showing an alternative configuration of an undulating seal structure.

[0027] FIG. **5** is a cross-sectional view of an interface between a stator and the neighboring rotating turbine components, showing a second sealing arrangement according to aspects of the invention.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[0028] Aspects of the present invention relate to a system for reducing leakage flow in a turbine engine. Embodiments of the invention will be explained in connection with one potential leakage flow path between neighboring rotating and stationary turbine structures, but the detailed description is intended only as exemplary. Embodiments of the invention are shown in FIGS. **3-5**, but aspects of the invention are not limited to the illustrated structure or application.

[0029] A sealing system according to aspects of the invention can be used in connection with an interface between neighboring rotating and stationary turbine components. FIG. **3** shows an example of one such interface **50** defined between at least an upstream rotor disk **52** and a stator **56**. The term "stator" is intended to include any portion of a stationary vane, such as a ID shroud portion of the vane and/or a seal housing **57** or other structure attached to the vane. The interface **50** can further include a downstream rotor disk **54**. The upstream and downstream rotor disks **52**, **54** can be associated with sequential rows of blades in the turbine. For instance, the upstream rotor disk **52** can be the first stage row of turbine blades (not shown), and the downstream rotor disk **54** can be associated with the second stage row of turbine blades (not shown).

[0030] Each rotor disk **52**, **54** can have at least one protrusion **58** that extends generally in the axial direction. For instance, each rotor disk **52**, **54** can have an upstream axial protrusion **58***a* and/or a downstream axial protrusion **58***b*. The upstream axial protrusion **58***a* can extend in a generally axially upstream direction from an upstream side of a rotor disk. The downstream axial protrusion **58***b* can extend in a generally axially upstream direction from a downstream stream side of a rotor disk. It should be noted that the terms "upstream" and "downstream" are intended to mean relative to the direction of gas flow through the turbine. As shown in FIG. **3**, the upstream axial protrusion **58***a* of the downstream rotor disk **54** and the downstream axial protrusion **58***b* of the upstream rotor disk **52** can extend toward each other. A sealing element **60** can be used to minimize leakage in the space therebetween. The stator **56** can circumferentially surround at least a portion of each of the axial protrusions **58***a*, **58***b*.

[0031] According to aspects of the invention, the interface **50** can include a sealing system **62** configured to minimize fluid leakage across the interface **50**. Some of the structures of the sealing system **62** will now be described. The sealing system **62** according to aspects of the invention can include a first row of a plurality of flow guides **64** provided on the upstream rotor disk **52** forming the interface **50**. For instance, a first row of a plurality of flow guides **64** can be provided on the downstream axial extension **58***b* of the upstream rotor disk **52**. The flow guides **64** can be distributed circumferentially about the downstream axial extension **58***b* of the upstream rotor disk **52**.

[0032] The flow guides **64** can have any suitable configuration. The flow guides **64** can be relatively short and angular. In one embodiment, the flow guides **64** can be configured as airfoils **66**. In one embodiment, the airfoils **66** can be low aspect ratio airfoils. In another embodiment, the flow guides **64** can be formed by flat plate like structures. The flow guides **64** can be oriented at any suitable angle relative to the axial direction.

[0033] There can be any quantity of flow guides **64** and the flow guides **64** can be provided at any suitable spacing. The flow guides **64** can be made of any suitable material. For instance, the flow guides **64** can be made of Nickel based alloys or stainless steel. The flow guides **64** can be attached to the upstream rotor disk **52** in any suitable manner, including, for example, by brazing. Alternatively or in addition, the flow guides **64** can retained by mechanical engagement with the rotor disk **52**. For example, the flow guides can include a portion that is received and retained in a slot (not shown) in the disk **52**, such as by interlocking engagement or other mechanical engagement.

[0034] In one embodiment, there can be more than one row of flow guides (not shown). In such case, the flow guides **64** in a first row can be identical to the flow guides **64** in one or more other rows, or at least one of the rows can have flow guides **64** that are different from the flow guides **64** in the other rows in one or more respects, including, for example, size, shape, angle, spacing, arrangement, material selection and/or quantity.

[0035] A sealing system **62** according to aspects of the invention can also include a first undulating seal structure **68** downstream of the flow guides **64**. The first undulating seal structure **68** can be attached to the stator **56** in any suitable manner. For instance, the first undulating seal structure **68** can be brazed on the stator **56**. Alternatively, the first undulating seal structure **68** can be retained by mechanical engagement with a portion of the stator **56**, such as by being received in interlocking engagement with a groove in the stator **56**. The first undulating seal structure **68** can extend circumferentially about the stator and radially inward therefrom toward the axis of rotation of the rotor. The undulating seal structure **68** can be a substantially 360 degree ring, or it can comprise a plurality of segments that collectively form a ring.

[0036] The first undulating seal structure **68** can be have any suitable regular or irregular undulating pattern. In one embodiment, the first undulating seal structure **68** have a periodic waveform conformation. For instance, as shown in FIG. **4**A, the first undulating seal structure **68** can have a triangular waveform configuration. In another embodiment, the first undulating seal structure **68** can have a sinusoidal waveform conformation, as is shown in FIG. **4**B. The first undulating seal structure **68** can also have other waveform conformations, such as square, sawtooth and pulse, just to name a few possibilities. Of course, the first undulating seal structure **68** can have a conformation that is a combination of any of these forms. It will be appreciated that the specific conformation of the undulating seal structure **68** can be optimized to achieve the desired performance.

[0037] The first undulating seal structure **68** can be made of any suitable material. The first undulating seal structure **68** can be made of a wear resistant material because the first undulating seal structure **68** may rub against the rotor disk during engine operation. In one embodiment, the first undulating seal structure **68** can be made of HASTELLOY-X or HAYNES 230, which are available from Haynes International, Kokomo, Ind. In another embodiment, the first undulating seal structure **68** can be made of stainless steel. The above materials are just a few examples of suitable materials for the first undulating seal structure **68**. The particular material selected will depend on a number of factors, including the expected temperature exposure. The first undulating seal structure **68** can be made of a material that can withstand at least about 450 to about 500 degrees Celsius. The first undulating seal structure **68** can be a rigid structure.

[0038] It should be noted that the sealing system **62** according to aspects of the invention can include a second undulating seal structure **70** provided downstream of the first undulating seal structure **68**. The above discussion concerning the first undulating seal structure **68** applies equally to the second undulating seal structure **70**. The first undulating seal structure **68** and the second undulating seal structure **70** can be identical or they can be different in one or more respects. Generally, the first undulating seal structure **68** can be positioned on the stator **56** such that it circumferentially surrounds a portion of the upstream rotor disk **52**, and the second undulating seal structure **70** can be positioned on the stator **56** such that it circumferentially surrounds a portion of the downstream rotor disk **54**, as shown in FIGS. **3** and **5**.

[0039] In addition to the flow guides **64** and the undulating seal structures **68**, **70**, the system **62** according to aspects of the invention can include any of a number of known seals, such as labyrinth seals or brush seals, at various points on the stator **56** and rotor disks **52**, **54**. These various features can be arranged so that vane guides or seals attached to the rotor generally alternate with seals on the stator **56**. In this way, a tortuous flow path can be created across the interface **50**.

[0040] FIG. **3** shows an example of a sealing system that can include seals in addition to the flow guides **64** and the undulating seal structures **68**, **70**. In the particular embodiment shown, a radial labyrinth seal **72** can be provided on the stator **56** upstream of the first undulating seal structure **68** but downstream of the flow guides **64**. The radial labyrinth seal **72** can be any suitable seal and can be operatively attached to the stator **56** in any suitable manner. The stator **56** can also include a brush seal **74**. The brush seal **74** can be any suitable brush seal and can be operatively attached to the stator **56** in any suitable manner.

[0041] The system **62** can also include additional seals provided on the rotor disks **52**, **54**. As shown in FIG. **3**, one or more canted labyrinth seals **76** can be operatively connected to the rotor disks **52**, **54**. In one embodiment, there can be a canted labyrinth seal **76** on the downstream axial protrusion **58***b* of the first rotor disk **52**. This canted labyrinth seal **76** can be located downstream of the flow guides **64** on the rotor disk **52** as well as the radial labyrinth seal **72** on the stator **56**. A pair of canted labyrinth seals **76** can be provided on the upstream axial protrusion **58***a* on the downstream rotor disk **54**. One of the canted labyrinth seals **76** can be upstream of the second undulating seal structure **70**, and the other of the canted labyrinth seals **76** can be downstream of the second undulating seal structure **70**, yet upstream of the brush seal **74**.

[0042] Now that many possible components of the sealing system **62** according to aspects of the invention have been described, an example of the operation of such a system will now be described. During engine operation, one or more fluids can enter a forward cavity **80** of the interface **50**. The fluid can be cooling and leakage air from various sources and/or hot gases ingested from the turbine gas path. The interface **50** also includes an aft cavity **82**. The pressure in the forward cavity **80** is greater than the pressure of the aft cavity **82**. This difference in pressure naturally results in the fluid seeking to flow from the forward cavity **80** toward the aft cavity **82**.

[0043] Due to the rotational motion of the rotor, a tangential motion is induced in the fluid in the forward cavity **80** in the direction of the rotor motion. As the fluid flows downstream, the tangential velocity of the flow can be increased by the flow guides **64** on the upstream rotor disk **52**. It will be appreciated that increasing the tangential velocity of the flow can reduce the axial component of the flow velocity. As a result, the effective leakage area normal to the flow can be reduced, which, in turn, can help to reduce leakage flow by impeding the axial downstream progression of the flow. In addition, higher leakage flow velocities can result in larger fluid head losses, which further helps in impeding leakage flow.

[0044] One manner of further increasing the tangential velocity and/or component of the flow is to provide multiple rows of flow guides **64**, as noted above. Alternatively or in addition, at least a portion of the stator **56** can be configured to define a decreasing cross-sectional flow area. For example, a conical flow passage **86** can be formed between the stator **56** and the upstream rotor disk **52**, as is shown in FIG. **5**. Naturally, the tips of the flow guides **64** can be configured to generally match the taper of the conical passage **86**. The conical flow passage **86** can be achieved in any of a number of ways. For instance, a separate piece **88** with a conical inner passage can be attached to the stator **56** to define the conical flow passage **86**, as is shown in FIG. **5**. As will be appreciated, the cross-sectional area of the conical flow path decreases as the flow moves downstream, thereby increasing the velocity of the flow exiting the flow guides **64**. As the velocity increases, the pressure loss increases, which, can diminish forward axial potential of the flow.

[0045] The system **62** according to aspects of the invention can further include features to minimize the inadvertent pressure increase in the cavity **92** immediately downstream of the row of flow guides **64**. For instance, the cavity **92** can be connected in fluid communication with the forward cavity **80** by way of one or more passages **94** in the stator **56**. Such passages **94** can be included in the stator **56** in any suitable manner, such as by drilling or machining. In one embodiment, there can be a plurality of passages **94** distributed circumferentially about the stator **56**. If there is a pressure increase in the cavity **92**, the higher pressure fluid in the cavity **92** can be released by flowing through the passages **94** to the lower pressure of the forward cavity **80**. In this way, the pressures of the cavities **80**, **92** can remain substantially equalized. Further, there can be an additional benefit in that the flow exiting the passages **94** can create turbulence in the forward cavity **80**, which further disrupts the leakage flow.

[0046] Beyond the row of flow guides **64**, the leakage flow can encounter the tortuous path defined by any downstream seals. The flow can encounter the first undulating seal structure **68**, which can create unsteadiness in the flow and recirculation of the flow in the various pockets of the seal **68**, which causes mixing losses. As the flow progresses axially downstream, it can encounter additional seals, including a second undulating seal **70** and possibly labyrinth seals **76**, brush seals **74** and possibly other seals. Such a tortuous path can physically impede the leakage flow and can cause sufficient pressure losses to diminish the flow across the interface **50**. As a result, improved engine efficiency and performance can be realized due to reduced consumption of pressurized cooling/leakage air.

[0047] While the foregoing description is provided in the context of an interface between a stator and the neighboring rotor disks, aspects of the invention can be applied to any and all potential leakage areas between stationary and rotating components in the turbine section. Thus, it will of course be understood that the invention is not limited to the specific details described herein, which are given by way of example only, and that various modifications and alterations are possible within the scope of the invention as defined in the following claims.

What is claimed is:

1. A leakage flow control system for a turbine engine comprising:

a turbine stator;

a turbine component rotatable about an axis of rotation;

a plurality of flow guides provided on the rotatable turbine component and being circumferentially arrayed thereabout, the flow guides being angled relative to the axis of rotation, the flow guides extending from the rotatable turbine component rotatable in a radially outward direction, whereby the flow guides increase tangential velocity on a leakage flow across an interface defined between the stator and the rotatable turbine component; and

an undulating seal operatively connected to stator and extending radially inward therefrom, the undulating seal further extending circumferentially about the stator so as to circumferentially surround at least a portion of the rotatable turbine component, the undulating seal being located axially downstream of the plurality of flow guides, whereby the undulating seal creates imbalances and recirculation in the leakage flow.

2. The system of claim **1** wherein the flow guides are airfoils.

3. The system of claim **1** wherein the undulating seal has one of a generally triangular waveform conformation and a generally sinusoidal conformation.

4. The system of claim **1** wherein the undulating seal has a substantially periodic waveform conformation.

5. The system of claim **1** further including a second undulating seal operatively connected to the stator and extending radially inward therefrom, wherein the second undulating seal extends circumferentially about the stator, wherein the second undulating seal is located axially downstream of the first undulating seal, whereby the undulating seal creates imbalances and recirculation in the leakage flow.

6. The system of claim **5** wherein the undulating seal and the second undulating seal are substantially identical.

7. The system of claim **1** wherein at least a portion of the stator surrounds the flow guides and includes a conical passage.

8. The system of claim **1** further including a forward cavity defined between the stator and the rotatable turbine engine component upstream of the flow guides and a cavity immediately downstream of the flow guides defined between the stator and the rotatable turbine engine component, wherein a passage extends through the stator so as to connect in fluid communication the forward cavity and the cavity downstream of the flow guides.

9. The system of claim **1** further including at least one of a labyrinth seal and a brush seal operatively connected to the stator.

10. The system of claim **1** wherein the stator is defined at least in part by a seal housing.

11. A leakage flow control system for a turbine engine comprising:

an first rotor disk having a generally axially downstream extending protrusion, the first rotor disk being rotatable about an axis of rotation;

a seal housing being spaced radially outward from the axially downstream extending protrusion of the rotor disk; and

a plurality of flow guides provided on the axially downstream extending protrusion and being circumferentially arrayed thereabout, the flow guides being angled relative to the axis of rotation, the flow guides extending from the axially downstream extending protrusion in a radially outward direction, whereby the flow guides increase tangential velocity on a leakage flow across an interface defined between the rotor disk and the seal housing.

12. The system of claim **11** wherein the flow guides are airfoils.

13. The system of claim **11** further including a first undulating seal operatively connected to seal housing and extending radially inward therefrom, wherein the first undulating seal extends circumferentially about the seal housing so as to circumferentially surround at least a portion of the axially downstream extending protrusion, wherein the first undulating seal is located axially downstream of the plurality of flow guides, whereby the first undulating seal creates imbalances and recirculation in the leakage flow across the interface.

14. The system of claim **13** wherein the first undulating seal has a substantially periodic waveform conformation.

15. The system of claim **14** further including a second undulating seal operatively connected to seal housing and extending radially inward therefrom, wherein the second undulating seal extends circumferentially about the seal housing, wherein the second undulating seal is located axially downstream of the first undulating seal, whereby the second undulating seal creates imbalances and recirculation in the leakage flow across the interface.

16. The system of claim **15** wherein the second undulating seal has a substantially periodic waveform conformation.

17. The system of claim **15** further including a second rotor disk having a generally axially upstream extending protrusion, wherein the second rotor disk is rotatable about an axis of rotation, wherein the second undulating seal circumferentially surrounds at least a portion of the axially upstream extending protrusion.

18. The system of claim **17** further including:

a first seal operatively connected to the axially upstream extending protrusion of the second rotor disk in a region that is upstream of the second undulating seal; and

a second seal operatively connected to the axially upstream extending protrusion of the second rotor disk in a region that is downstream of the second undulating seal.

19. The system of claim **11** wherein a portion of the seal housing surrounds the flow guides and at least partially defines a conical passage, whereby the cross-sectional area of the interface decreases in the axial direction.

20. The system of claim **11** further including a forward cavity defined between the seal housing and the first rotor disk upstream of the flow guides and a cavity immediately downstream of the flow guides defined between the seal housing and the first rotor disk, wherein a passage extends through the seal housing so as to connect in fluid communication the forward cavity and the cavity downstream of the flow guides.

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