US 20130011248A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2013/0011248 A1

(43) Pub. Date: Jan. 10, 2013

Croteau et al.

(54) **REDUCTION IN THERMAL STRESSES IN MONOLITHIC CERAMIC OR CERAMIC MATRIX COMPOSITE SHROUD**

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(21) Appl. No.: **13/176,112**

(22) Filed: **Jul. 5, 2011**

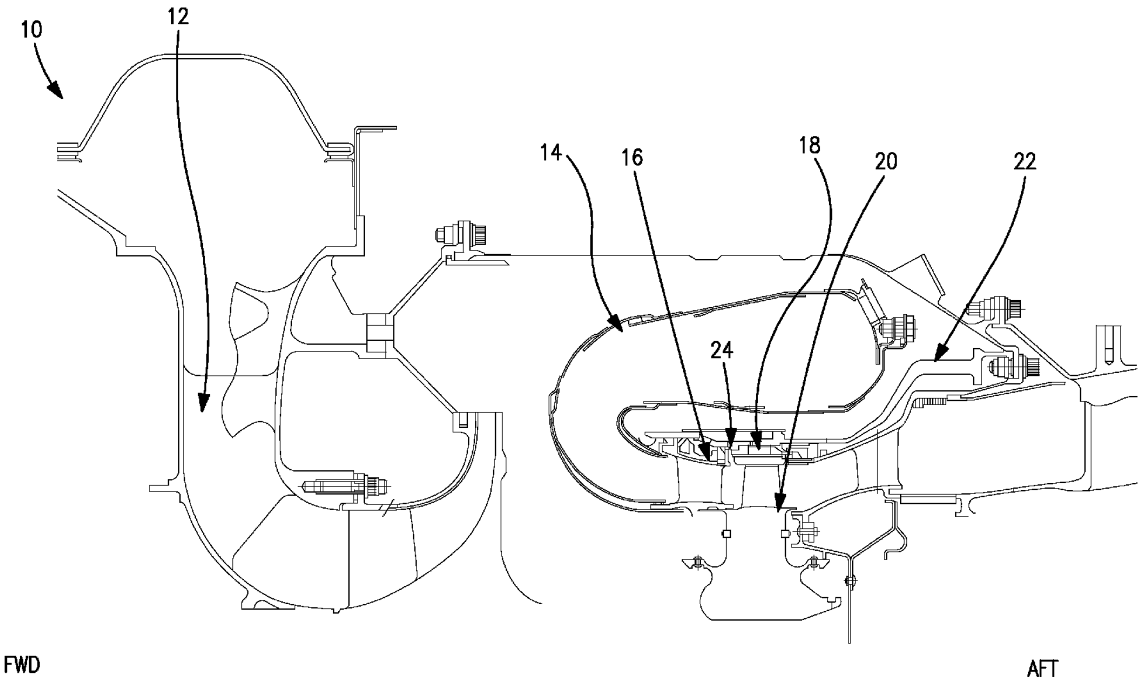
Publication Classification

(51) **Int. Cl.**
F01D 25/24 (2006.01)

(52) **U.S. Cl.** **415/200**

(57) **ABSTRACT**

A shroud for use in a gas turbine engine has a ring with a plurality of protrusions and a plurality of slots and each of the protrusions having an arc length and parallel sides.



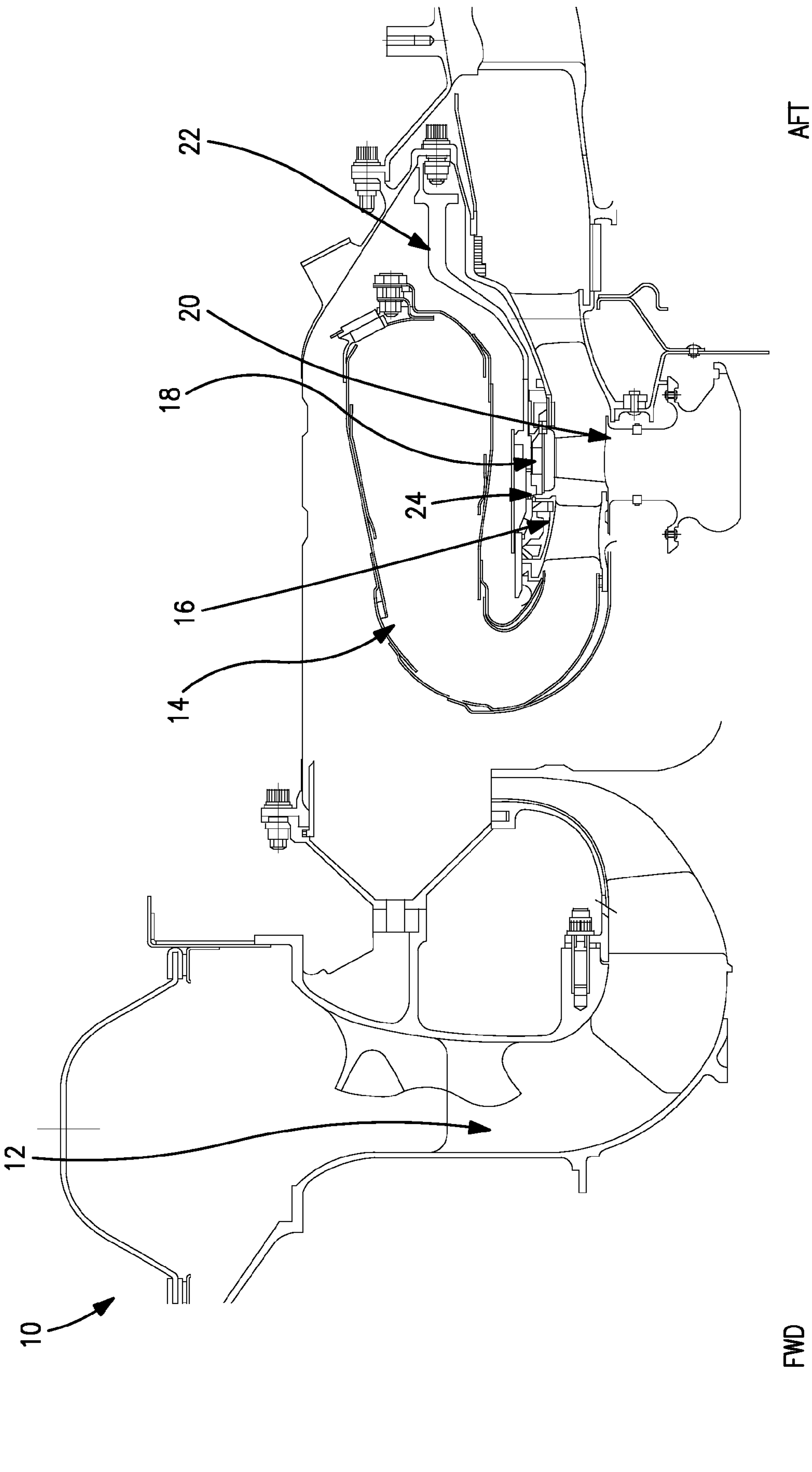


FIG. 1

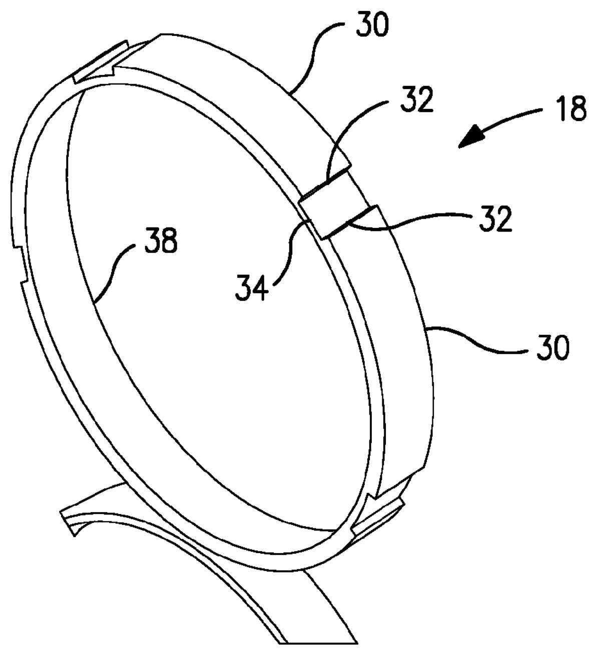


FIG. 2

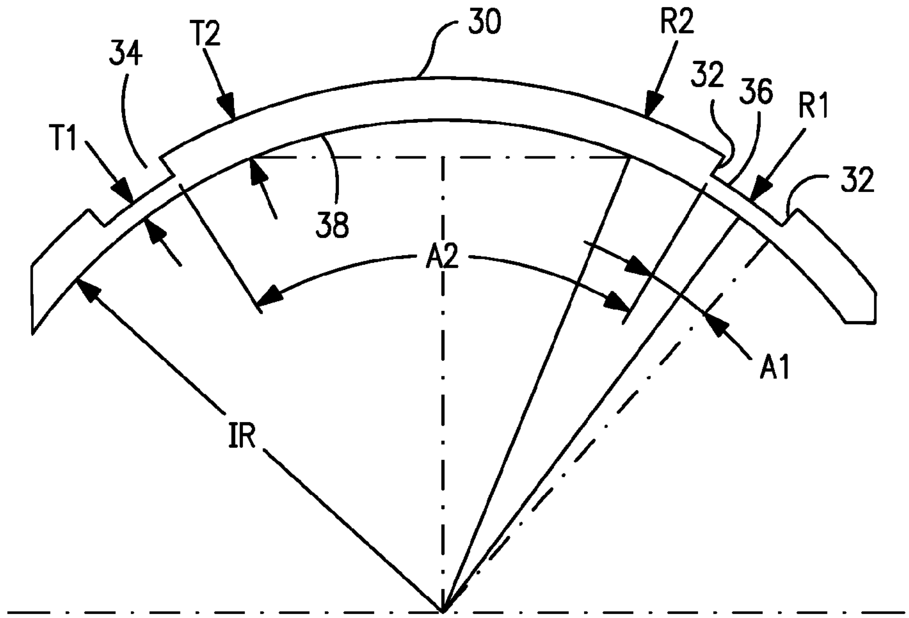


FIG. 3

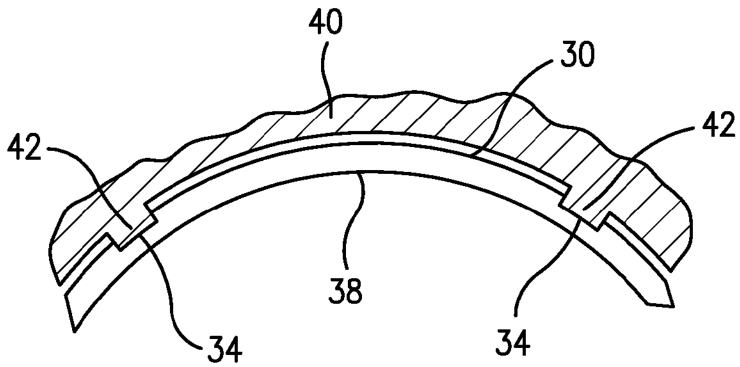

40
30
42
42
38
34
34

FIG. 4

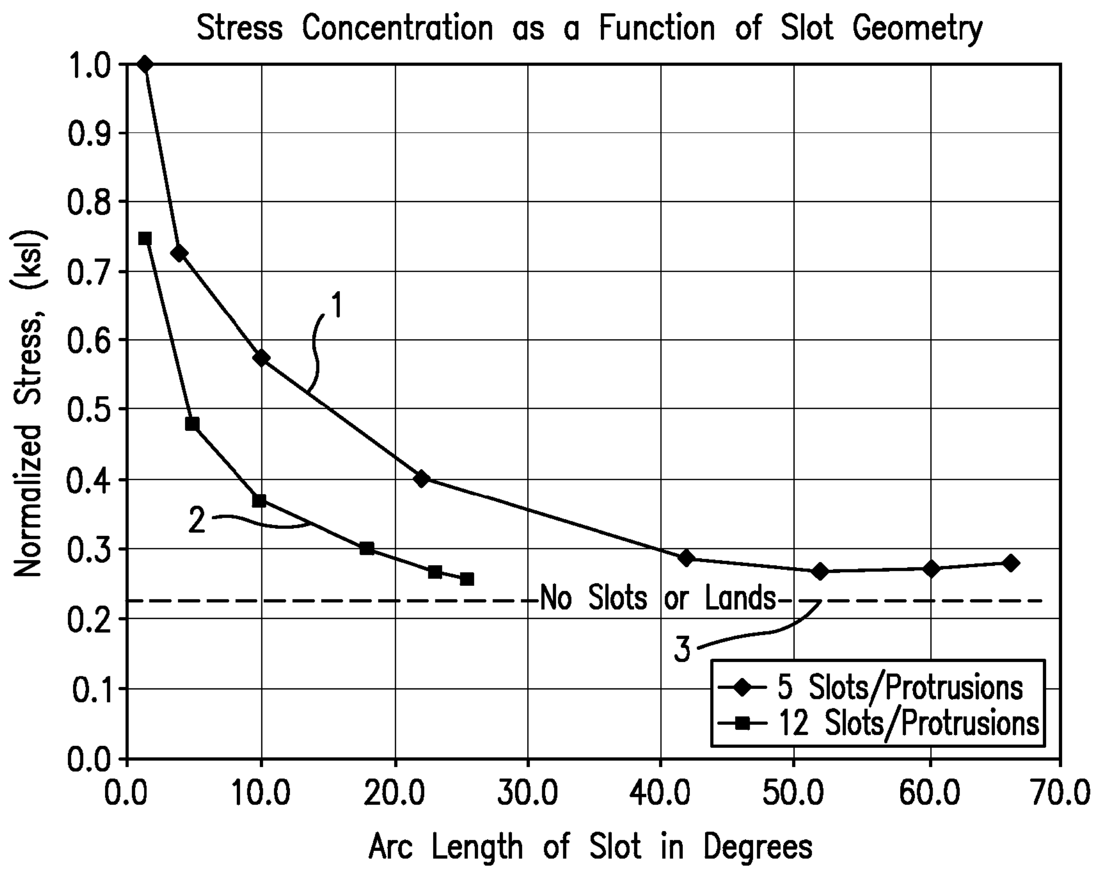

Stress Concentration as a Function of Slot Geometry
Normalized Stress, (ksi)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
Arc Length of Slot in Degrees
1
2
3
No Slots or Lands
5 Slots/Protrusions
12 Slots/Protrusions

FIG. 5

REDUCTION IN THERMAL STRESSES IN MONOLITHIC CERAMIC OR CERAMIC MATRIX COMPOSITE SHROUD

BACKGROUND

[0001] The present disclosure is directed to a geometry to minimize feature related thermal stresses in a monolithic ceramic or Ceramic Matrix Composite (CMC) shroud used in a gas turbine engine.

[0002] The incorporation of a ceramic or CMC shroud in the hot section of a gas turbine engine as a replacement of a similar metallic component is beneficial. A metal shroud requires substantial cooling in order to withstand the high temperature in the turbine section. Often a metal shroud is composed of multiple arc sections held by a complex assembly of support hardware to provide close positional tolerance and circularity to provide gap control with the rotor blade tips. A one piece ceramic shroud, by virtue of its inherent thermal material properties and high temperature capability, provides the ability to reduce the running blade tip clearance and reduced cooling air, providing improvements in efficiency and increased power.

[0003] From a thermal stress point of view, a simple ring structure provides the most stable structure with the least distortion and lowest thermal stress. Various techniques exist for shroud support which require designing and fabricating the shroud ring structure with features onto which to support and locate the shroud within the metal assembly. Features may range from tabs or protrusions on the outer diameter surface or on one or both end faces, to slots or grooves on the outer diameter surface of the shroud. Although consideration needs to be made for attachment and assembly of the ceramic shroud, structural considerations also need to be made to insure ceramic integrity and life.

SUMMARY

[0004] In accordance with the present disclosure, there is provided a shroud comprising a ring with a plurality of protrusions and a plurality of slots and each of said protrusions having an arc length and parallel sides.

[0005] Further in accordance with the present invention, there is provided an engine broadly comprising a rotor and ceramic shroud surrounding said rotor and said shroud comprising a ring with a plurality of protrusions and a plurality of slots and each of said protrusions having an arc length and parallel sides.

[0006] Other details of the monolithic ceramic or CMC shroud having reduced thermal stresses are set forth in the following detailed description and the accompanying drawings in which like reference numerals depict like elements.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** is a sectional view of a gas turbine engine;

[0008] FIG. **2** is a perspective view of a shroud in accordance with the present disclosure;

[0009] FIG. **3** is a side view of a portion of the shroud of FIG. **1**;

[0010] FIG. **4** is a sectional view of a metal ring mating with the shroud of FIG. **2**; and

[0011] FIG. **5** is a graph showing stress relative to slot arc length for a thermally stressed shroud ring.

DETAILED DESCRIPTION

[0012] There is shown in FIG. **1**, a cross section of an engine **10**. The engine includes a compressor **12** through which a fluid flows and is compressed, a combustor **14** in which the compressed fluid is mixed with a fuel and combusted, and a turbine section **24** in which the heated fluid is expanded to drive the turbine for creating power to drive the compressor **12** and other systems. As can be seen in FIGS. **1** and **2**, the turbine section **24** includes a turbine vane **16**, a turbine shroud **18**, a turbine rotor **20**, and a turbine support case **22**.

[0013] From a thermal stress point of view, the ideal structure would be a simple ring structure. This is because such a structure provides the most stable structure with the least distortion and lowest thermal stress. For purposes of holding and positioning the shroud in the engine assembly, the ring structure of shroud **18** as shown in FIG. **2** may have a plurality of outer diameter protrusions **30** creating slots **34** with parallel sides **32**. The use of parallel sides **32** across slot **34** is useful and relevant when the arc length of slot A**1** is much less than arc length of A**2**. For embodiments of the shroud where A**2**<<A**1**, it is useful and relevant for sides **32** to be parallel across protrusion **30**.

[0014] A simple ring provides the hoop strength and the stable structure needed to withstand the thermal gradient that the shroud **18** will be exposed to. A ring structure with uniform thickness and no other features, such as tabs or slots, exposed to a uniform through thickness temperature gradient, can exhibit stresses considered acceptable for ceramics used for this purpose. The loading experienced in the ring structure from a through thickness temperature gradient is a bending load, with the hotter inner diameter surface in compression and the cooler outer diameter surface in tension. If the ring were unwrapped into a simply supported flat bar, the temperature gradient would cause a differential of thermal expansion from one side to the other and cause the bar to bend. To eliminate the deformation from the flat bar, a pure moment, equal and opposite, would need to be applied at each end of the bar. But if the bar is shaped into a hoop and the ends joined to form a ring with uniform cross section, the bending loading at each end of this joint is equal and opposite, and therefore prevents any deformation due to bending. The only deformation of the ring is thermal expansion typical of any heated volume of material.

[0015] A featureless ring, though, is not practical and some means are needed to provide support and location of the ring structure to the assembly. Various features pertaining to assembly have been proposed and may be valid for reasons specific to the design requirements. But once a feature is introduced into the structure of the ring and eliminates the constant cross section of the ring, the bending load in the ring becomes evident through higher strains and ring distortion. Depending on the feature, the distortion and localized high strain can cause increased stress and stress concentrations. These stress concentrations are most often associated with fillets at the attachment feature and are inherently tensile surface stresses or 1st principal stresses.

[0016] As can be seen from FIGS. **2** and **3**, the shroud **18** is provided with a plurality of slots **34** bordered by the sides **32** of adjacent protrusions **30**. Each slot **34** has an inner surface **36** which may be either a flat surface of a curved surface with a radius R**1**. Further, each slot **34** has a slot arc length A**1**. As noted before, each protrusion **30** has an arc length A**2**. The slots **34** may be equally spaced around the periphery of the shroud **18**. There may be from 3 to 18 slots **34**. Each slot **34** may have an arc length in the range of 20 to 60 degrees.

[0017] As noted before, the sides **32** of the slots **34** are parallel. With a multitude of identical slots positioned around the circumference of the ring **38** forming the shroud **18**, concentric and circumferential position of the ring **38** can be maintained with a mating ring **40** with mating features **42** that contact the parallel sides **32** of each slot as shown in FIG. **5**. The parallel sides **32** of each slot **34** allows thermal expansion of the ring **38** relative to its support ring **40** with introducing additional stress due to thermal mismatch between mating parts.

[0018] With slot arc lengths much less than protrusion arc lengths, or A**1**<<A**2**, than a majority of the ring **38** is dominated by the maximum ring thickness T**2**. This provides a stiffer cross section to withstand the bending load from the through thickness thermal gradient. This may cause a significant stress riser in the fillet region **33** of the slots **34** where the stress increases with decreasing slot arc length.

[0019] Conversely, as the arc length A**2** of the protrusion **30** decreases and the arc length A**1** of the slot **34** increases, then a majority of the ring **38** is dominated by the minimum ring thickness T**1** and the stress concentrations decreases. The mounting feature becomes the parallel sides **32** of a protrusion feature **30** for when A**1**>>A**2**.

[0020] FIG. **5** shows the relationship of stress concentrations for a shroud ring **38** with varying arc lengths of protrusions **30** and slots **34**, where the stress is normalized relative to the maximum stress condition for a 5 slot ring. A thermal finite element model was solved for a given temperature gradient through the thickness of the ring. The thermal solution was then passed to a structural finite element model to solve for the thermally induced stresses. Curve **1** is for a ring with five slots and protrusions. It indicates that the stress concentration in the fillet region decreases significantly as the slot arc length increases, to about ⅓ of the maximum stress of that of the narrowest slot. Note that there appears to be an optimal protrusion arc length of approximately 20 degrees, or a slot arc length of 52 degrees, as illustrated by Curve **1** for the five slot/protrusion ring, where the stress concentration is at 27% of the maximum case.

[0021] Curve **2** in FIG. **5** is for a similar shroud ring with 12 slots and protrusions with similarly changing arc lengths. Note that the magnitude of the stress concentration is essentially equal for when arc lengths of the slots are at the maximum, or where the arc lengths of the protrusions are equal. Also, the maximum stress for when the slot is at its minimum is lower for the 12 slot ring as compared to the 5 slot ring, which is expected as 12 slots allow more deflection of the ring from the internal bending load induced from the through thickness temperature gradient. It is interesting to note that the same optimal protrusion arc length for the 5 slot case is not apparent for the 12 slot/protrusion case shown in Curve **2**.

[0022] The maximum hoop stress of a plain ring thickness T**1** is approximately 15% less than the lowest maximum stress condition, as shown by the dotted line **3** in FIG. **5**.

[0023] A featureless shroud ring is not a useful solution for assembly into the hot section of a gas turbine engine. Therefore, the geometry that provides the least thermally induced stress is a ring with a multitude of protrusions with an arc length as small as practical to provide adequate mounting support. From FIG. **5**, it is apparent that more slots for a given slot length will reduce the maximum stress. Also, FIG. **5** shows that as the slot length increases, the maximum stress decreases, indicating that protrusions are more desirable than slots, from a stress point of view.

[0024] While there has been discussed herein, a shroud **18** having 5 to 12 slots, determining the number of useful slots to use in a particular design application depends on issues including manufacturing cost. It follows that the more features the ring will have will in turn increase the cost of the shroud ring. Close tolerance control in ceramic components requires much of the machining of the contact surfaces and other critical features need to be done in the ceramic's hardened state. Therefore, to decrease manufacturing costs, as much machining in the green state should be performed prior to densification if the ceramic, leaving only a minimal amount of machining to obtain the required tolerance.

[0025] The shroud ring **18** may be formed from any suitable ceramic material known in the art. The shroud ring **18** may be a monolithic ceramic material.

[0026] There has been discussed herein a geometry to minimize feature related thermal stresses in a monolithic ceramic shroud. While the geometry has been described in the context of specific embodiments thereof, other unforeseen alternatives, modifications, and variations may become apparent to those skilled in the art having read the foregoing description. Accordingly, it is intended to embrace those alternatives, modifications, and variations, as fall within the broad scope of the appended claims.

1. A shroud comprising:

a ring with a plurality of protrusions and a plurality of slots; and

each of said protrusions having an arc length different from the arc length of each said slot.

2. The shroud of claim **1**, wherein said shroud is formed from a monolithic ceramic material or Ceramic Matrix Composite (CMC) material.

3. The shroud of claim **21**, wherein each of said slots has parallel sides.

4. The shroud of claim **21**, wherein said slots are equally spaced around a circumference of said ring.

5. The shroud of claim **21**, wherein said plurality of slots comprises said ring having from 3 to 18 slots.

6. The shroud of claim **21**, wherein each said slot has an arc length and said arc length of each slot is greater than the arc length of each said protrusion.

7. The shroud of claim **6**, wherein said ring has a minimum thickness and a majority of the ring is dominated by the ring minimum thickness so as to decrease stress concentrations.

8. The shroud of claim **6**, wherein each said slot has an arc length in the range of 20 to 60 degrees.

9. The shroud of claim **6**, wherein each said slot has an arc length of 3 to 20 degrees.

10. An engine comprising:

a rotor;

a ceramic or CMC shroud surrounding said rotor; and

said shroud comprising a ring with a plurality of protrusions and a plurality of slots and each of said protrusions having an arc length and parallel sides.

11. The engine of claim **10**, wherein said shroud is located in a hot section of said engine.

12. The engine of claim **10**, wherein said shroud is formed from a ceramic material and is monolithic.

13. The engine of claim **10**, wherein each of said slots has parallel sides.

14. The engine of claim **13**, further comprising a mating ring with mating features that contact the parallel sides of the slots.

15. The engine of claim **10**, wherein said slots are equally spaced around a circumference of said ring.

16. The engine of claim **10**, wherein said plurality of slots comprises said ring having from 5 to 12 slots.

17. The engine of claim **10**, wherein each said slot has an arc length and said arc length of each slot is greater than the arc length of each said protrusion.

18. The engine of claim **17**, wherein said ring has a minimum thickness and a majority of the ring is dominated by the ring minimum thickness so as to decrease stress concentrations.

19. The engine of claim **17**, wherein each said slot has an arc length in the range of 20 to 60 degrees.

20. The engine of claim **17**, wherein each said slot has an arc length in the range of 3 to 20 degrees.

21. A shroud comprising:

a ring with a plurality of protrusions and a plurality of slots; and

said shroud being formed from a monolithic ceramic material and being monolithic or Ceramic Matrix Composite (CMC) material.

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