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(54) ADVANCED PASSIVE CLEARANCE CONTROL (APCC) CONTROL RING PRODUCED BY FIELD ASSISTED SINTERING TECHNOLOGY (FAST)

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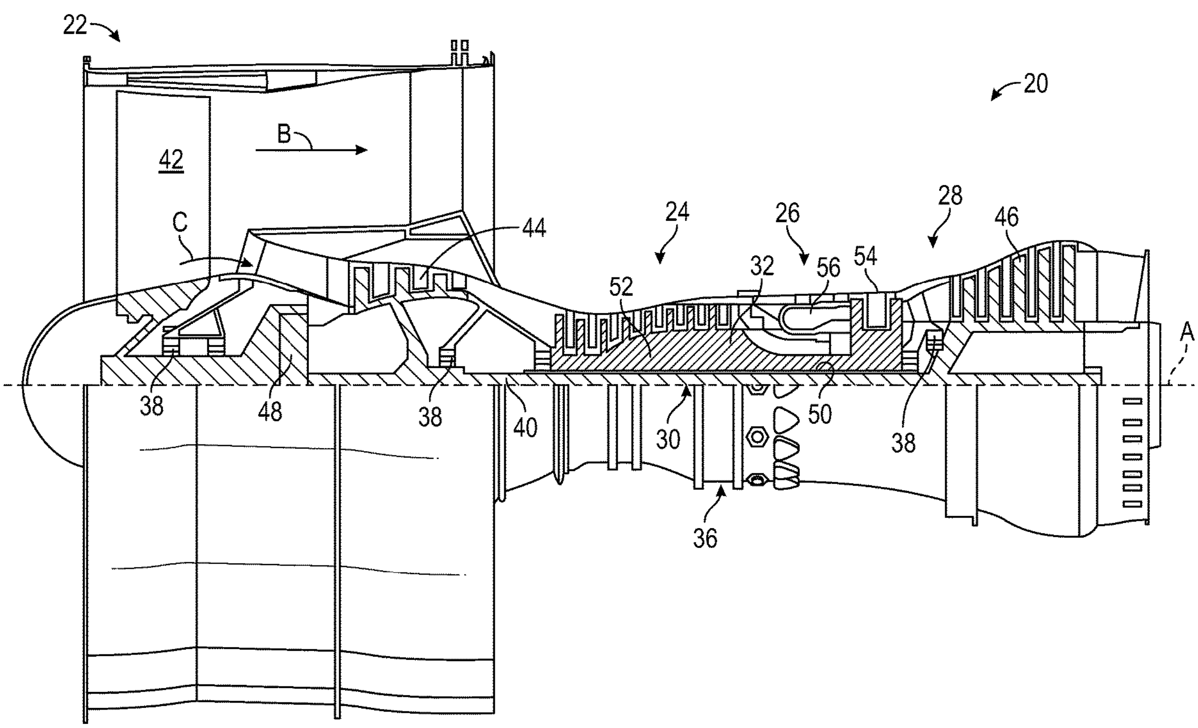
(57) **ABSTRACT**

An advanced passive clearance control (APCC) control ring is provided. The APCC control ring includes first and second cover sections, first and second wall sections and a control ring. At least one of the first and second cover sections is bonded to corresponding edges of the first and second wall sections by field assisted sintering technology (FAST) processing along a bond surface to form an enclosure for the control ring.



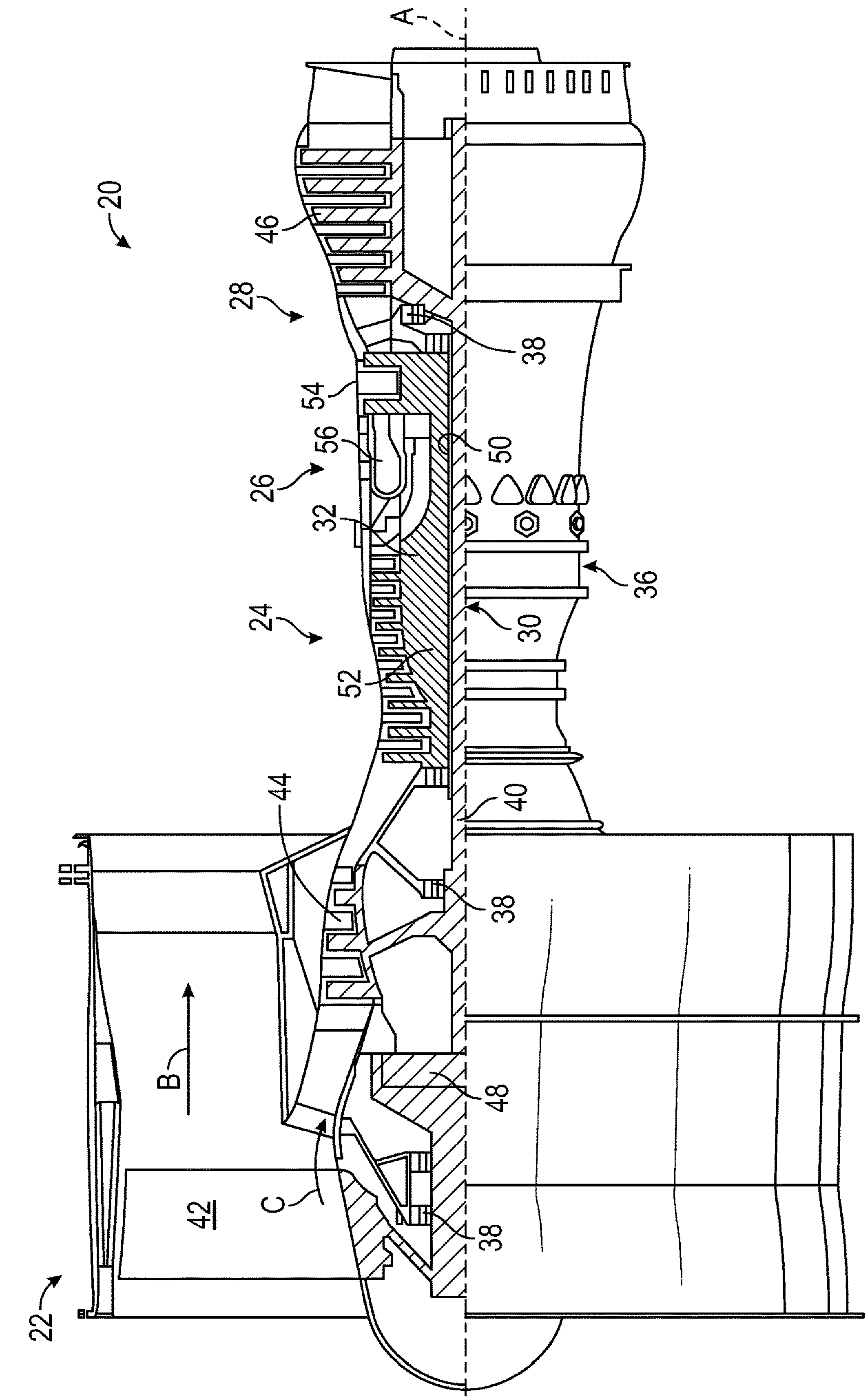


FIG. 1

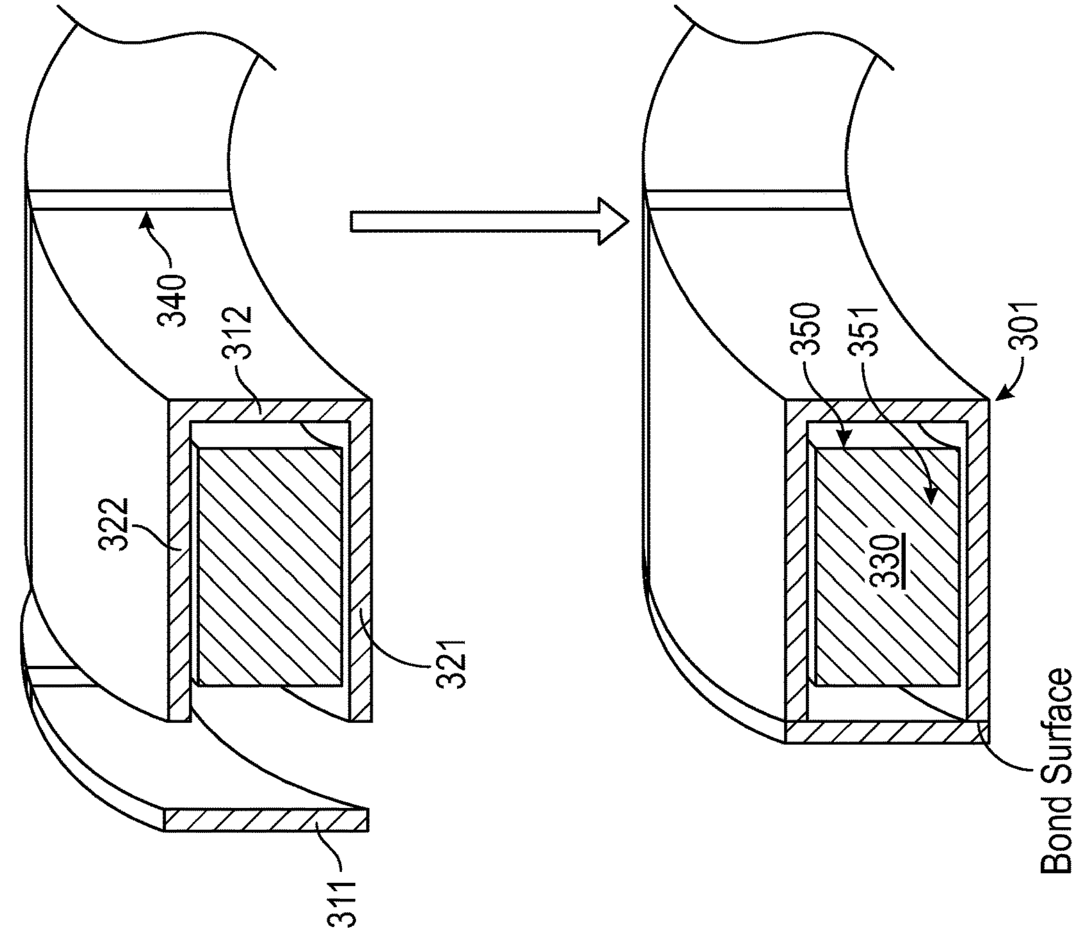

340
312
322
321
311
350
351
330
301
Bond Surface

FIG. 3

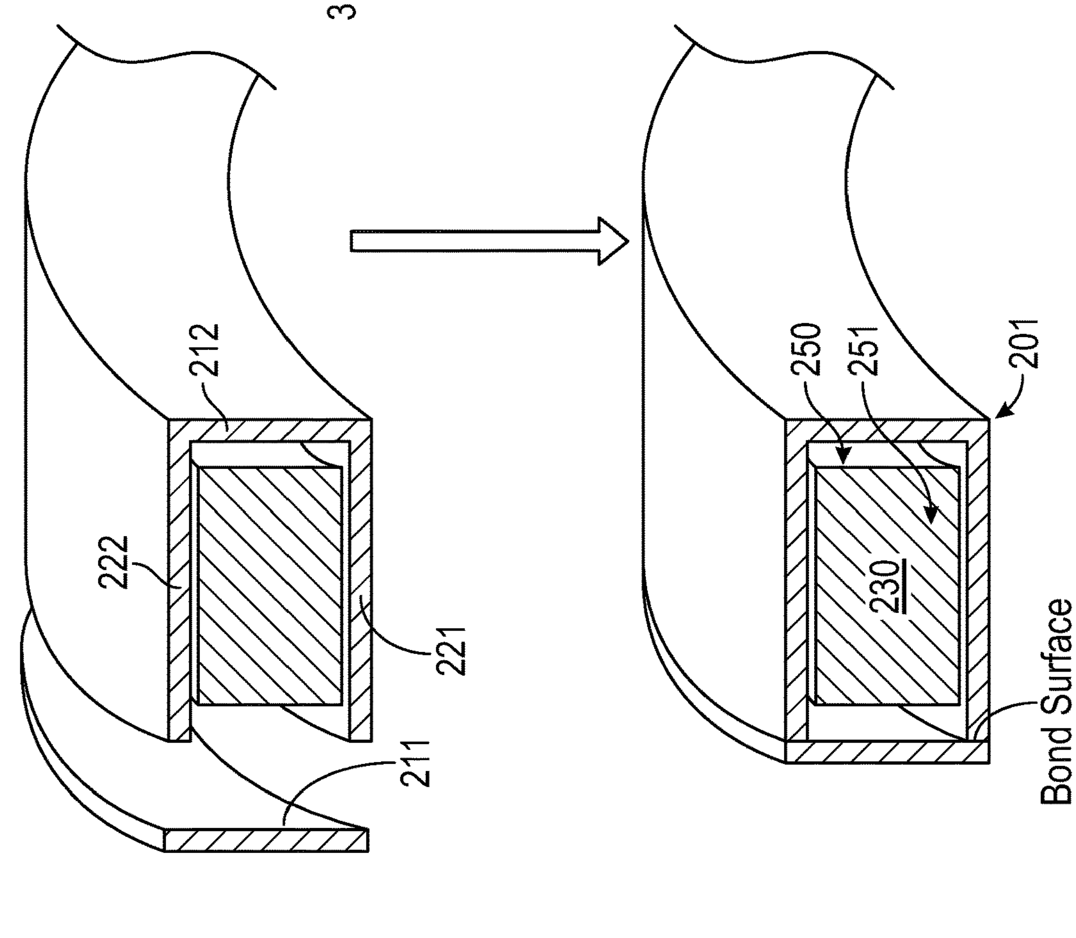

212
222
221
211
250
251
230
201
Bond Surface

FIG. 2

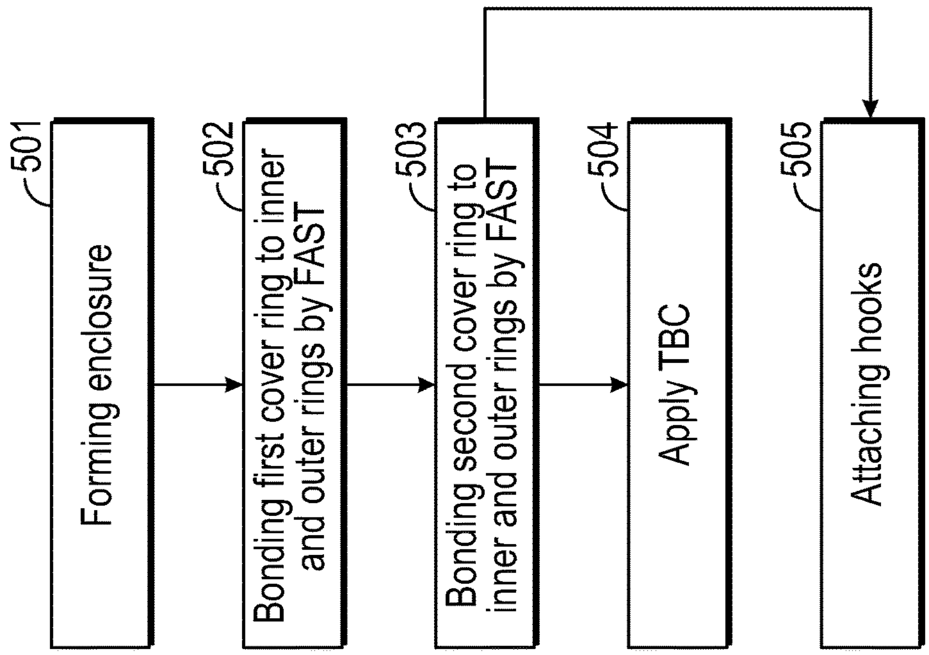

501
Forming enclosure
502
Bonding first cover ring to inner and outer rings by FAST
503
Bonding second cover ring to inner and outer rings by FAST
504
Apply TBC
505
Attaching hooks

FIG. 5

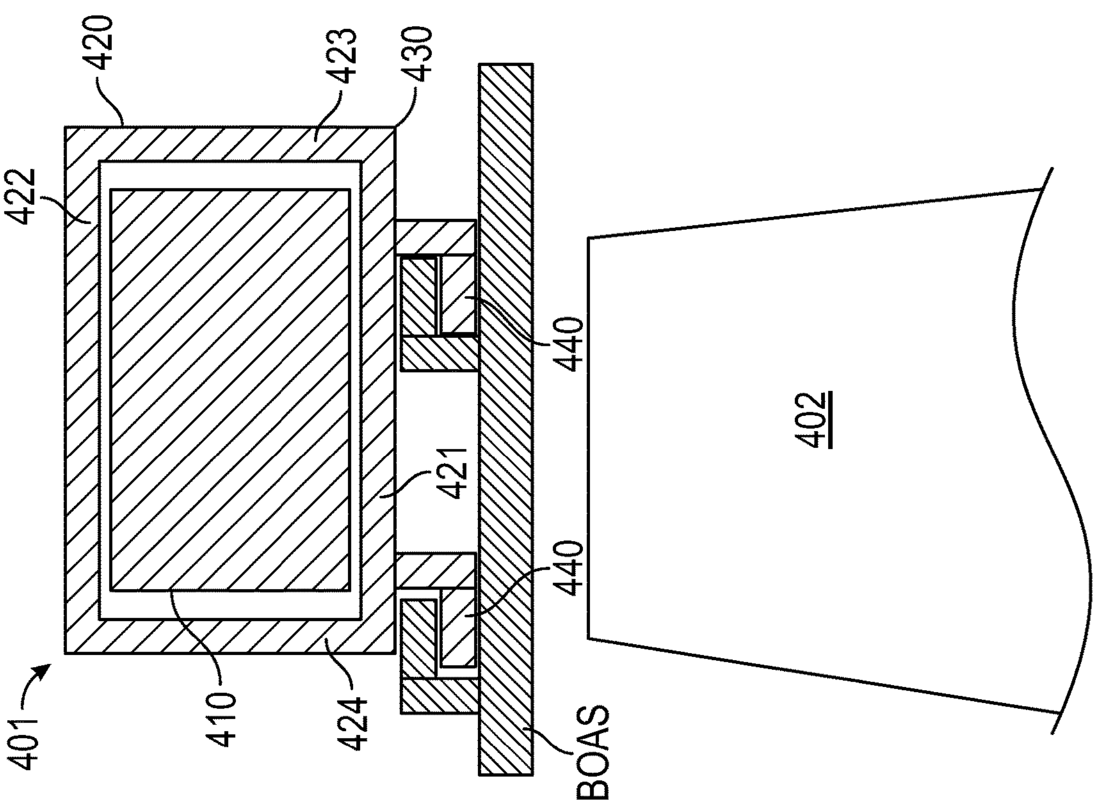

420
423
430
422
440
402
421
440
401
410
424
BOAS

FIG. 4

ADVANCED PASSIVE CLEARANCE CONTROL (APCC) CONTROL RING PRODUCED BY FIELD ASSISTED SINTERING TECHNOLOGY (FAST)

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application No. 63/212,325 filed Jun. 18, 2021, and U.S. Provisional Application No. 63/232,967 filed Aug. 13, 2021, the contents of which are hereby incorporated by reference in their entirety.

BACKGROUND

[0002] The present disclosure relates to a control ring and, more particularly, to an improved advanced passive clearance control (APCC) control ring that can be produced by field assisted sintering technology.

[0003] In a gas turbine engine, an APCC system is often used to control tip clearance within a high-pressure turbine or HPT. To maximize the performance of the APCC system, the APCC is typically configured such that the control ring provides a slow thermal response to throttle changes. Generally, such a slow thermal response requires relatively high mass and reduced surface areas to be achievable.

[0004] Accordingly, a need exists for a production method that allows an improved APCC control ring to be produced.

BRIEF DESCRIPTION

[0005] According to an aspect of the disclosure, an advanced passive clearance control (APCC) control ring is provided. The APCC control ring includes first and second cover sections, first and second wall sections and a control ring. At least one of the first and second cover sections is bonded to corresponding edges of the first and second wall sections by field assisted sintering technology (FAST) processing along a bond surface to form an enclosure for the control ring.

[0006] In accordance with additional or alternative embodiments, both the first and second cover sections are bonded to corresponding edges of the first and second wall sections by the FAST processing along corresponding bond surfaces.

[0007] In accordance with additional or alternative embodiments, the control ring is a full-hoop control ring and the first and second cover sections and the first and second wall sections are fully annular.

[0008] In accordance with additional or alternative embodiments, the control ring is segmented and the first and second cover sections and the first and second wall sections are partially annular.

[0009] In accordance with additional or alternative embodiments, the enclosure forms a thermally isolated cavity therein.

[0010] In accordance with additional or alternative embodiments, a thermal barrier coating (TBC) is applied to exterior surfaces of the first and second cover sections and the first and second wall sections.

[0011] In accordance with additional or alternative embodiments, hook elements are attached to one of the first and second wall sections.

[0012] According to an aspect of the disclosure, an advanced passive clearance control (APCC) control ring is provided. The APCC control ring includes first and second cover sections, first and second wall sections and a control ring. At least one of the first and second cover sections is bonded to corresponding edges of the first and second wall sections by field assisted sintering technology (FAST) processing along a planar bond surface to form an enclosure for the control ring.

[0013] In accordance with additional or alternative embodiments, both the first and second cover sections are bonded to corresponding edges of the first and second wall sections by the FAST processing along corresponding planar bond surfaces.

[0014] In accordance with additional or alternative embodiments, the control ring is a full-hoop control ring and the first and second cover sections and the first and second wall sections are fully annular.

[0015] In accordance with additional or alternative embodiments, the control ring is segmented and the first and second cover sections and the first and second wall sections are partially annular.

[0016] In accordance with additional or alternative embodiments, the enclosure forms a thermally isolated cavity therein.

[0017] In accordance with additional or alternative embodiments, a thermal barrier coating (TBC) is applied to exterior surfaces of the first and second cover sections and the first and second wall sections.

[0018] In accordance with additional or alternative embodiments, hook elements are attached to one of the first and second wall sections.

[0019] According to an aspect of the disclosure, a method of assembling an advanced passive clearance control (APCC) system is provided. The method includes forming an enclosure to thermally isolate a control ring. The forming of the enclosure includes bonding first a cover ring to respective first edges of inner and outer rings by field assisted sintering technology (FAST) and bonding a second cover ring to respective second edges of the inner and outer rings by the FAST.

[0020] In accordance with additional or alternative embodiments, the control ring and the enclosure are annular.

[0021] In accordance with additional or alternative embodiments, the control ring is a full-hoop control ring.

[0022] In accordance with additional or alternative embodiments, the control ring is segmented.

[0023] In accordance with additional or alternative embodiments, the method further includes applying a thermal barrier coating to exterior surfaces of the inner and outer rings and the first and second cover rings.

[0024] In accordance with additional or alternative embodiments, the method further includes attaching hook elements to the inner ring.

[0025] Additional features and advantages are realized through the techniques of the present disclosure. Other embodiments and aspects of the disclosure are described in detail herein and are considered a part of the claimed technical concept. For a better understanding of the disclosure with the advantages and the features, refer to the description and to the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] For a more complete understanding of this disclosure, reference is now made to the following brief description, taken in connection with the accompanying drawings and detailed description, wherein like reference numerals represent like parts:

[0027] FIG. **1** is a partial cross-sectional view of a gas turbine engine in accordance with embodiments;

[0028] FIG. **2** is a schematic side view of an APCC full-hoop control ring in accordance with embodiments;

[0029] FIG. **3** is a schematic side view of an APCC segmented control ring in accordance with embodiments;

[0030] FIG. **4** is a schematic side view of an APCC control ring in accordance with embodiments; and

[0031] FIG. **5** is a flow diagram illustrating a method of assembling an APCC control ring in accordance with embodiments.

DETAILED DESCRIPTION

[0032] FIG. **1** schematically illustrates a gas turbine engine **20**. The gas turbine engine **20** is disclosed herein as a two-spool turbofan that generally incorporates a fan section **22**, a compressor section **24**, a combustor section **26** and a turbine section **28**. Alternative engines might include other systems or features. The fan section **22** drives air along a bypass flow path B in a bypass duct, while the compressor section **24** drives air along a core flow path C for compression and communication into the combustor section **26** then expansion through the turbine section **28**. Although depicted as a two-spool turbofan gas turbine engine in the disclosed non-limiting embodiment, it should be understood that the concepts described herein are not limited to use with two-spool turbofans as the teachings may be applied to other types of turbine engines including three-spool architectures.

[0033] The exemplary engine **20** generally includes a low speed spool **30** and a high speed spool **32** mounted for rotation about an engine central longitudinal axis A relative to an engine static structure **36** via several bearing systems **38**. It should be understood that various bearing systems **38** at various locations may alternatively or additionally be provided, and the location of bearing systems **38** may be varied as appropriate to the application.

[0034] The low speed spool **30** generally includes an inner shaft **40** that interconnects a fan **42**, a low pressure compressor **44** and a low pressure turbine **46**. The inner shaft **40** is connected to the fan **42** through a speed change mechanism, which in exemplary gas turbine engine **20** is illustrated as a geared architecture **48** to drive the fan **42** at a lower speed than the low speed spool **30**. The high speed spool **32** includes an outer shaft **50** that interconnects a high pressure compressor **52** and high pressure turbine **54**. A combustor **56** is arranged in exemplary gas turbine **20** between the high pressure compressor **52** and the high pressure turbine **54**. An engine static structure **36** is arranged generally between the high pressure turbine **54** and the low pressure turbine **46**. The engine static structure **36** further supports bearing systems **38** in the turbine section **28**. The inner shaft **40** and the outer shaft **50** are concentric and rotate via bearing systems **38** about the engine central longitudinal axis A which is collinear with their longitudinal axes.

[0035] The core airflow is compressed by the low pressure compressor **44** then the high pressure compressor **52**, mixed and burned with fuel in the combustor **56**, then expanded over the high pressure turbine **54** and low pressure turbine **46**. The turbines **46**, **54** rotationally drive the respective low speed spool **30** and high speed spool **32** in response to the expansion. It will be appreciated that each of the positions of the fan section **22**, compressor section **24**, combustor section **26**, turbine section **28**, and fan drive gear system **48** may be varied. For example, gear system **48** may be located aft of combustor section **26** or even aft of turbine section **28**, and fan section **22** may be positioned forward or aft of the location of gear system **48**.

[0036] The engine **20** in one example is a high-bypass geared aircraft engine. In a further example, the engine **20** bypass ratio is greater than about six (6), with an example embodiment being greater than about ten (10), the geared architecture **48** is an epicyclic gear train, such as a planetary gear system or other gear system, with a gear reduction ratio of greater than about 2.3 and the low pressure turbine **46** has a pressure ratio that is greater than about five. In one disclosed embodiment, the engine **20** bypass ratio is greater than about ten (10:1), the fan diameter is significantly larger than that of the low pressure compressor **44**, and the low pressure turbine **46** has a pressure ratio that is greater than about five 5:1. Low pressure turbine **46** pressure ratio is pressure measured prior to inlet of low pressure turbine **46** as related to the pressure at the outlet of the low pressure turbine **46** prior to an exhaust nozzle. The geared architecture **48** may be an epicycle gear train, such as a planetary gear system or other gear system, with a gear reduction ratio of greater than about 2.3:1. It should be understood, however, that the above parameters are only exemplary of one embodiment of a geared architecture engine and that the present disclosure is applicable to other gas turbine engines including direct drive turbofans.

[0037] A significant amount of thrust is provided by the bypass flow B due to the high bypass ratio. The fan section **22** of the engine **20** is designed for a particular flight condition—typically cruise at about 0.8 Mach and about 35,000 feet (10,688 meters). The flight condition of 0.8 Mach and 35,000 ft (10,688 meters), with the engine at its best fuel consumption—also known as "bucket cruise Thrust Specific Fuel Consumption ('TSFC'"—is the industry standard parameter of lbm of fuel being burned divided by lbf of thrust the engine produces at that minimum point. "Low fan pressure ratio" is the pressure ratio across the fan blade alone, without a Fan Exit Guide Vane ("FEGV") system. The low fan pressure ratio as disclosed herein according to one non-limiting embodiment is less than about 1.45. "Low corrected fan tip speed" is the actual fan tip speed in ft/sec divided by an industry standard temperature correction of $[(\text{Tram } ° \text{R})/(518.7 ° \text{R})]^{0.5}$. The "Low corrected fan tip speed" as disclosed herein according to one non-limiting embodiment is less than about 1150 ft/second (350.5 m/sec).

[0038] Field assisted sintering technology (FAST) and spark plasma sintering (SPS) are consolidation processes that are executed at temperatures lower than the melting point of the subject materials. Similar to hot pressing, FAST forms bonds between materials but at temperatures ~200° C. lower. FAST utilizes a high amperage pulsed direct current (DC) electrical current to heat the subject materials to be bonded through Joule heating while under uniaxial compression. The consolidation is a combination of solid-state transport mechanisms including primarily diffusion and creep. The result is a metallurgical bond between the materials to be joined. Consolidation or joining can be accomplished in a variety of conductive and non-conductive materials and forms.

[0039] Recently, FAST/SPS has been gaining acceptance starting in the 1990s for consolidation of powder materials into dense compacts with significantly greater efficiency than hot pressing. Due to the lower processing temperatures of FAST/SPS over other consolidation methods, FAST/SPS mitigates significant grain growth common in other diffusional bonding methods. In some cases, bonding two dense metallic materials using the FAST process has been demonstrated. Material pairs included a same alloy (e.g., PWA 1429) and dissimilar alloys (e.g., PWA 1429 to CM247). Additionally, the ability to bond both single crystal (SX) and equiaxed (EQ) materials and the ability to retain fine features along bond surfaces or lines have been demonstrated.

[0040] As will be described below, FAST is used to provide a bonded geometry that encloses a lightweight structure. A thermal barrier coating (TBC) is provided on exterior surfaces which do not contact other hardware and sliding interfaces to reduce response times. Internal features can be machined to reduce weight. An outer shell so formed and mated by FAST can be used to enclose and isolate interior surfaces from convective heat transfer.

[0041] In greater detail, there are APCC systems that minimize tip clearances between blades and blade outer air seals (BOASs) in gas turbine engines such as the gas turbine engine **20** of FIG. **1**. In growth configurations, a full hoop ring is assembled into a BOAS carrier ring with a cover to complete an enclosure. This enclosure thermally isolates the full hoop ring such that it responds slowly to transient thermal changes due to rapid throttle movements. In practice, the ring used in certain engine tests was not thermally isolated due to various leakages. The disclosure in the following description would permanently bond the cover to the BOAS carrier ring to create an ideal thermally isolated cavity.

[0042] With continued reference to FIG. **1**, an APCC control ring can be disposable in various regions of a high pressure turbine as part of an APCC system to minimize tip clearances between blades and BOASs.

[0043] With reference to FIGS. **2** and **3**, an APCC with a full-hoop control ring **201** (see FIG. **2**) and an APCC with a segmented control ring **301** (see FIG. **3**) are provided for use in any of the various regions of the high pressure turbine.

[0044] As shown in FIG. **2**, the APCC with the full-hoop control ring **201** includes first and second annular side sections **211** and **212**, first and second annular wall sections **221** and **222** and a full-hoop control ring **230**. The first and second annular side sections **211** and **212** and the first and second annular side sections **221** and **222** can be formed independently from each other, though they are illustrated in FIG. **2** with the first annular side section **211** already being attached (by FAST processing along a planar bond surface) to the first and second annular wall sections **221** and **222**. In any case, as shown in FIG. **2** at least the second annular side section **212** is bonded to the first and second annular wall sections **221** and **222** by FAST processing along a bond surface. In some, but not all cases, the bond surface can be a planar bond surface. This forms an enclosure **250** with a thermally isolated cavity **251** therein for the full-hoop control ring **230**.

[0045] As shown in FIG. **3**, the APCC with the segmented control ring **301** includes first and second annular side sections **311** and **312**, first and second annular wall sections **321** and **322** and a segmented control ring **330** all of which are segmented at break point **340**. The first and second annular side sections **311** and **312** and the first and second annular side sections **321** and **322** can be formed independently from each other, though they are illustrated in FIG. **3** with the first annular side section **311** already being attached (by FAST processing along a planar bond surface) to the first and second annular wall sections **321** and **322**. In any case, as shown in FIG. **3** at least the second annular side section **312** is bonded to the first and second annular wall sections **321** and **322** by FAST processing along a bond surface. In some, but not all cases, the bond surface can be a planar bond surface. This forms an enclosure **350** with a thermally isolated cavity **351** for the segmented control ring **330**.

[0046] For the embodiments of FIGS. **2** and **3** and in other cases, the bond surface need not be a planar bond surface. For example, in some additional or alternative embodiments of FIG. **2**, the bond surface could be the annular outer surface of the first annular wall section **221** or the annular inner surface of the second annular wall section **222**. Similarly, in some additional or alternative embodiments of FIG. **3**, the bond surface could be the annular outer surface of the first annular wall section **321** or the annular inner surface of the second annular wall section **322**. Hybrid configurations are also possible.

[0047] Generally, it is to be understood that a requirement for FAST/SPS processing, as in the embodiments of FIGS. **2** and **3**, is a uniaxial loading direction where that loading brings the two surfaces being bonded into contact. The surfaces can be oriented as a flat surface perpendicular to the loading direction, at an offset angle to the loading direction (albeit not parallel to it), a shaped surface such as a "V", a sawtooth, a curve or any other complex arrangement.

[0048] With reference to FIG. **4**, an APCC system **401** is provided and includes a control ring **410**, which could be a full-hoop or segmented, and an enclosure **420** to thermally isolate the control ring **410**. Both the control ring **410** and the enclosure **420** are at least partially annular. The enclosure **420** includes an inner ring **421**, an outer ring **422**, a first cover ring **423** extending between respective first edges of the inner ring **421** and the outer ring **422** and a second cover ring **424** extending between respective second edges of the inner ring **421** and the outer ring **422**. The first and second cover rings **423** and **424** can be bonded by FAST to the respective first and second edges of the inner ring **421** and the outer ring **422** along respective bond surfaces, such as the respectively planar bond surfaces. A TBC **430** can be applied to exterior surfaces of the inner and outer rings **421** and **422**, the sidewall ring **423** and the cover ring **424**. Hook elements **440** can be attached to the inner ring **421** and can be attached to corresponding hook elements of a blade outer air seal (BOAS) for a turbine blade **402**.

[0049] Again, for the embodiments of FIG. **4** and in other cases, the bond surface need not be a planar bond surface. For example, in some additional or alternative embodiments of FIG. **4**, the bond surface could be the annular outer surface of the inner ring **421** or the annular inner surface of the outer ring **422**. Hybrid configurations are also possible.

[0050] Generally, it is to be understood that a requirement for FAST/SPS processing, as in the embodiments of FIG. **4**, is a uniaxial loading direction where that loading brings the two surfaces being bonded into contact. The surfaces can be oriented as a flat surface perpendicular to the loading direction, at an offset angle to the loading direction (albeit not parallel to it), a shaped surface such as a "V", a sawtooth, a curve or any other complex arrangement.

[0051] With reference to FIG. **5**, a method of assembling an APCC system is provided. As shown in FIG. **5**, the method includes forming an enclosure to thermally isolate a control ring (**501**), wherein the forming of the enclosure includes bonding a first cover ring to respective first edges of inner and outer rings by FAST (**502**) and bonding second a cover ring to respective second edges of the inner and outer rings by FAST (**503**). The control ring and the enclosure are at least partially annular and can be full-hoop components or segmented. The method can further include applying a TBC to exterior surfaces of the inner and outer rings and the first and second cover rings (**504**) and attaching hook elements to the inner ring (**505**).

[0052] In an embodiment, a first alloy for use in the APCC control ring and the methods described herein may be a "high strength" metal alloy. Examples of the first alloy include PWA 1429, René N5, CMSX-4, CMSX-10, TMS-138 or TMS-162. The metal alloys are nickel-based metals that in addition to nickel comprise one or more of chromium, cobalt, molybdenum, aluminum, titanium, tantalum, niobium, ruthenium, rhenium, boron and carbon. The metal alloys contain one or more of the following metals in addition to nickel—2 to 10 wt % of chromium, 2 to 11 wt % of cobalt, 0.5 to 5 wt % molybdenum, 4 to 7.5 wt % of tungsten, 3-7 wt % of aluminum, 0 to 5 wt % of titanium, 3 to 10 wt % of tantalum and 2-8 wt % of rhenium. The metal alloys may also contain ruthenium, carbon and boron.

[0053] The composition of these alloys is defined to maximize mechanical properties in a single crystal form while maintaining an adequate level of environmental resistance. Table 1 and Table 2 shows preferred ranges (of the ingredients) for the compositions (in weight percent) that may be used for the first alloy. Table 2 contains broader ranges for some of the alloys (than those indicated in Table 1) that may be used in the first portion.

TABLE 1

Composition of cast superalloys.

Class		Alloy	Compositions (wt. %)														
			Cr	Co	Mo	W	Al	Ti	Ta	Nb	Re	R⑦	Hf	C	B	Zr	Ni
Conventional		IN-713LC	12	—	4.5	—	⑦	0.6	—	2	—	—	—	0.05	0.01	0.1	Bal
Cast(CC)		IN-738LC	16	8.5	1.75	⑦	3.4	3.4	1.75	0.9	—	—	—	0.11	0.01	0.04	Bal
		René 80	14	9	4	4	3	4.7	—	—	—	—	0.8	0.16	0.015	0.01	Bal
		M⑦-M297	8	10	⑦	10	⑦	3	3	—	—	—	3.5	0.15	0.015	0.03	Bal
OS	1st	M⑦-M20⑦	8	⑦	—	12	3	⑦	—	1	—	—	2	0.13	0.015	0.03	Bal
		CM247LC	8.1	9.2	0.5	9.5	⑦	0.7	3.2	—	—	—	14	0.07	0.015	0.007	Bal
	2nd	CM186LC	6	9.3	0.5	8.4	5.7	0.7	3.4	—	3.0	—	1.4	0.07	0.015	0.005	Bal
		PWA1426	⑦	10	1.7	6.5	⑦	—	4	—	3.0	—	1.5	0.1	0.015	0.1	Bal
	1st	CMSX-2	⑦	⑦	0.6	8	3.6	1	⑦	—	—	—	—	—	—	—	Bal
		PWA1480	10	⑦	—	4	5	⑦	12	—	—	—	—	—	—	—	Bal
		René N4	9	5	2	6	3.7	4.2	4	0.5	—	—	—	—	—	—	Bal
		AM⑦	7	5	2	5	⑦	1.5	⑦	1	—	—	—	—	—	—	Bal
		RR2000	10	15	3	—	5.3	4	—	—	—	—	—	—	—	—	Bal
SC	2nd	CMSX-4	6.5	⑦	0.6	⑦	5.6	⑦	6.3	—	3	—	0.1	—	—	—	Bal
		PWA1484	5	10	2	6	5.6	—	9	—	3	—	0.1	—	—	—	Bal
		René N⑦	7	8	2	5	⑦	—	7	—	3	—	0.2	—	—	—	Bal
	3rd	CMSX-10	2	3	⑦	5	⑦	0.2	8	—	⑦	—	⑦	—	—	—	Bal
	4th	TMS138	2.9	5.9	2.9	5.9	5.9	—	5.8	—	4.9	2	0.1	—	—	—	Bal
		TMS-162	2.9	5.8	3.9	5.8	5.8	—	5.8	—	4.9	6	0.09	—	—	—	Bal
	Re-free	CMSX-7	⑦	10	0.6	⑦	5.7	0.8	9	—	—	—	0.2	—	—	—	Bal
	Low Re	CMSX-8	5.4	10	0.6	8	5.7	0.7	8	—	1.5	—	0.1	—	—	—	Bal

⑦ indicates text missing or illegible when filed

[text missing or illegible when filed]

TABLE 2

	Cr	Co	Mo	W	Al	Ti	Ta	Nb	Re	Ni
PWA1429	5-7	9-11	1.5-2.5	5.5-7.5	5-7	—	3-10	—	2-4	balance
René N5	6-10	7-9	1.5-2.5	4-7	3-7	0-5	3-8	0-1	0-4	balance
CMSX-4	4-8	7-10	0.5-1.5	5.5-7.5	5-6	0-2	5-8	—	2-4	balance
CMSX-10	1-3	2-4	0.1-1	4-6	5-7	0.1-0.4	6-10		4-8	balance
TMS-138	2-4	3.5-6.5	2-4	5-7	5-7	—	5-7		4-6	balance
TMS-162	2-4	3.5-6.5	3-5	5-7	5-7	—	5-7		5-7	balance

[0054] The high strength alloys can withstand stresses of greater than 800 MPa at temperatures greater than 600° C. and stresses of greater than 200 MPa at temperatures of greater than 800° C.

[0055] Second alloys for use in the APCC control ring and the methods described herein are selected for their ability to handle harsh environmental conditions and can include René 195 and René N2. These compositions were developed with an eye to improved environmental resistance. This can be seen in the Al and Cr levels as compared with Re, W, Mo shown in the Table 3. The cobalt to chromium ratios are lower for the second alloys, while the aluminum to cobalt ratio is much higher for the second alloys when compared with the first alloys.

[0056] The second alloys can be a nickel-based alloy that in addition to nickel includes one or more of chromium, cobalt, molybdenum, aluminum, titanium, tantalum, niobium, ruthenium, rhenium, boron and carbon. The metal alloys contain one or more of the following metals in addition to nickel—7 to 14 wt % of chromium, 3 to 9 wt % of cobalt, 0.1 to 0.2 wt % molybdenum, 3 to 5 wt % of tungsten, 6-9 wt % of aluminum, 0 to 5 wt % of titanium, 4 to 6 wt % of tantalum, 0.1 to 0.2 wt % of hafnium and 1-2 wt % of rhenium. The metal alloys may also contain ruthenium, carbon and boron.

TABLE 3

	Cr	Co	Al	Ta	Mo	W	Re	Hf	Ni
René 195	7-9	3-4	7-9	5-6	0.1-0.2	3-5	1-2	0.1-0.2	balance
Rene N2	12-14	7-9	6-8	4-6		3-4	1-2	0.1-0.2	balance

[0057] The high strength alloys used in the second alloys can withstand stresses of at least 50% of the first alloys. In an embodiment, the high strength alloys used in the second alloys are environmentally resistant and withstand temperatures of greater than 1200° C. (under oxidation conditions) while undergoing less than 0.05 grams of weight loss per unit weight.

[0058] Technical effects and benefits of the present disclosure are the provision of FAST processing to produce a lightweight and slowly responding APCC control ring.

[0059] The corresponding structures, materials, acts, and equivalents of all means or step plus function elements in the claims below are intended to include any structure, material, or act for performing the function in combination with other claimed elements as specifically claimed. The description of the present disclosure has been presented for purposes of illustration and description, but is not intended to be exhaustive or limited to the technical concepts in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the disclosure. The embodiments were chosen and described in order to best explain the principles of the disclosure and the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

[0060] While the preferred embodiments to the disclosure have been described, it will be understood that those skilled in the art, both now and in the future, may make various improvements and enhancements which fall within the scope of the claims which follow. These claims should be construed to maintain the proper protection for the disclosure first described.

What is claimed is:

1. An advanced passive clearance control (APCC) control ring, comprising:

first and second cover sections;

first and second wall sections; and

a control ring,

at least one of the first and second cover sections being bonded to corresponding edges of the first and second wall sections by field assisted sintering technology (FAST) processing along a bond surface to form an enclosure for the control ring.

2. The APCC control ring according to claim **1**, wherein both the first and second cover sections are bonded to corresponding edges of the first and second wall sections by the FAST processing along corresponding bond surfaces.

3. The APCC control ring according to claim **1**, wherein the control ring is a full-hoop control ring and the first and second cover sections and the first and second wall sections are fully annular.

4. The APCC control ring according to claim **1**, wherein the control ring is segmented and the first and second cover sections and the first and second wall sections are partially annular.

5. The APCC control ring according to claim **1**, wherein the enclosure forms a thermally isolated cavity therein.

6. The APCC control ring according to claim **1**, further comprising a thermal barrier coating (TBC) applied to exterior surfaces of the first and second cover sections and the first and second wall sections.

7. The APCC control ring according to claim **1**, further comprising hook elements attached to one of the first and second wall sections.

8. An advanced passive clearance control (APCC) control ring, comprising:

first and second cover sections;

first and second wall sections; and

a control ring,

at least one of the first and second cover sections being bonded to corresponding edges of the first and second wall sections by field assisted sintering technology (FAST) processing along a planar bond surface to form an enclosure for the control ring.

9. The APCC control ring according to claim **8**, wherein both the first and second cover sections are bonded to corresponding edges of the first and second wall sections by the FAST processing along corresponding planar bond surfaces.

10. The APCC control ring according to claim **8**, wherein the control ring is a full-hoop control ring and the first and second cover sections and the first and second wall sections are fully annular.

11. The APCC control ring according to claim **8**, wherein the control ring is segmented and the first and second cover sections and the first and second wall sections are partially annular.

12. The APCC control ring according to claim **8**, wherein the enclosure forms a thermally isolated cavity therein.

13. The APCC control ring according to claim **8**, further comprising a thermal barrier coating (TBC) applied to exterior surfaces of the first and second cover sections and the first and second wall sections.

14. The APCC control ring according to claim **8**, further comprising hook elements attached to one of the first and second wall sections.

15. A method of assembling an advanced passive clearance control (APCC) system, the method comprising:

forming an enclosure to thermally isolate a control ring, wherein the forming of the enclosure comprises:

bonding first a cover ring to respective first edges of inner and outer rings by field assisted sintering technology (FAST); and

bonding a second cover ring to respective second edges of the inner and outer rings by the FAST.

16. The method according to claim **15**, wherein the control ring and the enclosure are annular.

17. The method according to claim **15**, wherein the control ring is a full-hoop control ring.

18. The method according to claim **15**, wherein the control ring is segmented.

19. The method according to claim **15**, further comprising applying a thermal barrier coating to exterior surfaces of the inner and outer rings and the first and second cover rings.

20. The method according to claim **15**, further comprising attaching hook elements to the inner ring.

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