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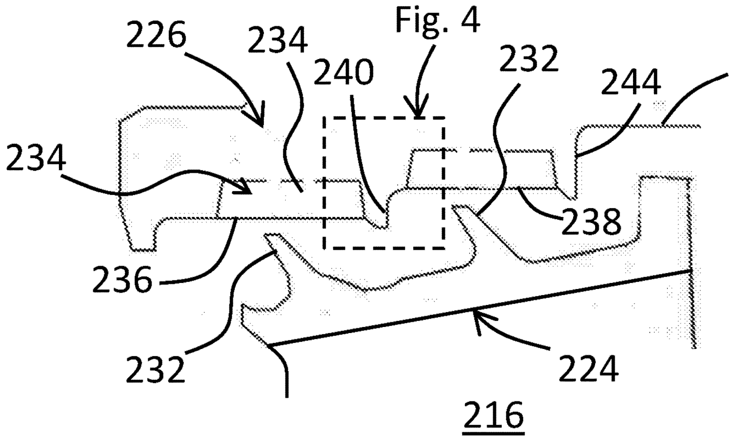
(58) Field of Search:
INT CL **F01D**
Other: **EPODOC, WPI, TXTE**

(54) Title of the Invention: **A seal segment for a gas turbine engine**
Abstract Title: **A stepped Seal Segment for a gas turbine engine**

(57) A seal segment 226 bounding a main gas path in a gas turbine engine and which opposes the free end a rotor blade, comprising: a gas path facing surface having a series of axially separated radially offset lands 236, 238 which oppose the corresponding free ends of a rotor blade in use, the radial offset being provided by a radial step 240; a circumferentially extending radial projection (figure 4, 246) which projects from the gas path facing surface towards the main gas path. A method of manufacturing a seal segment by providing an oversized seal segment blank having one or more steps, machining out a central portion of the steps to provide a land with a main gas path surface and a circumferential radial projection extending from the main surface. The projection may extend from the surface of the land by 0.25mm-1.5mm, the radial offset may be between 1mm and 6mm. The radial project can have an upstream side which is chamfered or filleted. The step of machining can be achieved by abrasively removing material, for example with an abrasive wheel. The blade maybe a shrouded blade with a plurality of offset tip fins corresponding each to a land.

Fig. 3



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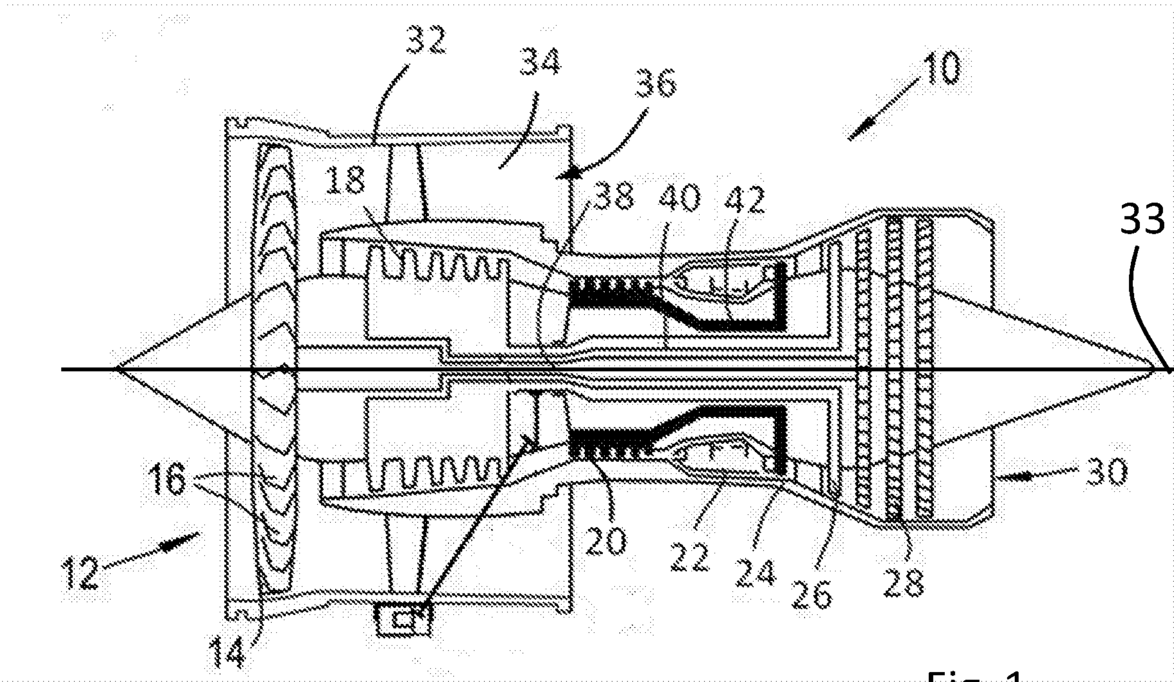
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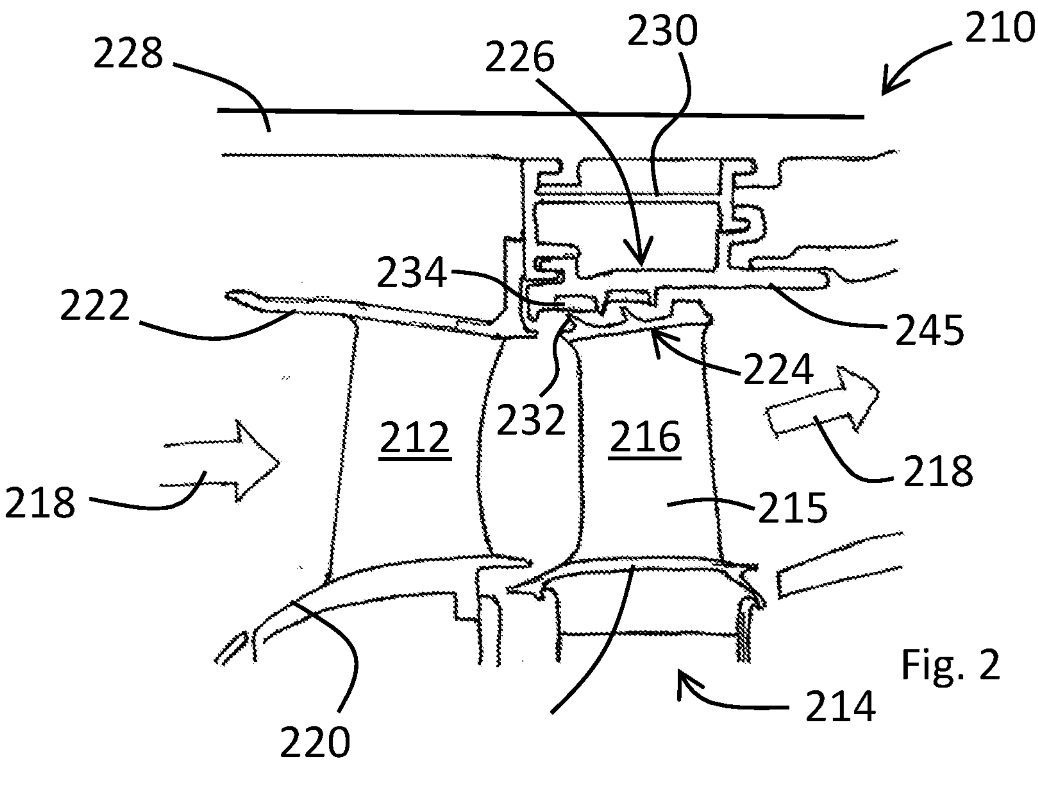
Fig. 1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226
230
210
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222
245
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232
212
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218
218
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214

Fig. 2

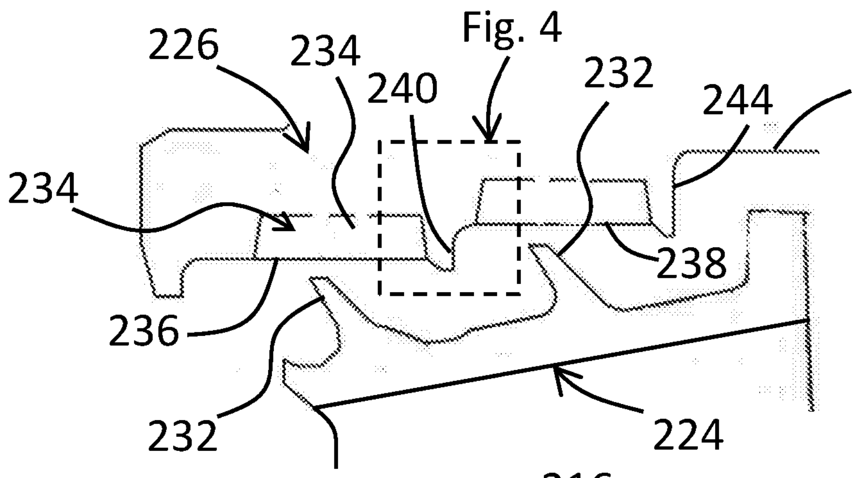
Fig. 4
226
234
240
232
244
234
238
236
232
224
216

Fig. 3

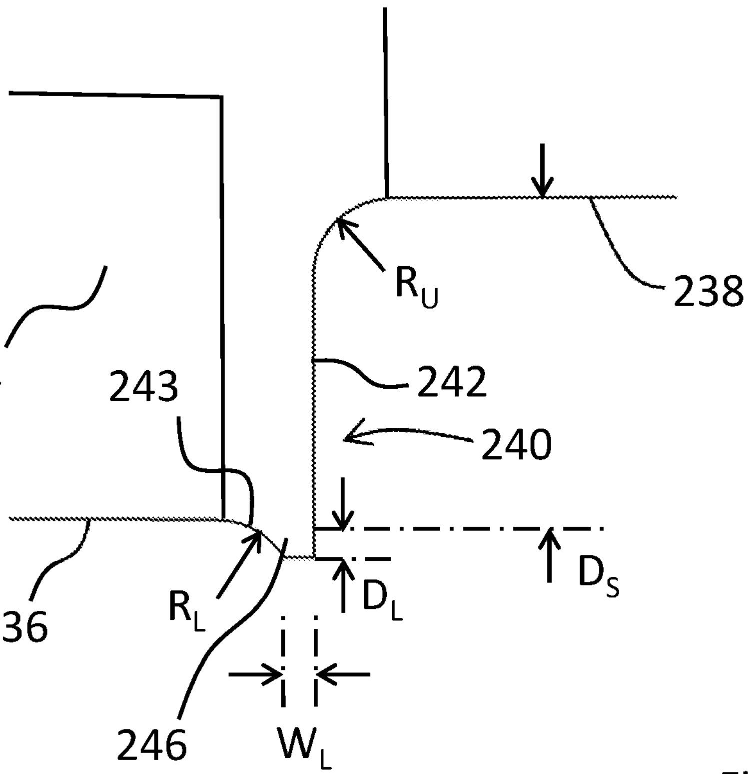
238
R_U
234
242
243
240
236
R_L
D_L
D_S
246
W_L

Fig. 4

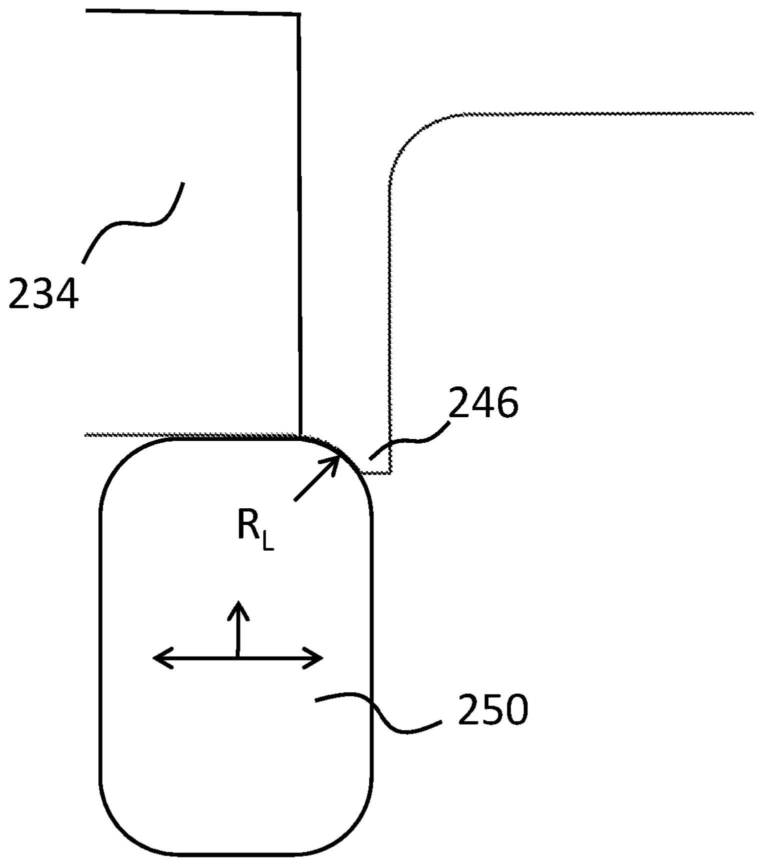

Fig. 5

A Seal Segment for a Gas Turbine Engine

Technical Field of Invention

The present invention relates to a seal segment for a gas turbine engine. In particular, the invention relates to a seal segment having radial steps and for use in conjunction with shrouded turbine blades.

Background of Invention

Figure 1 shows a ducted fan gas turbine engine 10 comprising, in axial flow series: an air intake 12, a propulsive fan 14 having a plurality of fan blades 16, an intermediate pressure compressor 18, a high-pressure compressor 20, a combustor 22, a high-pressure turbine 24, an intermediate pressure turbine 26, a low-pressure turbine 28 and a core exhaust nozzle 30. A nacelle 32 generally surrounds the engine 10 and defines the intake 12, a bypass duct 34 and a bypass exhaust nozzle 36.

Air entering the intake 12 is accelerated by the fan 14 to produce a bypass flow and a core flow. The bypass flow travels down the bypass duct 34 and exits the bypass exhaust nozzle 36 to provide the majority of the propulsive thrust produced by the engine 10. The core flow enters in axial flow series the intermediate pressure compressor 18, high pressure compressor 20 and the combustor 22, where fuel is added to the compressed air and the mixture burnt. The hot combustion products expand through and drive the high, intermediate and low-pressure turbines 24, 26, 28 before being exhausted through the nozzle 30 to provide additional propulsive thrust. The high, intermediate and low-pressure turbines 24, 26, 28 respectively drive the high and intermediate pressure compressors 20, 18 and the fan 14 by interconnecting shafts 38, 40, 42.

There are many well-known factors which affect the performance of a gas turbine engine. One of these is the over tip leakage associated with the various bladed rotors along the main gas path. Thus, generally, state of the art engines have the smallest possible build and running clearances as is possible in a production engine to minimise over tip leakage.

The present invention seeks to provide an improved arrangement to reduce the over tip leakage in a gas turbine engine.

Statements of Invention

The present invention provides a seal segment for bounding the main gas path in a gas turbine engine and opposes the free end a blade, comprising: a gas path facing surface having a series of axially separated radially offset lands which oppose corresponding of a blade free end in use, the radial offset being provided by a radial step; a circumferentially extending radial projection which projects from the gas path facing surface towards the main gas path.

Providing a radial projection in this way helps to reduce the over tip leakage. This is counterintuitive in a turbine engine having a stepped seal segment as the line of sight over the tip of the blade is generally obscured. The invention provides the advantage that a relatively small radial projection used in combination with a stepped profile is sufficient enough to trip the over tip leakage flow thereby significantly reducing it.

The radial projection may be a flange or lip. The projection may be an elongate member which extends circumferentially around the engine. The seal segment may be one of an annular set which encircles and bounds the main gas path. Each seal segment in the annular set may include a corresponding radial projection. The radial projections of adjacent seal segments may be provided at a common axial position at the interface of the seal segments to provide a segmented but substantially continuous radial projection. The radial projection may be placed local to the radial step.

The radial step may include a surface having a radial component. The radial step may include a surface lying in the normal plane of the principal axis of rotation of the gas turbine engine. The radial projection may be provided by a continuation of the radial step.

The lands may include an abradable portion.

The lands may be radially offset by between 1 and 6 mm. Preferably, the radial offset of the lands is between 1 and 2.5mm.

The radial projection extends from the surface of the land by between 0.25 mm and 1.5 mm. Preferably, the radial projection extends radially from the main gas path facing surface of the seal segment surface by between 0.4mm and 0.6mm.

Relative to the main gas path flow, the radial projection may include an upstream side and a downstream side. The upstream side may be chamfered or filleted. The chamfer or fillet may provide the radial projection with a thicker section towards the main gas path facing surface of the seal segment. The fillet may be concavely curved. The fillet may be have a constant radius of curvature.

The fillet may be concavely curved with a constant radius of curvature. The radius of curvature of the fillet may be greater than the radial extent of the projection. The radius of curvature may be in the range of between 0.35mm and 1.5mm. Preferably, the radius of curvature is between 0.8 and 1.2mm.

The downstream side of the radial projection may be a continuation of the radial step surface.

In another aspect, the invention provide a gas turbine engine comprising: a bladed rotor having a plurality of blades, each blade having a free end; a seal segment which bounds the main gas path in a gas turbine engine, the seal segment radially opposing the free ends of the blades and comprising: a gas path facing surface having an axially separated series of radially offset lands which oppose corresponding portions of the free ends of the blade, the radial offset being provided by a radial step; a circumferentially extending radial projection which projects from the gas path facing surface towards the main gas path.

Each blade of the bladed rotor may be a shrouded blade having a plurality of radially offset tip fins each of which radially oppose a corresponding land.

in yet another aspect, the present invention provides a method of manufacturing seal segment, comprising: providing an oversized seal segment blank having one or more steps, machining out a central portion of the one or more steps to provide a land with a main gas path facing surface and a circumferential radial projection extending from the main gas path facing surface.

The step of machining may be achieved by abrasively removing material. The abrasive removal may be carried out using an abrasive wheel. The abrasive wheel may have a surface profile which corresponds to the land and having a portion which is either chamfered or rounded. The method step of machining out a central portion of the one or more of the steps may include either or both plunging and traversing the abrasive wheel across the central portion to provide the land and radial projection.

The chamfered or rounded profile portion may be provided by a corner of the abrasive wheel. The corner may be provided where an outer radially facing surface meets a side face of the abrasive wheel.

Description of Drawings

Embodiments of the invention will now be described with the aid of the following drawings of which:

Figure 1 shows a conventional gas turbine engine.

Figure 2 shows a seal segment in section and incorporating the invention.

Figure 3 shows the seal segment of Figure 2 in more detail.

Figure 4 shows the some dimensional considerations for the seal segment shown in Figures 2 and 3.

Figure 5 shows an abrasive machining step for manufacturing the seal segment of Figures 2 to 4.

Detailed Description of Invention

Figure 2 shows a schematic section of a high pressure turbine section 210 of a gas turbine engine. The high pressure turbine section 210 includes a nozzle guide vane, NGV, 212 upstream of a bladed rotor 214 which rotates about the principal axis 33 of the engine. The nozzle guide vane 212 and an aerofoil portion 216 of the blade 215 are located within the main gas path 218. The nozzle guide vanes turn the upstream flow to present it to the bladed rotor 214 at the optimum angle such that the maximum amount of energy can be extracted by the blades 214. It will be appreciated that the nozzle guide vane 212 and blade 215 shown in Figure 2 are each one of a corresponding annular set which are distributed circumferentially around the engine core.

The main gas path 218 is contained within respective radially inner and outer annular walls. In the case of the NGV 212, these bounding walls are provided by radially inner 220 and outer 222 platforms. The blade 215 shown is a shrouded blade meaning the free end of each blade includes an integral shroud 224 or platform which is part of and rotatable with the blade in use. The shroud 224 of each blade 214 is placed in close proximity to the corresponding edge of an adjacent blade shroud so as to provide a substantially continuous yet segmented annular wall around the main gas path 218. On the outboard side of the shroud 224 is located a seal segment 226 which is in turn attached to the engine casing 228 via a secondary structure known as a carrier 230. The shrouds 224 are closely spaced to the seal segment 226 in use such that there is sufficient minimal clearance to allow the relative rotation of the bladed rotor 214. Thus, although there is an inevitable leakage path outboard of the shrouds 224, the preferred gas path is radially inboard of the shroud 224 so as to allow the hot gas to interact with and rotate the blades 215 of the rotor.

The spacing of the seal segment 226 and blade shroud 224 is difficult to control in use due to the manufacturing tolerances and the relative movement of associated parts caused by, for example, differential thermal expansion, transient off-centre running, vibration and centrifugal forces. To allow for and help minimise the variance in separation, and thus the incipient leakage flow path outboard of the blades 215, each shroud 224 includes a plurality of shroud tip fins 232 which are placed proximate to lands 236 of the seal segment surfaces. Thus, in the event of contact, the fin tips 232 cut into the corresponding land 234 and an abradable portion therein so as to allowing a controlled contact with minimal damage to the seal segment 226 and blade 215. The shroud tip fins 232 are in the form of radially projecting flanges which align with corresponding fins on adjacent blades to form a segmented annular flange around the shrouds.

The seal segment 226 shown in section in Figure 2 is one of an annular set which extend circumferentially around the engine. The seal segment 226 includes an inboard side which defines the main gas path radially outside of the shroud 224, and an outboard side which is attached to the carrier 230 via conventional bird mouth attachments.

Referring to Figures 2, 3 and 4, the inboard side of the seal segment is stepped along its axial length to provide discrete portions or lands 236, 238 which oppose the tip fins 232 of the shrouded tip 224 of the blade 216. Thus, in the described embodiment, the first land 236 extends axially from an upstream end at a constant radius from the principal axis of rotation of the engine until a first step portion 240 is reached. The step 240 is defined by the surface of the land 236 and a second surface 242 which extends radially and, in the described embodiment, normal to the rotational axis of the engine. The second, radially extending, surface terminates at the upstream end of the second land 238 which extends axially in a similar way to the first land 236 but at a different and, in this case, larger radius to the first. The second land 238 terminates in a second step 244 provided by a third radially extending surface. The second step meets a third axially extending portion or land which is at a yet further different and constant radius with respect to the principal rotational axis of the engine. The third land 245 extends to the trailing edge of the seal segment which provides a third and final radial surface for the seal segment which extends downstream of the blade. The axial extent of the first and second lands which oppose the tip fins are of equal length.

Thus, there is provided an axial series of radially offset lands against which portions of the blade may rub in use. The radial offset is provided by a radial step 240. Each land includes an abradable portion which preferentially wears upon contact with the tip fin seal to allow controlled contact between the blade tips and seal segment in use.

Further to the description of the steps above, each of the stepped portions includes a circumferentially extending radial projection 246 as best seen in Figure 4. Each radial projection 246 extends towards the blade shroud 224 and main gas path from a surface between the axial series of abradable lands.

Each radial projection is in the form of a shallow lip which includes an upstream side and a downstream side. In the described embodiment, the downstream side is a continuation of the radially extending face of the respective step. The upstream side includes a fillet 243 in the form of a concavely curved internal corner which provides a ski-jump like profile to the radially extending lip. The size of the radial projection will be determined by the specific requirements of the engine. In use, the radial lip projects into the leakage flow path so that it can obstruct the flow to a sufficient extent to allow it to be tripped. The tripping disrupts the leakage flow passing over the blade shroud and acts to reduce the flow. Further, the lip helps prevents direct line of sight over the blades in different running conditions.

The step 242 and radially projecting lip 240 can be characterised using the width of the projecting lip, W_L, the height of the projecting lip relative to the upstream land, D_L, and the radius R_L of the filleted corner. An additional consideration is the size of the lip D_L in relation to the radial component of the step D_S.

In the described embodiment, D_L is in the range of between 0.3mm and 1.5mm and, in one embodiment, is preferably 0.7mm.

The fillet 243 may be provided by any curvature or straight lined edge but will preferably be a continuous curvature having a radius determined in relation to D_L. The radius R_L will generally be greater than the radial height of the lip so as to provide a ramped fillet 243 in which the terminating angle which defines the radially inward face of the lip is substantially greater than 90 degrees. Thus, the axial extent of the fillet 243 is greater than the radial height so that the base portion of the lip is disproportionately larger and has a greater volume. The radial face extends into a surface having a radial and an axial component, the axial component being greater than the radial component.

Providing a ramped fillet 243 in this way allows the projection to be thicker towards the gas facing surface of the seal segment and so more resilient to oxidisation and transitory axial movements of the shroud fin tip.

The seal segment may be made using any suitable method. One method includes providing an oversized seal segment blank having oversized steps already provided therein. The blank may be produced using any suitable known technique, such as casting. A central portion a step is machined out to provide a land having the necessary constant radius of curvature in the circumferential direction to correspond to the travel path of the blades and the radial projection.

Figure 5 shows an abrasive machining operation in which a grinding wheel 250 is plunged into a face of the blank and traversed across the central portion to provide the land surface. The grinding wheel has a surface profile which corresponds to the finished surface of the land. The radius of the corner of the grinding wheel between the radially outer and end surfaces correspond to the resultant fillet 243 radius of the radial projection. Thus, the formation of the fillet 243 can be achieved in a single machining operation by plunging into the land portion at the appropriate place to the correct depth, or traversing across the land at the correct depth. It will be appreciated that the curvature which provides the radius may be provided by a suitable formation in the radially outer surface of the grinding wheel rather than by a corner portion.

The oversizing of the seal segment blank corresponds to the final lip depth D_L such that removing the required amount from central portion provides a lip of required depth. However, it will be appreciated that the radially inner surface of the lip may be also be machined to provide a required tolerance for D_L.

Other ways to produce the radial projection may include, for example, additive layer manufacturing techniques such as power bed processing or laser sintering. This is particularly advantageous where the seal segment is made using an additive layer technique. Alternatively, the projecting lip may be machined out of an oversized seal segment using machining techniques other than grinding.

It will be appreciated that the invention may be applied to other parts of the engine, including the intermediate or low pressure turbines, or compressor, where appropriate. Although the radial projections are shown as being at the most downstream portion of its associated land, this may not be the case. In some embodiments, the radially extending projection extends from a portion upstream of the step and is thus located along the length of a land. The ranges provided above for the steps and lands are typical for a civil large engine and are affected by the clearances needed to build the engines amongst other factors.

Claims:

1. A seal segment (226) for bounding the main gas path (218) in a gas turbine engine (10) and opposes the free end a blade (215), comprising:

a gas path facing surface having a series of axially separated radially offset lands (236, 238) which oppose corresponding of a blade free end in use, the radial offset being provided by a radial step (240);

a circumferentially extending radial projection (246) which projects from the gas path facing surface towards the main gas path.

2. A seal segment as claimed in claim 1, wherein the lands are radially offset by between 1 and 6 mm.

3. A seal segment as claimed in claims 1 or 2, wherein the radial projection extends from the surface of the land by between 0.25 mm and 1.5 mm.

4. A seal segment as claimed in any preceding claim, wherein relative to the main gas path flow, the radial projection includes an upstream side and a downstream side and the upstream side is chamfered or filleted.

5. A seal segment as claimed in claim 4, wherein the fillet is concavely curved with a constant radius of curvature.

6. A seal segment as claimed in claim 5, wherein the radius of curvature of the fillet is greater than the radial extent of the projection.

7. A seal segment as claimed in claim 6, wherein the radius of curvature is in the range of between 0.35mm and 1.5mm.

8. A seal segment as claimed in any preceding claim, wherein the downstream side of the radial projection is a continuation of the radial step surface.

9. A gas turbine engine comprising:

a bladed rotor (214) having a plurality of blades (215), each blade having a free end;

a seal segment (226) which bounds the main gas path in a gas turbine engine, the seal segment (226) radially opposing the free ends of the blades and comprising:

a gas path facing surface having an axially separated series of radially offset lands (236, 238) which oppose corresponding portions of the free ends of the blade (215), the radial offset being provided by a radial step (240);

a circumferentially extending radial projection (246) which projects from the gas path facing surface towards the main gas path.

10. A seal segment according to claim 9, wherein each blade of the bladed rotor is a shrouded blade having a plurality of radially offset tip fins (232) each of which radially oppose a corresponding land.

11. A method of manufacturing seal segment, comprising:

providing an oversized seal segment blank having one or more steps.

machining out a central portion of the one or more steps to provide a land with a main gas path facing surface and a circumferential radial projection extending from the main gas path facing surface.

12. A method as claimed in claim 11, wherein the step of machining is achieved by abrasively removing material.

13. A method as claimed in claim 12, wherein the abrasive removal is carried out using an abrasive wheel (250), the abrasive wheel having a surface profile which corresponds to the land and having a portion which is either chamfered or rounded, the method step of machining out a central portion of the one or more of the steps includes either or both plunging and traversing the abrasive wheel across the central portion to provide the land and radial projection.

14. A method as claimed in claim 13, wherein the chamfered or rounded profile portion is provided by a corner of the abrasive wheel.

Intellectual Property Office

Application No:	GB1416913.0	**Examiner:**	Adrian French
Claims searched:	1-14	**Date of search:**	9 March 2015

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
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X	1-14	US6331006 B1 BAILY, See whole document
X	1-14	US5632598 A MAIER, See whole document
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X	1-14	US2013/251534 A1 MATSUMOTO, See whole document
X	1-3, 8-14	US2012/076634 A1 VALLIAPPAN, See whole document
X	1-3, 8-14	US2012/288360 A1 KUWAMURA, See whole document

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X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

F01D

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI, TXTE

International Classification:

Subclass	Subgroup	Valid From
F01D	0011/08	01/01/2006
F01D	0005/20	01/01/2006