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(54) **Fan blade**

(57) A fan blade for the fan of a gas turbine engine has a radially outer tip portion which, in use, is adjacent to a fan case of the engine. The tip portion includes a movable sealing element for sealing a gap between the tip portion and the fan case. The sealing element movably adapts to changes in the spacing of the gap to maintain a seal between the tip portion and the fan case.

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Description

[0001] The present invention relates to a fan blade for the fan of a gas turbine engine.

[0002] The fan of a gas turbine engine comprises a cascade of circumferentially spaced fan blades mounted at their radially inward ends on a disc and extending radially outwardly towards a fan case. To minimise aerodynamic losses and maintain the performance and stability of the fan blades, it is important to reduce leakage of air between the tips of the fan blades and the case. To this end, it is usual to have a close clearance between the tips and the case.

[0003] A conventional method of achieving a close clearance is to use fan track liners. These are positioned outboard of the fan blades on the fan case, and typically comprise an abradable liner supported by an aluminium honeycomb structure. The abradable liner consists of Nomex™ (available from DuPont) honeycomb filled with lightweight epoxy filler. The liner forms an aerodynamic seal between the fan blades and the case.

[0004] In general, abradable liners seal the tip well at maximum engine speed, but less so at cruise when centrifugal forces on the blade are lower, and clearance between the tip and the fan case increases. This causes an efficiency drop at cruise. Under certain operating conditions (e.g. manoeuvre loading or abnormal engine conditions such as red line/over speed) it is acceptable for fan blades to make rubbing contact with the abradable liner. However, for every rub event, the efficiency drop at cruise increases.

[0005] Further, such contacts carry the risk of damaging the blade, and reducing its longevity. This risk can be higher with a blade formed of composite material, which may be susceptible to delamination or matrix damage under frictional loading. Ultimately, damage from excessive rubbing contacts accumulating over time may cause premature blade failure, particularly in blades formed of composite material.

[0006] Thus, in a first aspect, the present invention provides a fan blade for the fan of a gas turbine engine, the blade having a radially outer tip portion which, in use, is adjacent to a fan case of the engine, the tip portion including a movable sealing element for sealing a gap between the tip portion and the fan case, wherein the sealing element movably adapts to changes in the spacing of the gap to maintain a seal between the tip portion and the fan case.

[0007] In this way, sealing functionality is transferred from the fan case to the fan blade, and the use of an abradable liner on the fan case can be avoided. This reduces engine weight, as well as helping to avoid rubbing contact damage to the fan blade.

[0008] The fan blade can have one sealing element, typically running the length of the radially outer edge of the blade. Alternatively, the blade can have a plurality of sealing elements, for example in an overlapping arrangement, and again typically running along the radially outer edge of the blade.

[0009] The sealing element can be formed integrally with the blade. However, preferably, the sealing element is removably attached to the blade. For example, the blade can have a keyway slot or slots for slidingly receiving the sealing element(s). A removably attached sealing element can, advantageously, be easily replaced if it becomes damaged.

[0010] The sealing element may be formed of flexible material which flexes to adapt to changes in the spacing of the gap. For example, the element can be formed as a strip e.g. of flexible plastic or rubber. Or the element can be formed as brush, with the fibres of the brush, in use, extending across the gap. The fibres of a brush sealing element may be formed of carbon fibre.

[0011] Preferably, the sealing element responds to centrifugal loading by extending across the gap. For example, the element may have a curved or bent cross-section that straightens out under centrifugal loading to extend across the gap.

[0012] The fan blade may be configured to promote air film lubrication of the interface between the sealing element and the fan case. This can reduce the wear on the sealing element and, to a lesser extent, on the fan case.

[0013] A further aspect of the present invention provides a gas turbine engine having a fan comprising circumferentially spaced fan blades according to the previous aspect.

[0014] The fan case may have an acoustic liner at the interface between the sealing element and the fan case. This can reduce engine noise, and is possible because an abradable liner at this position is not needed.

[0015] The fan case may have debris removal channels at the interface between the sealing element and the fan case.

[0016] Embodiments of the invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1(a) and (b) show schematically a sealing element in the tip of, respectively, a composite and a metal fan blade;

Figure 2(a) and (b) show schematically the operation of a sealing element such as those shown in Figure 1;

Figures 3(a) and (b) show schematic end-on views of further sealing elements;

Figures 4(a) and (b) show schematic end-on views of a further sealing element;

Figure 5 shows a schematic end-on view of a further sealing element;

Figure 6 shows schematically (a) a transverse cross-section and (b) a plan view of a fan case; and

Figures 7(a), (b) and (c) show schematic end-on views of three fan blades.

[0017] Figures 1(a) and (b) show schematically the tips of a composite fan blade 1 and a metal fan blade 201.

[0018] The composite material 103 of the composite fan blade 1 is surrounded, at least in the region of the fan blade tip, by a metal protective sheath 105 extending around both the pressure and suction sides of the blade 1.

[0019] Near to the tip of each fan blade 1, 201 is provided a T-shaped slot 107, 207. Into the slot 107, 207 is fitted a strip sealing element 3 formed of a flexible material, such as plastic, rubber (e.g. silicone rubber) or coated metal foil. The sealing element 3 can be removed and replaced when worn or damaged.

[0020] The slot 107, 207 can be formed directly in the body of a composite or a metallic blade; or it can be formed by a separate part, e.g. facing side plates or the sheath 105, attached to the tip of such a blade.

[0021] Figure 2(a) and (b) show schematically the operation of the sealing element 3. In Figure 2(a), the engine is stationary. Sealing element 3 has a curved cross-section profile, and there is a relatively large cold build clearance 5 between the radially outer edge of the sealing member 3 and the fan case 4. In Figure 2(b), the blade is now rotating in the direction indicated by the curved arrow. A centrifugal force (CF) straightens out the profile of the sealing element so that it extends to achieve a close clearance 6 with the fan case.

[0022] The sealing element can be configured so that, under the pressure differential produced during operation, an air film is generated which lubricates the space between the sealing element and the case. In this way, excessive wear of the element can be avoided.

[0023] Instead of being attached via keyway 2, the sealing element can be adhesively bonded, or mechanically fastened in other ways to the tip of the blade. Preferably, the element is attached in such a way as to allow extraction and replacement during overhaul. However, particularly with a composite blade, the sealing element can be integrated with the blade, for example by moulding or co-moulding.

[0024] Other configurations of the flexible sealing element are possible. For example, instead of an element formed as a strip running along the radially outer edge of the blade, a brush sealing element could be adopted, in which a plurality of fibres extend from the blade tip towards the casing. These can be bonded in place or mechanically attached via side plates. For example, the fibres can be embedded at their radially inner ends in a retaining head, which itself can be held in a keyway at the radially outer edge of the blade. When the blade is formed from fibre-reinforced composite material, the fibres of the composite can themselves extend out of the matrix of composite at the blade tip to form the brush sealing element.

[0025] A brush sealing element may be constructed from pure carbon fibres. Break up of the carbon then produces lubrication on the fan case.

[0026] The strip sealing element of Figure 2 has a curved C-shaped profile. The fibres of a brush sealing element can be similarly curved so that on centrifugal loading, they straighten out to achieve a close clearance with the fan case.

[0027] Other shapes are possible, however. For example, the flexible sealing element may have one or more kinks serving as hinges about which the portion of the flexible sealing element radially outward of the kink rotates under centrifugal loading to straighten the element. Figure 3(a) shows a schematic end-on view of a sealing element with one such kink, and Figure 3(b) shows a schematic end-on view of a sealing element with two kinks.

[0028] Further embodiments of the sealing element do not rely on the intrinsic flexibility of a strip or brush, to achieve some or all of the movability to adapt to changes in the spacing between the fan blade and the casing.

[0029] For example, Figure 4(a) shows a schematic end-on view of a sealing element in which a flexible portion 7 of the element (e.g. a strip or brush) is fixed to the blade at a mechanical pivot 8, such as a pin or shaft. The engine is stationary and there is a large clearance between the sealing element and the fan case 4. However, as shown in Figure 4(b), when the engine rotates, the flexible portion 7 rotates about the pivot 8 by centrifugal force, and makes air-lubricated contact with the fan case.

[0030] Figure 5 shows a schematic end-on view of another sealing element, in which a spring 9 supports a tip portion 10. The spring is biased towards the blade so that when the engine is stationary there is a large clearance between the tip portion and the fan case 4. However, when the engine rotates, centrifugal force extends the spring and the tip portion makes air-lubricated contact with the fan case. The spring can be formed of e.g. carbon, glass or metal, and be bonded or mechanically fixed to the tip of the blade. The tip portion can be formed of e.g. metal, plastic, composite or ceramic, although a carbon tip is preferred. The spring 9 may be a variable-rate spring, to provide better control over the extension of the spring 9 at different engine speeds. In this way, the casing clearance can be kept close to its optimum value under a wider range of operating conditions. The tip portion 10 can be removed for in-service replacement.

[0031] The sealing element of any of the above embodiments may have a portion formed of relatively low friction material at its radially outer edge. For example, the low friction material portion can be of carbon, PTFE or PEEK. It may be applied as a coating to the sealing element. The material may be reapplied at intervals to regain efficiency losses.

[0032] Figure 6 shows schematically (a) a transverse cross-section and (b) a plan view of the fan case 4. In order to avoid blocking or damage, the fan case can have grooves 11 to allow any debris from the sealing element to be pushed away from the fan tip.

[0033] Figures 7(a), (b) and (c) show schematic end-on views of three fan blades. In Figure 7(a), the blade has a plurality of sealing elements distributed in an overlapping pattern along the radially outer edge of the blade to provide an efficient seal. In Figure 7(b), the blade has a single sealing element which follows the curved profile of the radially outer edge of the blade. In Figure 7(c), the blade again has a single sealing element which follows the curved profile of the radially outer edge of the blade, but in this case the element is contoured or shaped in the direction along the edge of the blade to increase its stiffness.

[0034] As well as the improvement in engine performance that can be achieved with the sealing element, for composite blades there is also a reduced risk of blade delamination due to tip rubs. Further, the sealing element can accommodate casing distortions. Additionally, eliminating the abradable liner from the fan case can reduce engine weight (providing further performance improvements) and allows an acoustic fan track liner to be provided with the potential to significantly reduce engine noise.

[0035] Because the sealing element has a relatively large clearance to the casing when the engine is stationary, the procedure for mounting fan blades onto the engine is facilitated. Further, once mounted, the ability of the sealing element to tolerate variation in blade length can reduce the amount of blade adjustment/shimming that has to be performed. Also, abradable liners need to be machined on engine when installed to provide the required fit, but with the sealing element this requirement is removed.

[0036] While the invention has been described in conjunction with the exemplary embodiments described above, many equivalent modifications and variations will be apparent to those skilled in the art when given this disclosure. Accordingly, the exemplary embodiments of the invention set forth above are considered to be illustrative and not limiting. Various changes to the described embodiments may be made without departing from the spirit and scope of the invention.

Claims

1. A fan blade (1, 201) for the fan of a gas turbine engine, the blade having a radially outer tip portion which, in use, is adjacent to a fan case of the engine, the tip portion including a movable sealing element (3, 7, 10) for sealing a gap between the tip portion and the fan case (4), wherein the sealing element movably adapts to changes in the spacing of the gap to maintain a seal between the tip portion and the fan case.

2. A fan blade according to claim 1, wherein the sealing element is formed integrally with the blade.

3. A fan blade according to claim 1, wherein the sealing element is removably attached to the blade.

4. A fan blade according to any one of the previous claims, wherein the sealing element is formed of flexible material which flexes to adapt to changes in the spacing of the gap.

5. A fan blade according to any one of the previous claims, wherein the sealing element responds to centrifugal loading by extending across the gap.

6. A fan blade according to any one of the previous claims, which is configured to promote air film lubrication of the interface between the sealing element and the fan case.

7. A gas turbine engine having a fan comprising circumferentially spaced fan blades according to any one of the previous claims.

8. A gas turbine according to claim 7, wherein the fan case has an acoustic liner at the interface between the sealing element and the fan case.

9. A gas turbine according to claim 7 or 8, wherein the fan case has debris removal channels (11) at the interface between the sealing element and the fan case.

Fig.1(a)

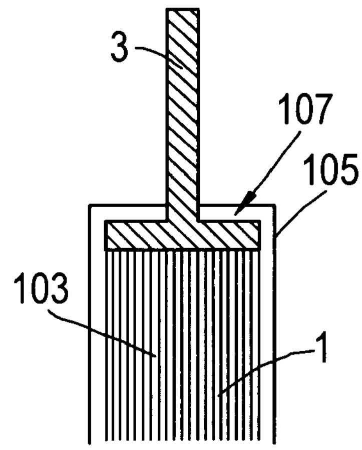

Fig.1(b)

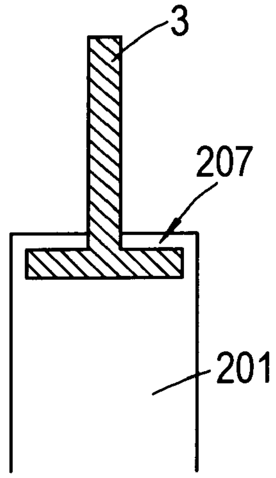

Fig.2(a)

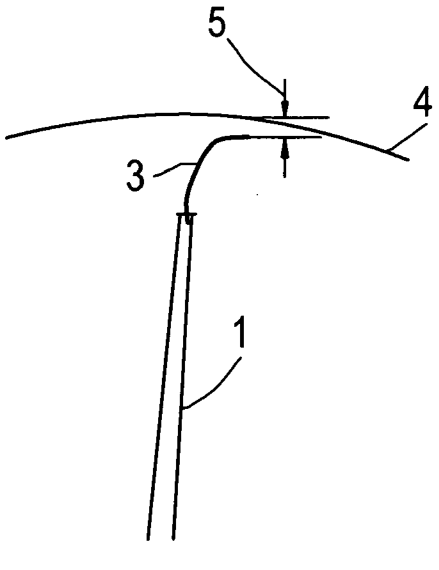

Fig.2(b)

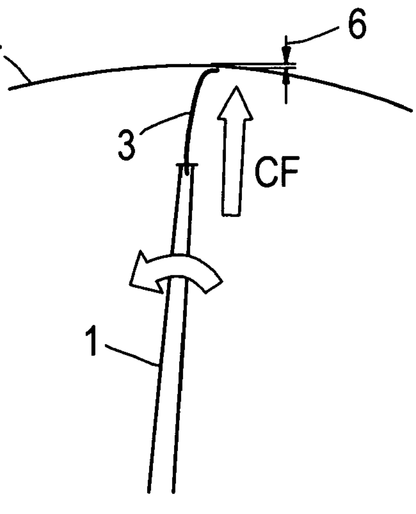

Fig.3(a)

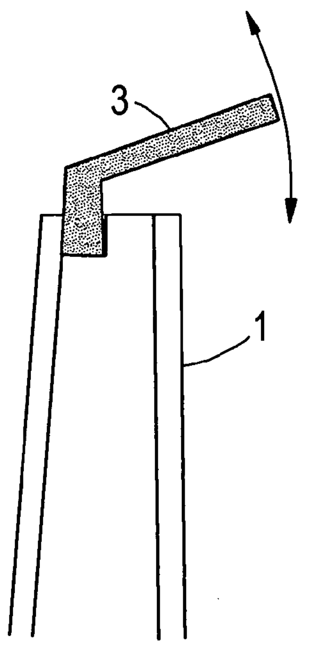

Fig.3(b)

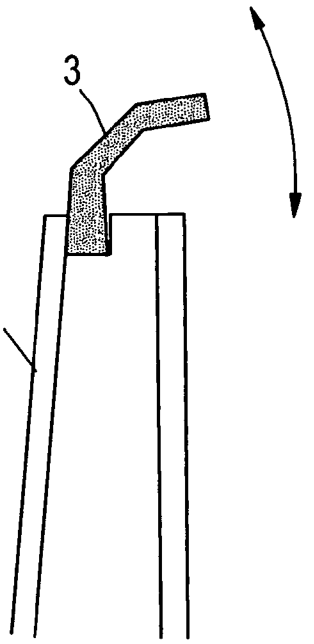

Fig.4(a)

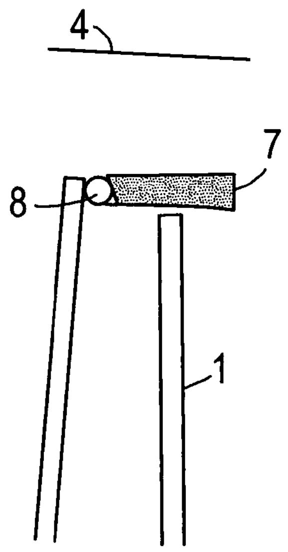

Fig.4(b)

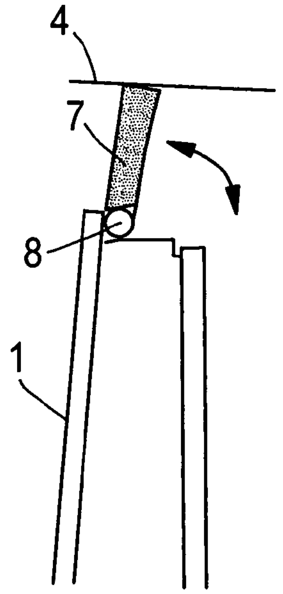

Fig.5

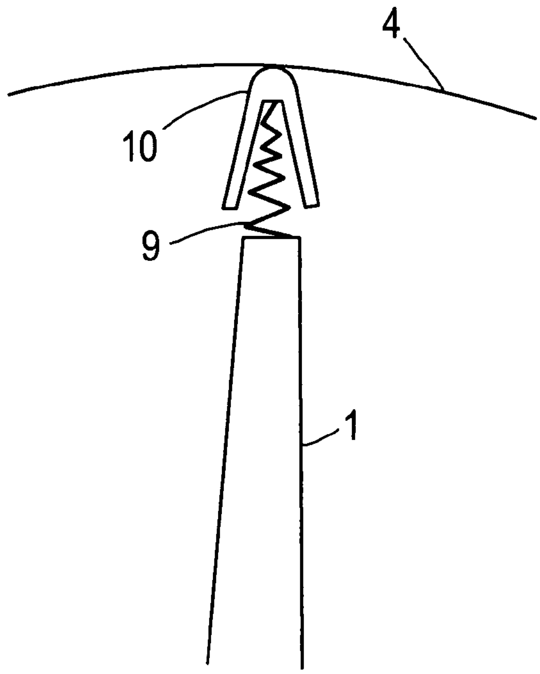

Fig.6(a)

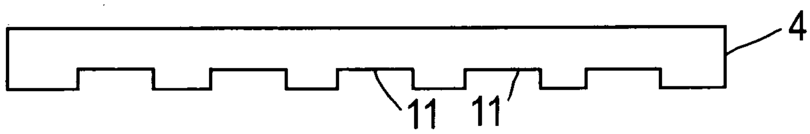

Fig.6(b)

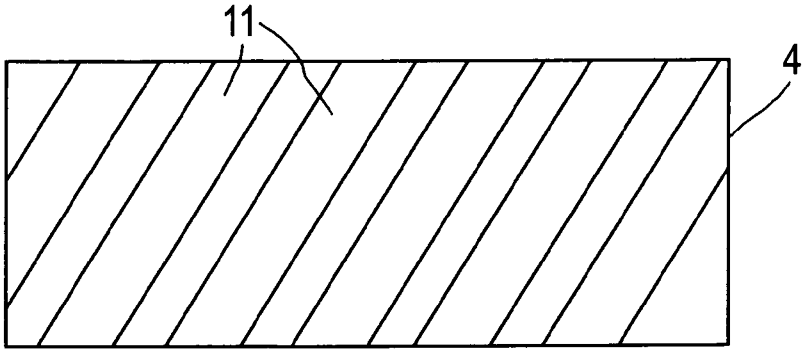

Fig.7(a)

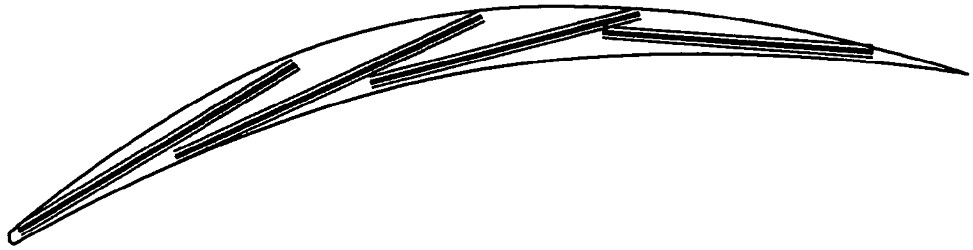

Fig.7(b)

Fig.7(c)