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(54) Turbine rotor assembly with seal plates

(57) Seal plates 230 on the rear side of a cooled turbine rotor assembly have side edges extending transversely of the radial and tangential directions, each seal plate 230 sealingly engaging the rotor disc 202 and one of the rotor blade platforms 101, and also extending across (and preferably engaging) the root portions 102 of one, or preferably two, other blades 10. In order to restrain the seal plates 230 against bending due to axial cooling air pressure loadings and against Euler buckling due to centrifugal loadings, the seal plates are adapted to engage at their abutting edges 400 with studs 108,110 provided on the blade roots 102. Air pressure forces the seal plates 230 into sealing contact with sealing surfaces 231,233 provided on the studs 108,110 and the angled disposition of the seal plates enables them to adjust themselves in unison and to remain sealed to each other along their abutting edges 400, and to the blades 10 and disc 202, even against the influences of differential temperature expansion and variable centrifugal effects, by means of limited rocking of their radially outer ends (700, Fig. 7) against the blade platforms 101 coupled with limited sliding of the seal plates against each other. The arrangement also gives good vibrational damping to the assembly.

The seal plates may be provided with strengthening ribs (501, 502, Fig. 6).

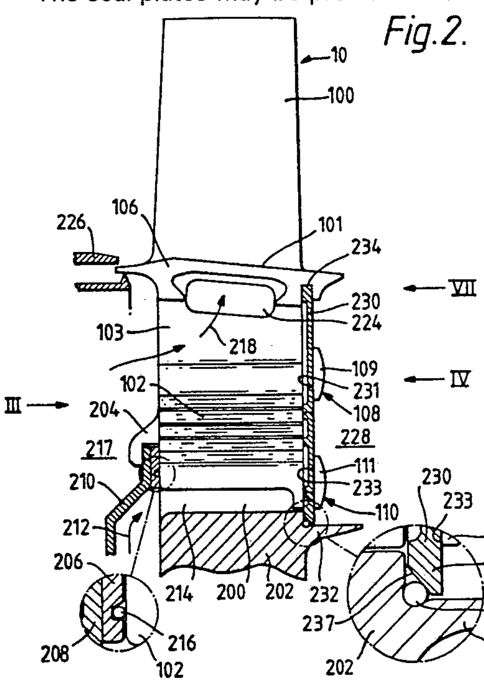
Fig.2.

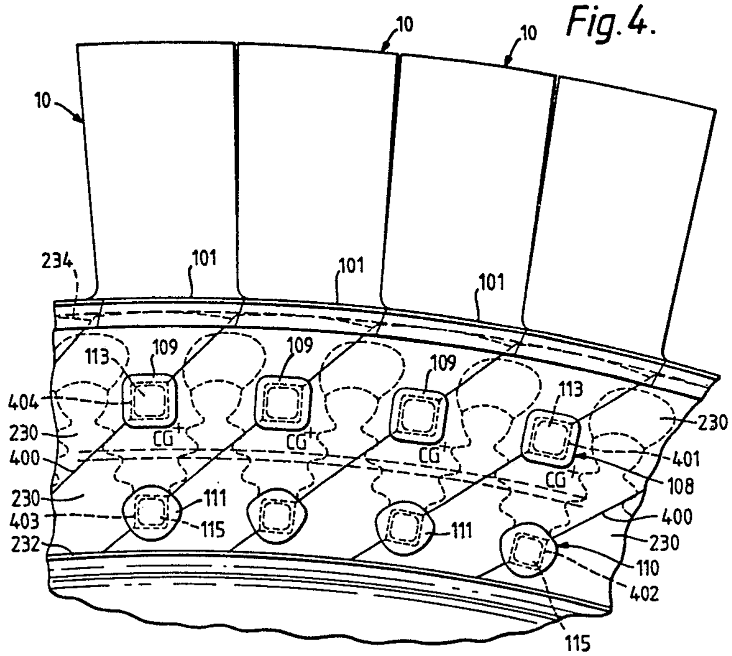
Fig.4.

The drawing(s) originally filed was/were informal and the print here reproduced is taken from a later filed formal copy.

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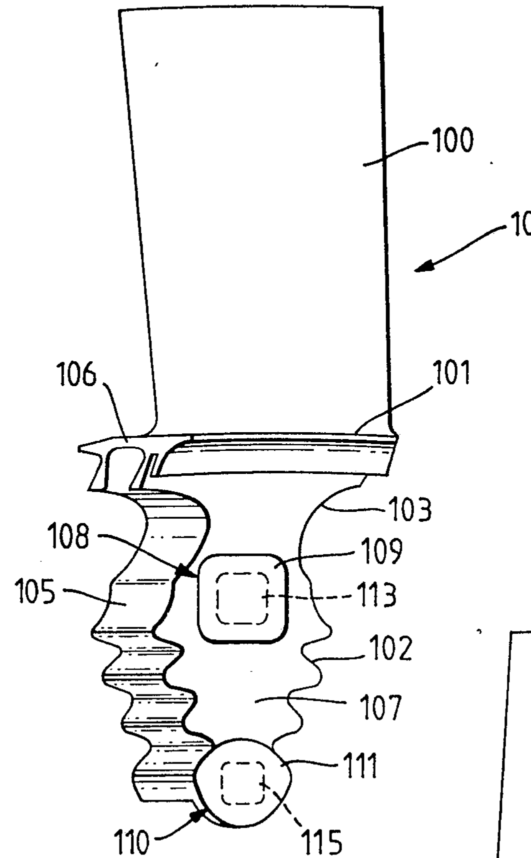

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Fig.1.

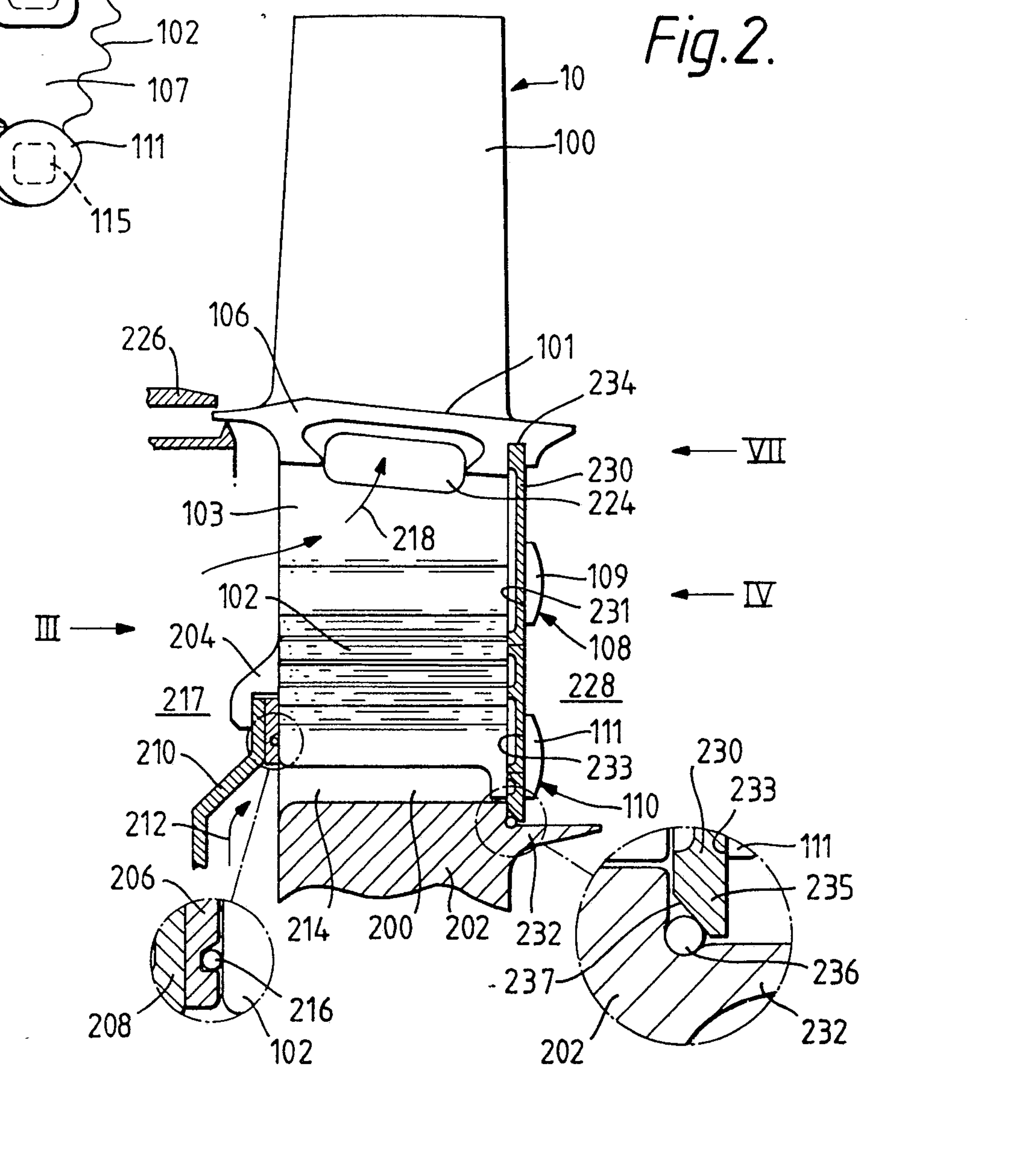

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Fig.2.

Fig.3.

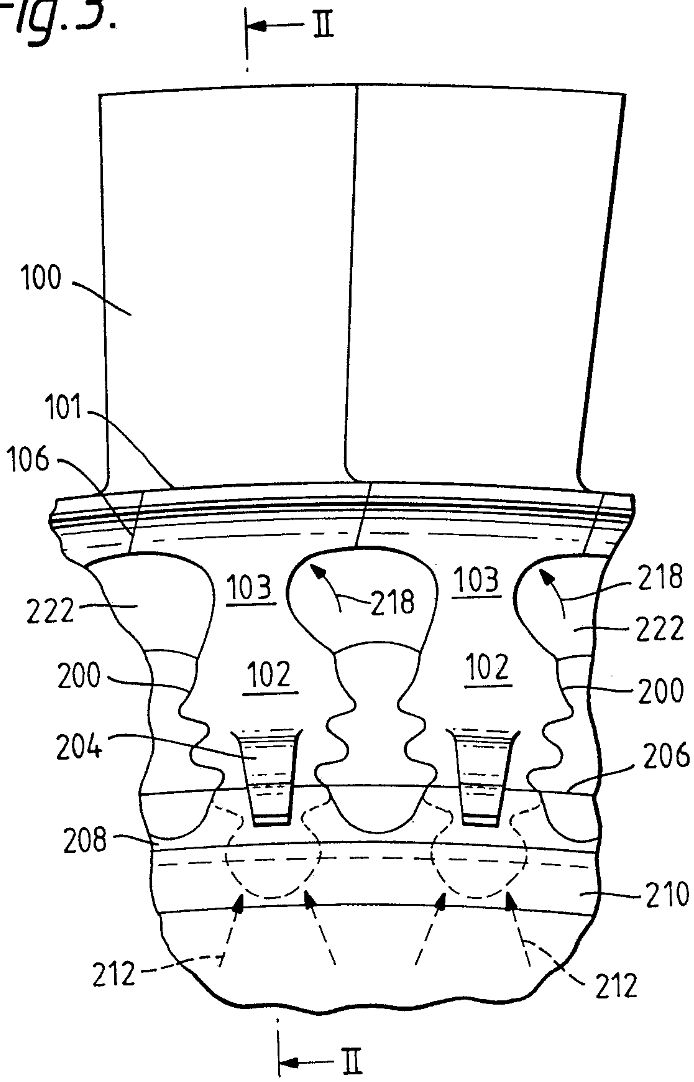


Fig.8.

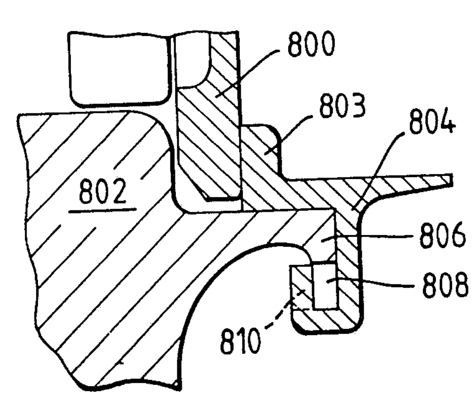


Fig.7.

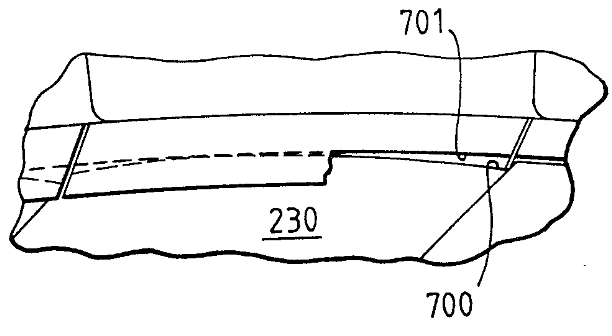


Fig. 4.

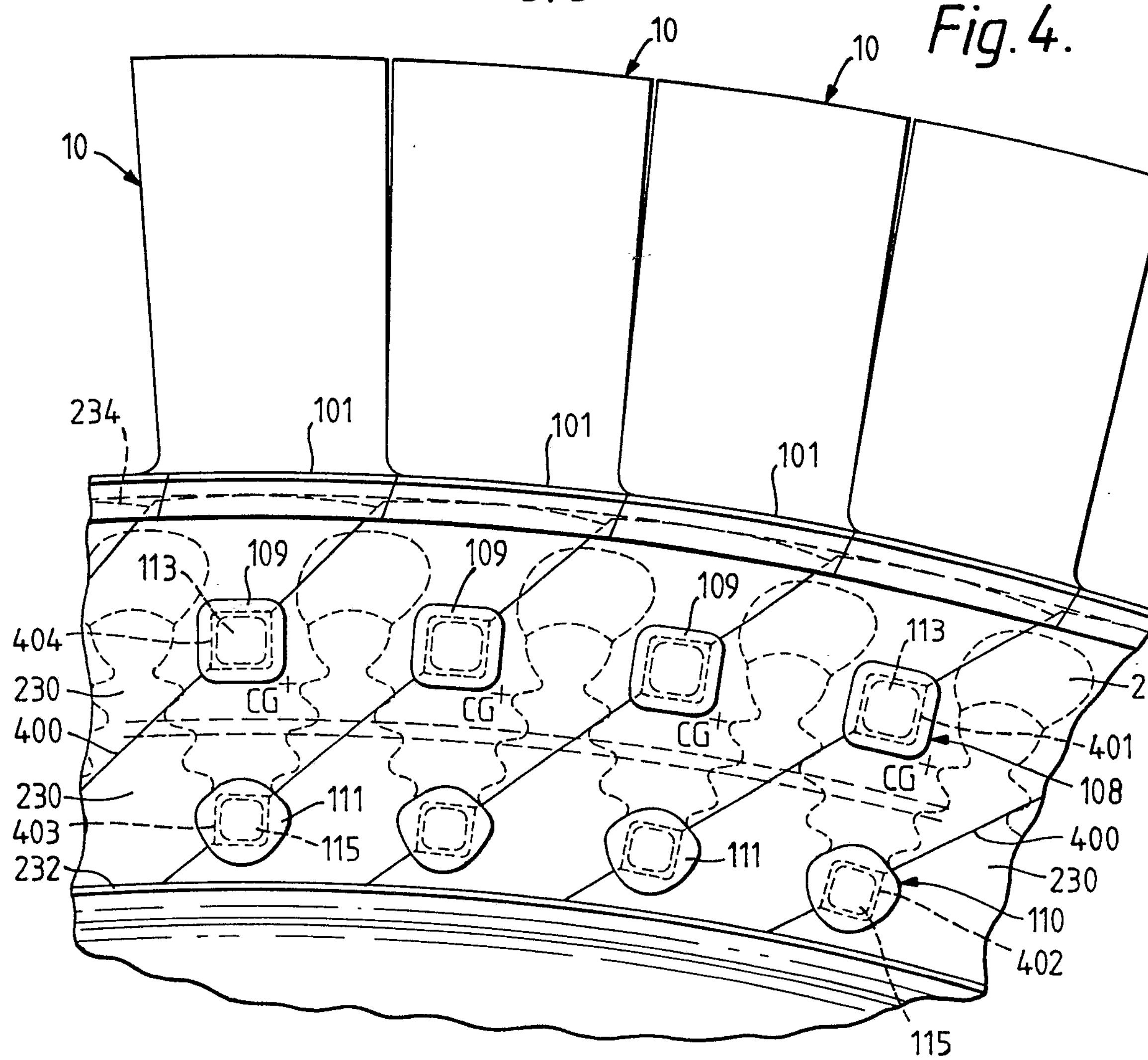


Fig. 5.

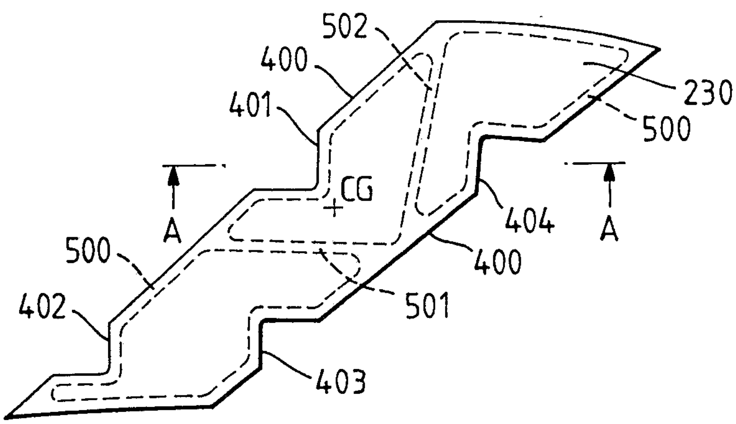
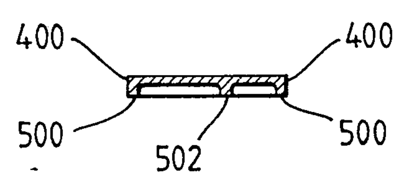


Fig. 6.



SPECIFICATION

Turbine rotor assembly

This invention relates to turbine rotor assemblies, and in particular to a cooled turbine rotor assembly provided with novel means for sealing the assembly against escape of cooling air.

Cooled gas turbine rotor assemblies are known in which a turbine rotor disc is provided with a plurality of air-cooled turbine rotor blades comprising aerofoil, platform and root portions, the rotor blades being fixed in the rotor disc by their root portions and having cooling air entry means positioned radially inwardly of their platform portions, the cooling air supply being pressurised. In order to seal such rotor assemblies against escape of the pressurised cooling air under the platforms and past the blade roots, seal plates are provided whose radially inner ends sealingly engage the rotor disc, whose radially outer ends sealingly engage the undersides of the blade platforms, and whose side edges extend between the rotor disc and the platforms in sealing abutting relationship with each other so that the seal plates together form a complete seal plate annulus, a pressure differential thereby being maintained across the annulus.

Various problems can be encountered with such seal plates under operational conditions. For example, assembly clearances between the seal plates can allow unwanted leakage of cooling air therepast. Furthermore, the seal plates in a modern gas turbine engine turbine rotor assembly experience high centrifugal loadings. Vibration of the seal plates, either on their own account or due to vibration of the blades with which they are engaged, can also be a problem. The centrifugal loading tends to produce distortion of the individual seal plates, leading to even more inefficient sealing between adjacent plates in the annulus and between the plates and the blade platforms and the rotor disc, whereas the vibration can cause fretting of the components against each other. A further problem which can reduce sealing efficiency is the difficulty of accommodating differential thermal expansion between the rotor disc, the rotor blades and the seal plates. These different types of components may be made of differing materials and experience differing temperatures and different rates of expansion and contraction during operation of the turbine.

In the present invention, the above problems are alleviated by providing a turbine rotor assembly with specially shaped and disposed seal plates.

In accordance with the invention:

(i) each seal plate engages the platform of one blade but extends across the root portion of at least one other blade such that each side edge of the seal plates extends in a direction which is transverse of both the radial and tangential directions,

(ii) the position of the centre of gravity of each seal plate, relative to the engagement of that seal plate with a blade platform, is such that during rotation of the rotor assembly centrifugal action applies a moment to each seal plate tending to turn the seal plates about their engagements with the blade platforms,

(iii) the radially outer ends of the seal plates are adapted to facilitate limited rocking of the seal plates about their engagements with the blade platforms, and

(iv) means are provided for restraining the seal plates to the rotor assembly whilst allowing said limited rocking of the seal plates;

whereby under centrifugal action the seal plates can adjust their attitude slightly in unison with each other and with respect to the rotor disc and rotor blades by simultaneously rocking against the rotor blade platforms and sliding relative to each other along their side edges.

In the above assembly the seal plates are free to adjust themselves to the effects of varying centrifugal loadings and differential expansion by means of their rocking/sliding action, the action of the seal plates whilst centrifugally loaded also serving to close assembly clearances between individual seal plates and to provide vibration damping.

Further problems arise from the fact that many modern gas turbines are designed with root portions having a large radial extent due to the inclusion of a shank portion of the rotor blade between the perimeter of the turbine disc and the underside of the blade platform. This necessitates a seal plate annulus with larger radial dimensions, thus accentuating distortion of individual seal plates due not only to centrifugal loadings but also to axially directed pressure loadings due to the pressure differential across the seal plate annulus. According to another aspect of the invention, such problems are alleviated by arranging that the means for restraining the seal plates to the rotor assembly includes seal plate engagement means provided on the root portions of the rotor blades for restraining the seal plates to the root portions, whilst still allowing the limited rocking and sliding action of the seal plates also required by the invention. It should be noted that in such an assembly, each seal plate is engaged with a plurality of blades, and this serves to provide increased vibration damping.

The seal plate engagement means further comprises means adapted to engage the seal plates such that the pressure differential across the seal plate annulus serves to urge the seal plates into sealing contact with the seal plate engagement means.

A specific form of the seal plate engagement means comprises at least one stud means protruding from the root portion of each rotor blade, each stud means comprising a button-like portion joined to the root portion by a stalk-like portion, the side edges of the seal plates being shaped to accommodate the stalk-like portions and being a clearance fit between the button-like portions and the blade roots, the pressure differential across the seal plate annulus serving to urge the seal plates into sealing contact with the undersides of the button-like portions. Where the seal plates are of sufficiently great length to require the extra support, it is preferred that the root portions of the rotor blades are provided with radially inner and radially outer stud means, the seal plates being engaged therewith near their radially inner ends and near their mid-spans respectively. In such a case, each seal plate engages the platform of a first blade and the root portions of second and third blades; preferably, a radially outer portion of each seal plate engages the root portions of the first blade and the second blade and a radially inner portion thereof engages the root portions of the second blade and the third blade.

Other aspects of the invention will be apparent from a perusal of the following description and claims.

An embodiment of the invention will now be further described, by way of example only, with reference to the accompanying drawings, in which:–

Figure 1 is a rear view of a gas turbine blade suitable for use in the present invention;

Figure 2 is a part-sectional side elevation of a gas turbine rotor assembly in accordance with the present invention, the turbine blade being shown unsectioned;

Figure 3 is a view on arrow III of Fig. 2;

Figure 4 is a view on arrow IV of Fig. 3;

Figure 5 is an enlarged view of one of the seal plates forming part of the assembly shown in Figs. 2 to 4;

Figure 6 is a view on section line A–A in Fig. 5;

Figure 7 is an enlarged partly "broken-away" view on arrow VII of Fig. 2, and

Figure 8 is a similar view to one of the insets to Fig. 2, but showing an alternative embodiment of the invention.

Referring first to Fig. 1, a turbine blade 10 for use in an axial flow gas turbine rotor in a gas turbine engine comprises an aerofoil 100, a platform portion 101, and a "fir-tree" root portion 102, the root portion 102 including a waisted shank portion 103 which joins it to the platform portion 101. In the view shown in Fig. 1, the upstream and downstream faces of the root, shank and platform portions of the blade (i.e. the front and rear faces with respect to the front and rear of the gas turbine engine) lie parallel to the plane of the paper, these upstream and downstream faces being offset from each other with respect to that plane, so that a side 105 of the root and shank portions and a shoulder 106 of the platform can be seen in perspective. The offset between the faces mentioned above enables satisfactory transfer of forces between the sides of the root portions and the turbine disc in which they are mounted and also between adjacent blades through the shoulders of abutting platform portions.

The rear face 107 of the root portion 102 is provided with two generally mushroom-shaped studs 108, 110, each comprising a button 109,111, and a "stalk" 113,115 which joins the button to the body of the root portion 102. The buttons, stalks and root portion are formed in unitary manner with the aerofoil and platform by casting, with electro-discharge machining to finish off the undercuts beneath the buttons, their purpose being to aid in the attachment and retention of seal plates against the downstream faces of the root and shank portions when the blades are assembled into the finished rotor; this is shown in Figs. 2 and 4.

Turning now to a consideration of Figs. 2 and 3 together, it will be seen in more detail how the blades 10 are fixed in the assembled turbine rotor. Note that Fig. 2 can be considered to be a view on a Section II–II in Fig. 3. The primary fixing is of course provided by the fir-tree root portions 102 of the blades 10, which slide into complementary-shaped slots 200 in the perimeter of the turbine disc 202, whose spacing is such that the shoulders 106 of the platforms 101 abut each other. Secondary fixing is also needed to secure the blades 10 against sliding in the rotor disc 202 due to air pressure differentials across the rotor assembly from front to rear and also due to aerodynamic loadings on the aerofoils 100. This secondary fixing is provided by the hooks 204 on the front faces of the root portions 102, which hook over the combination of a sealing ring 206 and a flange 208 which is the radially outer part of a seal plate disc 210. The latter rotates with the turbine rotor assembly as a whole and carries labyrinth seals or the like (not shown) to seal the rotating parts to static structure of the engine (not shown). High pressure air 212 for cooling the turbine blades is channeled between seal plate disc 210 and the rotor disc 202 and enters the spaces 214 between the bottom of the turbine blade roots 102 and the bottom of the slots 200. From space 214 under each blade the high pressure cooling air enters passages (not shown) in the blade roots 102, passing thence up through aerofoil 100 to cool it. In order to assist in preventing the high pressure air 212 from escaping into the adjoining low pressure chamber 217 sealing ring 206 carries a silver-plated sealing wire 216.

Low pressure cooling air 218 is also required by the aerofoil 100. Having previously passed through pre-swirl nozzles in static structure (not shown) forward of the turbine rotor disc 202, the low pressure air enters chamber 217 next to the rotor disc and then passes into small chambers 222 defined between the perimeter of the rotor disc, the undersides of the platforms 101 and the blade shanks 103. From chambers 222 the low pressure cooling air enters air intakes 224 under platforms 101. It then passes into the aerofoil and circulates through a different set of cooling passages (not shown) from those used to carry the high pressure cooling air. The pressurisation of chamber 217 is maintained by the sealing of the forward edge lip of the platforms 101 against adjacent static structure 226.

In order to prevent the low and high pressure cooling air from simply exhausting freely into the space 228 adjacent the rear face of the rotor assembly, it is necessary to provide the root, shank and platform portions of the blades 10 with an annulus of seal plates 230, which extend between the undersides of the platforms 101 at their radially outer ends and an axially extending lip 232 on the rotor disc 202 at their radially inner ends. Near their radially inner ends and at their mid-spans the seal plates 230 are retained to the assembly by means of sealing engagement with the undercut faces 231,233 of stud buttons 109,111 already mentioned, whereas at their radially out ends the seal plates are retained by their sealing engagement with a groove 234 formed in the underside of platforms 101. Sealing with the rotor disc 202 is by the provision of a silver-plated sealing wire 236 which is trapped between the body of the rotor disc 202, the lip 232 and the seal plates 230.

Seal plates 230 and their functioning will now be described in more detail in relation to Figs. 4 to 7.

Referring to Figs. 4 and 5, it will be noticed how the seal plate annulus is defined by inner and outer radii comprising the disc lip 232 and the platform groove 234, the individual seal plates 230 extending between the inner and outer radii in a direction which is transverse of both the radial and tangential directions. By virtue of this transverse orientation, each seal plate 230 spans and engages three adjacent blades 10; however, the radially outer end of each seal plate 230 sealingly engages the underside of the platform 101 of a first blade only, the mid-span of each seal plate sealingly engages the radially outer stud 108 of both the first blade and a second blade, and a part of each seal plate near its radially inner end sealingly engages the radially inner stud 110 of both the second blade and a third blade. Hence, each seal plate engages the platform of one blade, and the root portions of two others.

Sealing engagement of the seal plates 230 with the studs 108,110 is achieved by providing each seal plate with triangular cutouts 401–404 in its long abutting edges 400 (see particularly Fig. 5); these cooperate with corresponding cut-outs in the two adjacent seal plates to define quadrilateral holes in the seal plate annulus through which the stalks 113,115 of the studs project. The areas of the seal plate surface immediately surrounding the cut-outs cooperate with the undercut faces 231,233 (Fig. 2) of the buttons 109,111 to provide sealing against leakage of cooling air, the pressure of the cooling air itself serving to urge the seal plates into sealing contact with the buttons, since of course the seal plates must be a clearance fit between the buttons and the blade root surfaces. Similarly, the seal plates are a clearance fit in the groove 234 under platforms 101, air pressure urging them over against the side of the groove.

As will be seen from Figs. 5 and 6, although over most of their areas the seal plates 230 are thin for minimum weight, they are made sufficiently rigid against bending, caused by cooling air pressure, by the incorporation of ribs 500–502 (seen also in Fig. 2, but not referenced).

Ribs 501 and 502 extend from edge to edge of the seal plates in tangential and radial directions respectively in order to stiffen mid-portions of the plates. Ribs 500 form the perimeters of the seal plates and besides stiffening their edges also provide more extensive sealing surfaces between the abutting edges 400 of adjacent plates.

A further feature of the seal plate design will be apparent from a study of Figs. 2,4 and 7. This is that the radially outer end 700 of each seal plate 230 is of somewhat less radius than the radius of the floor 701 of the platform groove 234 which seal plate end 700 engages. This feature serves to allow the seal plates to adjust their attitude slightly with respect to the rotor disc 202 and blades 10 by sliding relative to each other along their abutting edges 400, this being enabled by limited rocking of the outer ends 700 of the seal plates on the floor 701 of platform groove 234. The rocking/sliding action of the seal plates is also facilitated by the fact that the radially inner edges 235 (see inset to Fig. 2) of the seal plates are bevelled at 237 and do not directly abut the lip 232 of disc 202, the sealing wire 236 being urged onto the bevel 237 under the action of centrifugal force and thereby sealing the gap between the seal plates and the disc 202.

In connection with the rocking/sliding action of the seal plates, it should be noted that although, when the rotor disc assembly is at rest, there are clearances between the seal plate edges 400 to allow easy assembly, nevertheless during operation of the rotor disc the position of the centre of gravity CG (Figs. 4 & 5) of each seal plate relative to its radially outer end 700 ensures that centrifugal action applies a positive moment to each seal plate, the resulting rocking and sliding action of the seal plates thereby closing any assembly clearances between the seal plates. It should be particularly noted that when the side edges of the seal plates are positively engaged with each other due to the centrifugal action, the seal plates can only move in unison with each other.

Some advantages believed to arise from the rotor disc assembly design just described will now be mentioned.

The type of turbine blade 10 shown in the figures has a shank portion 103 of substantial radial extent between the platform 101 and the root 102. This helps with cooling the blade below the platform 101 and hence prevents some of the heat in the aerofoil 100 and platform 101 being conducted into the disc 202. However in conventional designs the use of such a shank portion necessitates radially elongated seal plates which are therefore subjected to greater vibrational axial and centrifugal loads than seal plates used with blades which have radially shorter shank portions, or non at all. Relatively greater loadings on the seal plates tends to increase problems related to excessive buckling or bending of the seal plates, increased fretting and wear of the seal plates against the blade platforms and disc, and difficulties in preventing the edges of abutting seal plates from overriding each other and in maintaining a good seal against leakage of cooling air.

The rotor assembly design here addresses these problems in various ways. For instance, the studs 108,110 which are cast integrally with the rest of the blade at the time of manufacture help to restrain the seal plates 230 against axially directed pressure forces due to the cooling air. The flat undercut surface 231, 233 on the back of each button 109,111 gives axial support to the seal plates in contact with it, sealing contact being assured by the pressure drop across the plates which force them into contact with the buttons. This axial restraint imposed by the studs also prevents Euler buckling of the seal plates due to centrifugal loading.

Besides providing axial restraint, the studs prevent circumferential movement of the seal plate annulus.

Excessive bending of the seal plates 230 under pressure and centrifugal forces is also prevented by the ribs 500–502, which stiffen the edges 400 of the seal plates and also their interiors, whilst allowing them to flex sufficiently to make sealing contact with the buttons as already mentioned. The ribs 500–502 also provide the seal plates with thick edges 400 which are helpful in preventing them from overriding each other, as well as providing good wearing seal surfaces.

An important feature of the design is that each seal plate 230 is urged (by the pressure and centrifugal forces) into engagement with three blades 10, and each blade is engaged by three seal plates. This multiple inter-engagement of blades and seal plates provides the assembly with inherently good vibration damping characteristics, thereby alleviating the fretting problem. The assembly's vibration damping characteristics are further enhanced by sliding contact between the elongate transversely extending edges 400 of the seal plates.

The rocking/sliding action of the seal plates 230, to which reference has already been made—resulting from their angled disposition, the reduced radius of their radially outer ends 700 bearing against the platforms, and their edgewise abutment against each other—has the important benefit mentioned previously of the closing up of clearances between seal plates. It also has another important benefit, namely that the seal plates can accommodate differential thermal expansion in the rotor assembly by adjusting their angles slightly relative to the disc 202 and blades 10. Such differential expansion arises between the blade platforms 101 and the disc 202.

A further important property of the seal plate annulus is that although some relative sliding movement between the seal plates can occur to accommodate differential expansion and other movement as already mentioned, the plates in the annulus are frictionally engaged with each other under centrifugal forces so that they tend to act as a unitary sealing ring unless disturbing forces acting through the blade platforms are above certain threshold values. This has the advantageous result that fretting due to small rocking movements or vibrations of the blades tends to be concentrated at the contacts between the seal plate ring and the platform grooves 234 of blades 10, instead of being concentrated at points of contact between the inner ends 231 of the seal plates and the disc 202 due to movement and vibration being transferred through the seal plates. It is desireable to control fretting so that it occurs on the blades and the seal plates rather than on the rotor disc because one or several blades and seal plates are cheaper and easier to replace than a rotor disc.

In the design of a rotor assembly according to the invention, the amount of friction between the seal plate edges 400 is clearly an important factor controling the amount of sliding movement actually occuring between adjacent plates under the combined disturbing forces and centrifugal loadings. In order to produce a satisfactory coefficient of friction between the abutting seal plate edges 400 and to avoid excessive wear, we have found it desireable to electroplate these edges with a cobalt graphite low friction coating of about 0,125 mm thickness in the finished state. Anti-wear or low friction coatings could also be applied at other points in the rotor assembly as desireable, where relative movement occurs between surfaces in contact with each other.

The above-described embodiment may be modified or varied without departing from the scope of the invention. For example, in the case of blades provided with substantially shorter shank portions, the seal plate annulus can be of lesser radial extent and the individual seal plates can also be shorter, engaging the platform of one blade as before, but extending across and engaging the root portion of only one other blade. In such a case, each root portion would be provided with only one stud to engage and retain the two seal plates with which it would be in contact.

For blade root portions of sufficiently small radial extent (for example, those without shank portions and/or those used in a small diameter turbine), it may be possible to dispense with the studs or other means connecting the seal plates directly to the blade roots, the seal plates being engaged by, and retained to, the assembly only at the blade platforms and the turbine disc. Such positive engagement with the turbine disc is shown in Fig. 8, where the arrangement of Fig. 2 has been replaced with an alternative arrangement providing axial restraint for the radially inner ends of the seal plates, but which also allows the necessary rocking/sliding action of the seal plates to occur as before. Thus, the inner end of the seal plate 800 is a clearance fit between the face of the turbine disc 802 and an upstanding flange 803 on a ring 804 which is secured to a flange 806 on the disc 802 by means of a bayonnette fixing involving engageable projections 808,810 on the disc flange 806 and a hooked portion of ring 804 respectively. Such bayonnette fixings are of course well known in the industry, and incude the provision of pin fixings to obviate relative rotation between the engaged members. Effective sealing between seal plate 800 and flange 803 occurs because cooling air pressure urges the seal plate over against the flange.

CLAIMS

1. A turbine rotor assembly comprising;

(a) a rotor disc,

(b) a plurality of air-cooled turbine rotor blades comprising aerofoil, platform and root portions, the latter being fixed in the rotor disc, the rotor blades being adapted to receive pressurised cooling air through at least one air intake means positioned radially inwardly of the platforms.

(c) a plurality of seal plates having radially inner ends which sealingly engage the rotor disc and radially outer ends which sealingly engage the undersides of the blade platforms, the seal plates having side edges which extend between the rotor disc and the platforms in abutting relationship with each other whereby the seal plates together form a seal plate annulus for sealing the rotor assembly against escape of the cooling air past the rotor blade root portions, thereby maintaining a pressure differential across the seal plate annulus: wherein;

(i) each seal plate engages the platform of one blade but extends across the root portion of at least one other blade such that each side edge of the seal plates extends in a direction which is transverse of both the radial and tangential directions,

(ii) the position of the centre of gravity of each seal plate, relative to the engagement of that seal plate with a blade platform, is such that during rotation of the rotor assembly centrifugal action applies a moment to each seal plate tending to turn the seal plates about their engagements with the blade platforms,

(iii) the radially outer ends of the seal plates are adapted to facilitate limited rocking of the seal plates about their engagements with the blade platforms, and

(iv) means are provided for restraining the seal plates to the rotor assembly whilst allowing said limited rocking of the seal plates;

whereby under centrifugal action the seal plates can adjust their attitude slightly in unison with each other and with respect to the rotor disc and rotor blades by simultaneously rocking against the rotor blade platforms and sliding relative to each other along their side edges.

2. A turbine rotor assembly according to claim 1, in which the means for restraining the seal plates to the rotor assembly includes seal plate engagement means provided on the root portions of the rotor blades for restraining the seal plates to the root portions.

3. A turbine rotor assembly according to claim 2, in which the seal plate engagement means comprise means adapted to engage the seal plates such that the pressure differential across the seal plate annulus serves to urge the seal plates into sealing contact with the seal plate engagement means.

4. A turbine rotor assembly according to claim 2, in which the seal plate engagement means comprises at least one stud means protruding from the root portion of each rotor blade, each stud means comprising a button-like portion joined to the root portion by a stalk-like portion, the side edges of the seal plates being shaped to accommodate the stalk-like portions and being a clearance fit between the button-like portions and the blade roots, the pressure differential across the seal plate annulus serving to urge the seal plates into sealing contact with the undersides of the button-like portions.

5. A turbine rotor assembly according to claim 4 in which the root portions of the rotor blades are provided with radially inner and radially outer stud means, the seal plates being engaged therewith near their radially inner

ends and near their mid-spans respectively.

6. A turbine rotor assembly according to claim 1, in which each seal plate engages the platform of a first blade and extends across the root portions of second and third blades.

7. A turbine rotor assembly according to claim 6 in which a radially outer portion of each seal plate engages the root portions of the first blade and the second blade and a radially inner portion thereof engages the root portions of the second blade and the third blade.

8. A turbine rotor assembly according to any one of the preceding claims in which the radially outer ends of the seal plates are sealingly engaged with a groove in the undersides of the blade platforms.

9. A turbine rotor assembly according to any one of claims 2 to 5 and 7 in which the radially inner ends of the seal plates are sealingly engaged with a sealing wire trapped between the seal plates and a sealing surface associated with the rotor disc.

10. A turbine rotor assembly substantially as described in the present specification with reference to and as illustrated in Figs. 1 to 7 in the accompanying drawings.

11. A turbine rotor assembly substantially as described in the present specification with reference to and as illustrated in Fig. 8 of the accompanying drawings.

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