Jan. 21, 1969 C. E. CORRIGAN 3,423,070

SEALING MEANS FOR TURBOMACHINERY

Filed Nov. 23, 1966

Fig 1

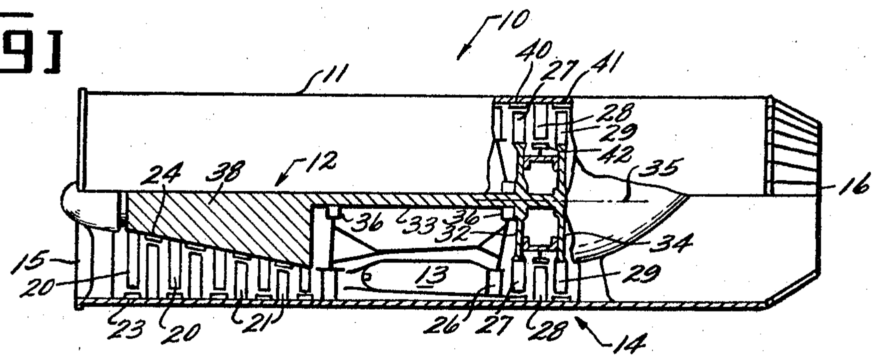

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Fig 2

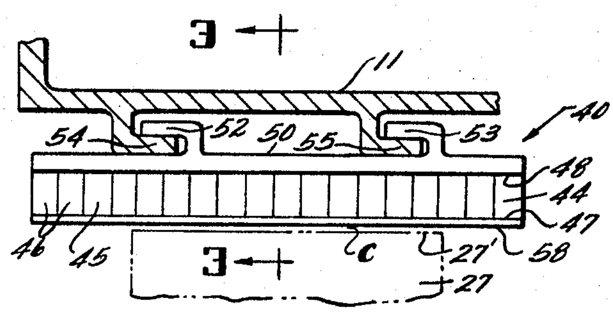


Fig 3

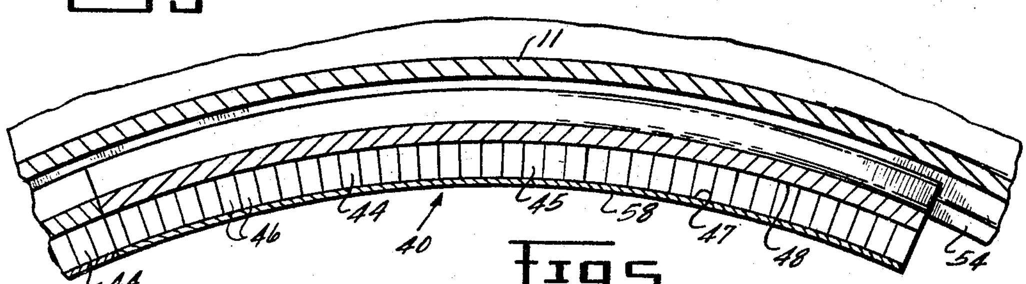


Fig 5

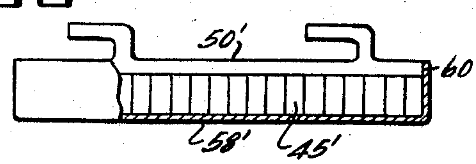
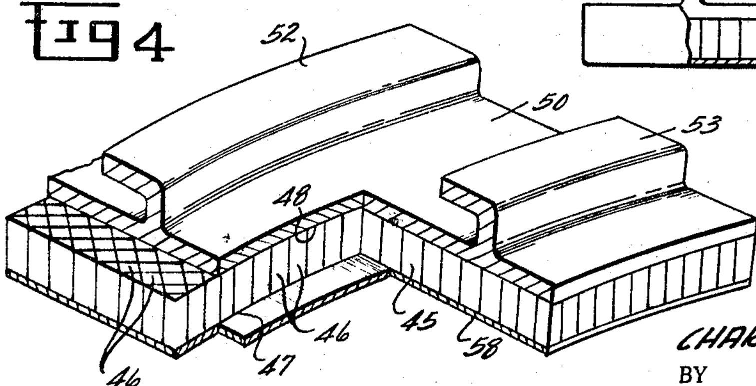


Fig 4



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SEALING MEANS FOR TURBOMACHINERY

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ABSTRACT OF THE DISCLOSURE

A composite seal member for turbomachinery, the seal member including a core layer of honeycomb material and surface layers of imperforate material secured to the honeycomb core.

This invention relates to a sealing means for turbomachinery and, more particularly, to improved shroud means for preventing undesired leakage around the tips of rotating airfoils during turbomachine operation.

In turbomachines such as axial flow compressors and turbines, the overall operating efficiency is adversely affected by leakage of the working fluid around the tips of the rotating airfoils. Specifically, in a compressor, leakage of the compressed fluid around the blade tips to lower pressure regions results in a loss to the system of the energy utilized in initially compressing the fluid since it must then be recompressed. Similarly, leakage of high temperature fluid around the tips of turbine buckets also results in an energy loss to the system since the fluid performs no useful work on the turbine. In high performance turbomachines such as gas turbine engines used for aircraft propulsion, the overall operating efficiency is an extremely important operating parameter, and it is therefore very desirable that this tip leakage be prevented or at least maintained at an acceptably low level. To this end, various shroud arrangements have been proposed and used in the past. The primary design objective in these prior art arrangements has been to surround the blade tips during operation as closely as possible in order to maintain the smallest possible leakage path. However, because of eccentricities in the annular members comprising actual turbomachines, variations in "stack-up" tolerances, and thermal transient growths of the turbomachine elements, it has been common in this part to install shrouds with relatively large tip clearances in order to avoid interference, i.e., rubbing, under all conceivable operating conditions. These arrangements do not, of course, reduce leakage to the extent desired in theory. Therefore, in order to provide enhanced sealing at the airfoil tips, abradable shrouds have been proposed and used in the past, these arrangements usually providing smaller clearances since there is no need to anticipate and provide for all situations which might conceivably cause rubbing. While providing smaller clearances, abradable shrouds available heretofore have tended to display performance losses due to surface roughness generating high turbulence on the shroud surface. Efforts have been made to provide abradable shrouds having the more desirable aerodynamic characteristics of non-abradable shrouds, but these configurations have not been altogether satisfactory with respect to strength, durability, and structural integrity.

It is an object of this invention to provide improved sealing means capable of maintaining small seal clearances in combination with a high degree of aerodynamic efficiency.

Another object of this invention is to provide for turbomachines an improved shroud means for preventing leakage of working fluid around the tips of rotating airfoils.

Yet another object is to provide for turbomachines an improved shroud means having the small clearances normally associated with abradable shrouds in combination with the aerodynamic characteristics of non-abradable shrouds.

A still further object of this invention is to provide the foregoing objects with a shroud arrangement having sufficient strength, durability, and structural integrity for sustained operation in high performance turbomachines such as aircraft gas turbine engines.

Briefly stated, in carrying out the invention in one form, a turbomachine shroud or similar sealing device includes a composite seal member of honeycomb sandwich construction. More particularly, the composite seal member includes a core layer of honeycomb material having a pair of substantially parallel faces, the individual cells comprising the core layer being disposed to intersect the pair of intersecting faces and thereby form a large number of open passages extending through the core layer. A layer of imperforate material is secured to each of the parallel faces to close the individual cell passages to prevent flow into and through the cells, the layer of imperforate material secured to at least one of the faces being relatively smooth and thereby adapted for use as an aerodynamically smooth sealing surface in conjunction with mating seal members, including the tips of rotating airfoils. Both the core layer of honeycomb and the smooth layer of imperforate material are of really abradable construction such that any rubbing will result in preferential abrading of the composite seal member. Accordingly, the composite seal member can be mounted with relatively small clearances with respect to the mating seal members.

By a further aspect of the invention, both the core layer of honeycomb material and the smooth layer of imperforate material are comprised of relatively thin and easily abraded sheet metal, the smooth cover layer of sheet metal preferably having a thickness in the range of 0.003 to 0.006 inch. In actual practice, a shroud or other sealing device formed in accordance with this invention may be comprised of a single composite seal member or a plurality of cooperating seal members, such as arcuate shroud segments forming a complete annular shroud.

While the novel features of this invention are set forth with particularity in the appended claims, the invention, both as to organization and content, will be better understood and appreciated, along with other objects and features thereof, from the following detailed description taken in conjunction with the drawing, in which:

FIG. 1 is a view partially in section of a gas turbine engine having a turbine shroud constructed in accordance with the present invention;

FIG. 2 is an enlarged view of the turbine shroud arrangement illustrated by FIG. 1;

FIG. 3 is a view taken along line **3—3** of FIG. 2 illustrating one of the arcuate shroud segments comprising the turbine shroud;

FIG. 4 is a pictorial view, partially cut-away, of the shroud segment of FIG. 3; and

FIG. 5 is an end view, partially cut-away of a modified shroud segment in which the honeycomb core is encased in sheet metal.

Referring to the drawing, and particularly to FIG. 1, an axial flow gas turbine engine **10** of the turbojet type is illustrated, the engine having an outer cylindrical casing **11** circumferentially surrounding an axial flow compressor **12**, an annular combustor **13**, and a turbine **14** axially disposed in serial flow relationship between a compressor inlet **15** and an exhaust nozzle **16**. More particularly, the engine components just described cooperate to form an annular passageway extending axially between the inlet 15 and the nozzle 16 for the flow of motive fluid, which is initially air and later combustion products. Within the compressor 12, the air flows through a number of axially spaced-apart and alternating rows of rotor blades 20 and stator vanes 21, each adjacent pair of rotor blades 20 and stator vanes 21 comprising a compression stage for increasing the pressure of the air. To prevent undesired leakage around the outer tips of the rotor blades 20, annular shroud assemblies 23 are provided in close running clearance with the blade tips; similarly, annular seal assemblies 24 are provided for preventing undesired leakage around the inner tips of the stator vanes 21.

Within the combustor 13, fuel is injected into the high pressure air and burned to produce high pressure and high temperature products of combustion. The high energy combustion gases are then directed through the turbine 14 for producing power to drive the compressor 12 and, finally, through the exhaust nozzle 16 for producing thrust. As illustrated by FIG. 1, an annular nozzle diaphragm 26 is located at the downstream end of the combustor 13 for supplying the combustion gases to a first stage row of turbine buckets 27 at the proper velocity and angle. From the turbine buckets 27, the hot gases flow through a second stage turbine nozzle diaphragm 28 from which they are redirected to a second stage row of turbine buckets 29. The turbine buckets 27 are peripherally mounted on a turbine wheel 32 which, along with its associated shaft 33 and a second turbine wheel 34 upon which the turbine buckets 29 are mounted, is rotatably mounted on the engine axis 35 by suitable mounting means including bearing arrangements 36. The turbine unit comprising the wheels 32 and 34 and the shaft 33 drives the compressor rotor 38 upon which the rotor blades 20 are mounted. As in the case of the compressor airfols 20 and 21, it is desirable that leakage of the working or motive fluid be prevented from occurring around the unsupported ends of the turbine airfoils 27–29. Accordingly, annular shroud assemblies 40 and 41 are provided at the outer tips of the turbine buckets 27 and 29, respectively, and an annular seal assembly 42 is provided at the inner end of the nozzle diaphragm 28.

The annular shroud assembly 40 surrounding the tips 27′ of the turbine buckets 27 is formed in accordance with the present invention and is illustrated in detail by FIGS. 2–4. As shown, the shroud assembly 40 includes a number of arcuate seal members 44 which abut to form a complete annular shroud ring surrounding the tips 27′ with a relatively small clearance C. The size of this clearance C is selected such that rubbing will not occur between the tips 27′ and the arcuate seal members 44 under ordinary operating conditions; the clearance C need not, however, be large enough to assure that rubbing never occurs since the shroud assembly of this invention can accommodate rubs.

The arcuate seal members 44 are composite structures including a core layer 45 of open-celled honeycomb material, the individual cells 46 comprising the core layer 45 being radially disposed with respect to the engine axis 35 to intersect inner and outer substantially cylindrical faces 47 and 48, respectively, of the layer 45. In other words, the individual cells 46 thus form open passages between the faces 47 and 48. This core layer 45 of honeycomb material is of abradable construction and is preferably formed of expanded sheet metal as described in United States Patent 2,963,307 to Bobo, issued Dec. 6, 1960, and assigned to the assignee of the present invention. As in the Bobo sealing device, a backing layer 50 of imperforate material such as metal is secured to the outer face 48 to close the outer ends of the cells 46, and support means such as the flanges 52 and 53 are provided for cooperating with casing flanges 54 and 55 to support the seal members 44 within the casing 11 with the proper clearance C.

To provide the unique sealing features of this invention, each of the composite sealing members 44 has an inner layer 58 of imperforate material secured to the inner face

47 of the core layer 45. In addition to cooperating with the backing layer 50 to close both ends of the honeycomb cells 46, the inner layer 58 is both smooth and abradable. In practice, it has been found that, for shroud assemblies used in jet engines, this inner layer 58 may be comprised of relatively thin sheet metal, preferably having a thickness in the range of 0.003 to 0.006 inch. The material from which the inner layer 58 is formed should, of course, possess any other necessary characteristics for satisfactory use in its operating environment, including suitable resistance to normal operating temperatures.

In normal operation, the clearance C between the arcuate seal members 44 and the bucket tips 27′ will be quite small, and the leakage around the tips will be correspondingly small. In addition, the smooth surface provided by the inner layer 58 will maintain turbulence and accompanying areodynamic losses at reasonably low levels. In other words, the arcuate seal members 44 provide extremely satisfactory leakage and aerodynamic characteristics under ordinary operating conditions. Under unusual conditions where the relative growth between the bucket tips 27′ and the shroud assembly 40 is greater than anticipated, rubbing can occur with preferential abrading of the inner layer 58 of the arcuate seal member 44 and possibly the core layer 45 since these elements have substantially less mass than the bucket tips 27′. This abrading of the composite seal member 44 will not, however, affect its integrity as a seal even though surface turbulence may increase at those areas, usually quite limited in extent, when abrasion has occurred and the inner layer 58 has been entirely removed. The reason that the seal integrity is not destroyed is that the honeycomb core layer 45 will continue to serve in those areas as a seal in accordance with the teaching of the Bobo patent, leakage into and out of the motive fluid passageway through the cells 46 being prevented by the backing layer 50. In those areas where the inner layer 58 has not been entirely removed, the seal member 44 will continue to exhibit both low leakage and the desirable aerodynamic characteristics of smooth shroud surfaces.

As described above, the backing and inner layers 50 and 58, respectively, of imperforate material are separate and distinct elements. It may be desirable, however, to provide additional strength and durability by encasing the entire core layer 45′ in imperforate material as illustrated by FIG. 5, the inner layer 58′ being wrapped around the sides and ends of the core layer 45′ and secured by brazing or other means at 60 to the backing layer 50′. Similarly, it may be desirable to wrap the entire core layer with a single sheet of sheet metal to provide both the inner rubbing layer and the backing layer.

Other modifications will also occur to those skilled in the art. For example, although the shroud assemblies of FIGS. 2–5 are preferably formed of arcuate seal members, it would be quite possible to provide an "arcuate" seal member that is a complete, unsegmented ring having the composite structure of this invention. Similarly, although the seal construction of this invention has been described only in conjunction with the shroud assembly 40 for the turbine buckets 27, it will be appreciated that the invention could also be utilized with respect to the shroud assemblies 41 and 23 and the stator seal assemblies 42 and 24. Furthermore, even though the described embodiments are all of arcuate configuration with substantially cylindrical face surfaces, it will be appreciated that seal members could be made in accordance with this invention in which the faces are substantially flat, parallel surfaces or inclined surfaces. Accordingly, the term "parallel faces" as used in the claims appended hereto is hereby defined to means surfaces that are spaced apart a substantially uniform distance; as such, the surfaces may be flat or curved.

It is thus seen that this invention provides improved sealing means capable of maintaining small seal clearances in combination with a high degree of aerodynamic efficiency. More specifically, as applied to shrouds for rows of airfoils, the invention provides in combination the small clearances normally associated with abradable shrouds and the aerodynamic characteristics of non-abradable shrouds.

It will be understood that the invention is not limited to the specific details of construction and arrangement of the particular embodiments illustrated herein. It is therefore intended to cover in the appended claims all such changes and modifications which may occur to those skilled in the art without departing from the true spirit and scope of the invention.

What is claimed as new and is desired to secure by Letters Patent of the United States is:

1. A composite seal member comprising:

a core layer of honeycomb material having a pair of substantially parallel faces,

the individual cells comprising said core layer of honeycomb material being disposed to intersect said pair of parallel faces,

and a layer of imperforate material secured to each of said parallel faces to close said individual cells and thereby prevent fluid flow into said individual cells,

the layer of imperforate material secured to at least one of said parallel faces being relatively smooth and thereby adapted for use as a sealing surface in conjunction with a mating seal member, said smooth layer of imperforate material and said core layer of honeycomb material being readily abradable, whereby any rubbing between said composite seal member and a mating seal member will result in preferential abrading of said composite seal member.

2. A composite seal member as defined by claim **1** in which said core layer of honeycomb material is comprised of sheet metal and in which the layers of imperforate material secured to said parallel faces are comprised of sheet metal substantially encasing the entire core layer of honeycomb material, the sheet metal being relatively thin so as to be readily abraded in the event of rubbing between said composite seal member and a mating seal member.

3. A composite seal member as defined by claim **1** in which said core layer of honeycomb material is comprised of sheet metal and in which the layers of imperforate material secured to said parallel faces comprise separate sheets of sheet metal secured to said respective faces, the sheet metal being relatively thin so as to be readily abraded in the event of rubbing between said composite seal member and a mating seal member.

4. A composite seal member as defined by claim **1** in which said smooth layer of imperforate material and said core layer of honeycomb materials are comprised of sheet metal, the sheet metal being relatively thin so as to be readily abraded in the event of rubbing between said composite seal member and a mating seal member.

5. A composite seal member as defined by claim **4** having a generally arcuate configuration for use in a turbomachine, said parallel faces being curved surfaces spaced-apart radially a substantially uniform distance.

6. For use in a turbomachine for preventing leakage around the tips of rotating airfoils, an annular shroud comprising at least one composite seal member as defined by claim **5**, the parallel faces of said composite seal member being of substantially cylindrical configuration and

said smooth layer of sheet metal being secured to the radially inner one of said faces.

7. In a turbomachine including a rotor mounted for rotation about an axis and a row of radial airfoils peripherally mounted on said rotor, an annular shroud assembly peripherally surrounding said airfoils, said annular shroud assembly comprising:

at least one arcuate composite seal member;

said composite seal member comprising:

a core layer of honeycomb material having inner and outer radially spaced, substantially cylindrical faces,

the individual cells comprising said core layer of honeycomb material being radially disposed to intersect said inner and outer faces,

and a layer of imperforate material secured to each of said inner and outer faces to close said individual cells and thereby prevent flow into said individual cells,

the layer of imperforate material secured to said inner face being relatively smooth;

said smooth layer of imperforate material and said core layer of honeycomb material being readily abradable,

and means supporting said composite seal member in closely spaced relation to the radially outer tips of the airfoils,

whereby leakage of motive fluid around the tips of the airfoils during turbomachine operation is substantially prevented.

8. An annual shroud assembly as defined by claim **7** in which said smooth layer of imperforate material and said core layer of honeycomb material of said composite seal member are comprised of sheet metal, the sheet metal being relatively thin so as to be readily abraded in the event of rubbing between said composite seal member and the tips of the airfoils during turbomachine operation.

9. An annular shroud assembly as defined by claim **8** in which the sheet metal comprising said smooth layer of imperforate material has a thickness in the range of 0.003 to 0.006 inch.

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U.S. Cl. X.R.

230—133; 253—39; 277—53