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TIP CLEARANCE CONTROL SYSTEM FOR TURBOMACHINES

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2 Sheets-Sheet 1

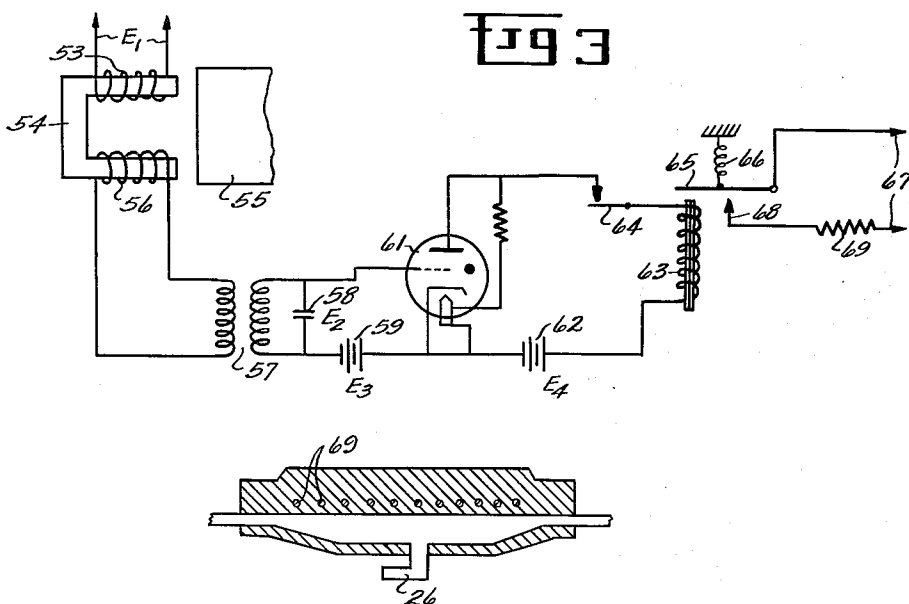
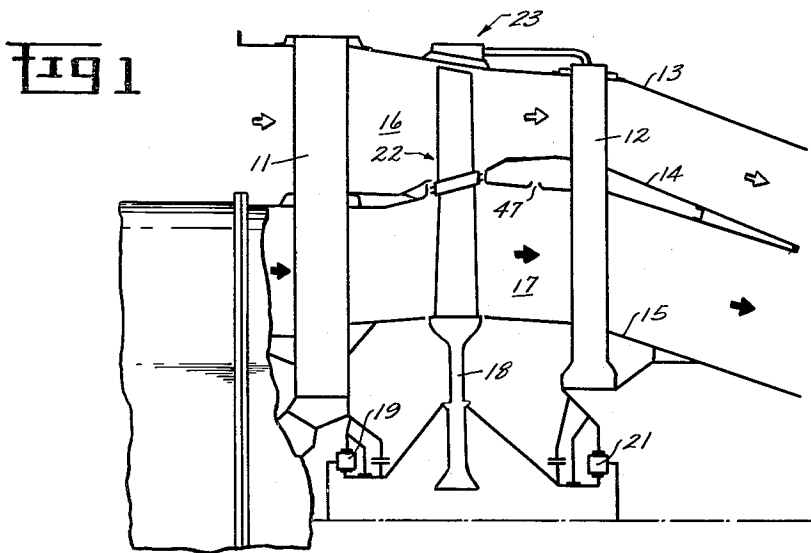


Fig 4

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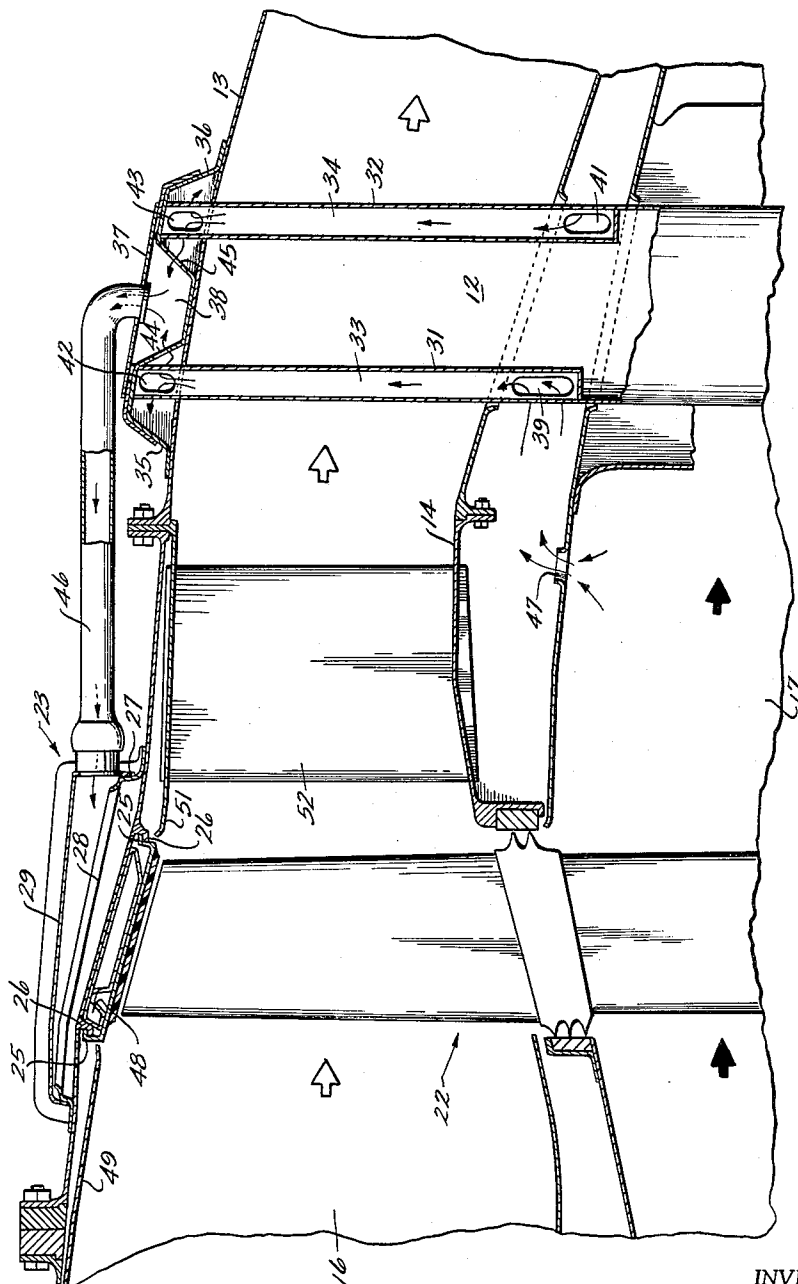
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Fig. 2



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TIP CLEARANCE CONTROL SYSTEM FOR TURBOMACHINES

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The present invention relates to a tip clearance control system for turbomachines and more particularly to a system for controlling the tip clearances of compressor blades.

It is well known that the efficiency of a compressor is adversely affected if it is operated with large clearances between the tips of the rotating blades and the attendant stationary components (i.e. shrouds). The requirement for tip clearances results from the fact that the rotating components, such as the blades and the wheel, increase in diameter considerably due to centrifugal stresses and thermal expansion while the stationary components, the shroud and casing, are subject to changes in dimension to a lesser degree. The difficulties of this situation are compounded in the case of a post turbine fan thrust augmentor where the rotor is subjected to the high temperature turbine discharge gases while the compressor casing and shroud are not subject to any appreciable temperature increase.

During the continuous operation of a compressor the occurrence of a variety of operating conditions is to be expected. These varying conditions may cause considerable variations in compressor tip clearance. For a particular set of operating conditions any desired running clearance between the rotating and stationary components can be obtained if the components are fabricated and assembled with an appropriate initial tip clearance. However, the heavier rotating components of a compressor having a large mass are necessarily slow to respond to changes in operating conditions, thus requiring large initial tip clearances. Previous known means for reducing tip clearances, have involved shrouded blades, or abradable shrouds which are worn away by the blades as the rotating parts expand. These devices have not afforded a completely satisfactory solution to the problem of large tip clearances. The shrouded blades lead to a design which is inherently heavier and more difficult to manufacture than the unshrouded blade. The abradable shroud provides close clearances while it is wearing in, but this advantage does not accrue upon subsequent operation. In addition, no provision is made in any of the prior known devices for controlling tip clearances during all phases of compressor operation.

An object of the present invention is to provide a tip clearance control system for maintaining minimum tip clearances between rotating and stationary components of a compressor during all phases of compressor operation.

The present invention comprehends a tip clearance control system which compensates for thermal expansion of the rotating components. This is accomplished by providing means for applying heat to the stationary components, thus causing the compressor casing and the shroud attached thereto to expand, thereby matching closely the expansion of the rotating components. By this means, the initial tip clearances are materially reduced, thereby providing desirable operating characteristics to the compressor. The amount of heat applied to the stationary components can be controlled so that the rates of growth of both the stationary and rotating components are essentially the same.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same be-

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comes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. 1 is a schematic view in section of a post turbine fan thrust augmentor embodying the present invention;

FIG. 2 is an elevation view partly in section illustrating in detail one form of the present invention;

FIG. 3 is a schematic view of an alternative embodiment of the invention; and

FIG. 4 is an elevation view of the heating element of FIG. 3 as installed on a casing.

The present invention is illustrated in FIG. 1 as applied to a post turbine fan thrust augmentor which includes front and rear frame struts 11 and 12, respectively, supporting an outer casing 13, an intermediate casing 14 and an inner casing 15. An annular compressor duct 16 is formed between the outer casing 13 and the intermediate casing 14 and a turbine duct 17 is formed between the intermediate casing 14 and the inner casing 15. A single stage rotor assembly 18 is supported in two bearings 19 and 21 which are carried by the front and rear struts respectively. The rotor assembly 18 includes a plurality of airfoil elements 22 which are made up of a turbine bucket and a compressor blade joined together in end to end relation. A shroud clearance control means 23 according to the present invention surrounds the outer casing adjacent the tips of the airfoil elements.

Referring to FIG. 2, a shroud segment 24 is illustrated as positioned on the outer casing 13 over the tips of the airfoil elements 22. The lateral edges of the shroud are turned outwardly and provided with axially extending projections 25 which are engaged by retaining hooks 26 secured to the outer casing. A cylindrical manifold 27 surrounds the outer casing in the area of the retaining hooks 26. The periphery of the manifold 27 is provided with a plurality of laterally extending openings 28 equally spaced around the circumference of the manifold. A box-like housing 29 surrounds each of the openings 28 in sealing engagement with the housing 27. As illustrated in FIG. 2, the intermediate casing 14 and the rear frame strut 12 are hollow. The leading and trailing edges of the rear frame strut are sealed off by partitions 31 and 32 to provide radially extending channels 33 and 34. The rear frame structure also includes two hollow rings 35 and 36 which surround and are attached to the outer casing 13 and are also secured to the ends of the rear frame struts 12. A cylindrical plate 37 connects the two rings 35 and 36 and defines an annular space 38 therebetween. Channels 33 and 34 are connected to the interior of the intermediate casing by means of openings 39 and 41 respectively. The opposite ends of the channels connect with the interior of the rings through openings 42 and 43 and the rings 35 and 36 are in turn connected to space 38 by openings 44 and 45. A conduit 46 extends between the plate 37 and each box-like housing 29, thereby connecting the annular space 38 with the interior of each such housing.

Turbine discharge gases within the turbine duct 17 flow through opening 47 into the interior of the intermediate casing 14, entering the struts 12 through openings 39 and 41. The gases then flow outwardly through channels 33 and 34, discharging through openings 42 and 43 into the rings 35 and 36. The gases continue into space 38 through openings 44 and 45 and through conduit 46 into housing 29. From the housing the gases flow through opening 28 into manifold 27 and circulate circumferentially about the casing. The gases are discharged to the atmosphere from openings (not shown) located in manifold 27 between adjacent housings 29. By the application of the turbine discharge gases to the outer casing, the casing and the shroud retaining hooks 26 expand. To prevent excessive heat losses an insulating

member 48 is positioned in the space between the shroud and the casing. The shroud 24 itself is formed in segments to permit the shroud to follow the aforementioned growth of the casing 13 and hooks 26, thereby effecting the desired growth of the shroud.

The outer boundary of the gas passage of the compressor in the area adjacent to the shroud is formed by the cantilever supported liners 49 and 51. An outlet guide vane 52 is mounted between the intermediate casing 14 and the liner 51.

As pointed out earlier, the rotor assembly during engine operation increases considerably in diameter due to both centrifugal stresses and thermal expansion. The radial growth of the turbine buckets due to thermal expansion follows changes in engine operating conditions rapidly because they are directly exposed to the turbine discharge gases. The response of the wheel to any changes in operating conditions is necessarily slow due to its large mass. The casing and the attached shroud when not heated would not be subject to any appreciable increase in temperature and consequently the shroud would not increase in diameter.

The present shroud control system permits the casing to expand and contract as desired for maintaining a minimum tip clearance under all operating conditions by matching the expansion or contraction of the wheel.

It should be noted that the embodiment of the present system illustrated in FIGS. 1-3 does not need an active control device, such as a sensing element and associated servo system for controlling the application of heat, because it tends to be self-regulating. This derives from the fact that the engine parameter which determines the final wheel and bucket temperatures is the turbine inlet temperature. Indirectly the turbine inlet temperature also controls the rotor r.p.m. and therefore the centrifugal expansion. The shroud expansion depends directly on the gas employed for heating the casing which is taken from the turbine exhaust and, thus it follows that the parameter controlling shroud growth is also turbine inlet temperature. When the cause of expansion of the rotor is related to turbine inlet temperature and the correction of the expansion of the shroud is made dependent on turbine inlet temperature it follows that the system will be essentially self-regulating.

Another modification of the present invention is illustrated in FIGS. 3 and 4. In this modification electrical energy is used for heating the casing. The electrical system comprises a means for detecting the shroud clearance and a thyatron control of the power applied to a casing heating element. Referring to FIG. 3, a voltage supply E_1 is applied to the primary coil 53 of a variable reluctance transformer 54. The rotating elements 55 of the rotor assembly each in turn pass the transformer forming thereby the gap d which is the tip clearance. By the variation of the reluctance of the magnetic path of the transformer caused by the passing of the rotating elements, a secondary voltage is induced in the coil 56. A transformer 57 is used to induce a voltage E_2 across a condenser 58. The voltage E_2 is counter-acted by voltage E_3 applied by a suitable source 59. The sum of ($E_2 - E_3$) is used as the grid control voltage of the thyatron 61. The plate voltage for the thyatron is supplied by source 62, the plate circuit being completed by an electromagnet 63 and a bi-metallic circuit breaker 64. Opposite magnet 63 is a switch 65 loaded by a mechanical spring 66, contact 67 closes the power circuit supplied by source 67 which is controlled by contact 68 and which powers the casing heating coil 69.

The operation of this embodiment of the invention may be explained as follows: the magnetic flux H in the transformer 54 increases as the clearance d decreases. The increased flux H causes an increase in the secondary voltage produced by coil 56 and thereby also the voltage E_2 . The thyatron is prevented from firing by the bucking voltage E_3 applied to the grid until the value of

E_2 , applied opposite to E_3 , drives the grid voltage high enough to permit firing of the tube 61. The switch 68 is energized when the magnet 63 overcomes the attraction of the spring 66. Consequently the power source 67 flows current through the coil 69 heating the casing and the shroud retaining hooks 26, thus opening the clearance d . The bi-metallic switch 64 provides the required interruption of the plate circuit through the thyatron. If the clearance d increases the result will be a decrease of H , therefore of E_2 and of ($E_2 - E_3$). The thyatron cannot fire when the bi-metallic switch closes again until the clearance d decreases below the minimum value desired.

Referring to FIG. 4, the heating coil 69 is shown surrounding the casing above the shroud retaining hooks 26. The coil is imbedded in a suitable insulating material so that heat is applied to the casing and dissipation to the atmosphere is inhibited. The remaining shroud retaining hook is heated in the same manner.

While the present invention is illustrated as applied to a post turbine fan thrust augments, it is understood that it has applicability to any turbomachine having concentric turbine and compressor passages.

While a particular embodiment of the invention has been illustrated and described, it will be obvious to those skilled in the art that various changes and modifications may be made without departing from the invention and it is intended to cover in the appended claims all such changes and modifications that come within the true spirit and scope of the invention.

What I claim is:

1. In a turbomachine including a turbine passage and a compressor passage surrounding and concentric with the turbine passage, a casing defining the outer boundary of the compressor passage, a rotor assembly within the casing having blade elements extending across both passages, a shroud mounted interiorly of the casing adjacent the radial extremities of the rotor blade elements, and heating means mounted to said casing in heat transfer relationship to said shroud for effecting thermal expansion of the shroud to control radial clearance between it and the rotor blade elements.

2. In a turbomachine including concentrically disposed annular turbine and compressor fluid flow passages, a casing defining the outer boundary of the outer of said fluid flow passages, a rotor assembly within the casing having blade elements extending across both said passages, a shroud mounted interiorly of the casing adjacent the radial extremities of the blade elements, said casing and shroud including means defining a manifold disposed adjacent said shroud in heat transfer relationship therewith, and conduit means for conducting fluid from the inner of said fluid flow passages to said manifold to reduce the temperature differential between the shroud and rotor assembly and thus reduce differential thermal expansion thereof.

3. In a turbomachine which includes a turbine passage and a compressor passage surrounding and concentric with the turbine passage, a casing defining the outer boundary of the compressor passage, a rotor assembly within the casing having blade elements extending across both passages, a shroud mounted on the interior of the casing adjacent the radial extremities of the rotor blade elements, said casing and shroud including means defining a manifold surrounding said shroud in heat transfer relationship therewith, and conduit means for conducting fluid from said turbine passage to said manifold to raise the temperature of the shroud and thus reduce differential thermal expansion between it and said rotor assembly.

4. For use in a turbo-machine having an external cylindrical casing and a rotor assembly mounted for rotation therein, the rotor assembly being exposed to hot gases, and a shroud mounted on the interior of the casing between the rotor assembly and the casing, means for controlling the clearance between the rotor and the shroud

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comprising: a heating element surrounding the exterior of the casing opposite the shroud; sensing means for sensing the clearance between the shroud and rotor assembly; and means for energizing the heating element to heat the casing locally in the area surrounding the shroud, said means being connected to the heating element and the sensing means.

5. For use with a turbo-machine which includes a turbine passage, a compressor passage surrounding and concentric with the turbine passage, a casing forming the outer boundary of the compressor passage, a rotor assembly within the casing having blade elements extending across both passages, and a shroud mounted on the interior of the casing adjacent the radial extremities of the rotor blade elements, means for controlling the clearance between the shroud and the radial tips of the blade elements comprising: heat applying means surrounding the casing and mounted thereon opposite the shroud; and a source of heat energy connected to the last named means; the heat applying means controlling radial expansion of the casing and the attached shroud to maintain a minimum clearance between the shroud and rotor elements under all operating conditions of the turbo-machine.

6. The combination set forth in claim 5 in which the means for controlling the clearance includes: a manifold surrounding the exterior of the casing opposite the shroud; and conduit means extending between the manifold and the turbine passage for conducting hot gases from the turbine passage to the manifold.

7. The combination set forth in claim 5 in which the

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means for controlling the clearance includes: a heating element surrounding the exterior of the casing opposite the shroud; means connected to the heating element for energizing the element to apply heat to the casing; and means connected to the last named means for sensing the clearance between the shroud and the rotor elements.

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