

Jan. 4, 1966

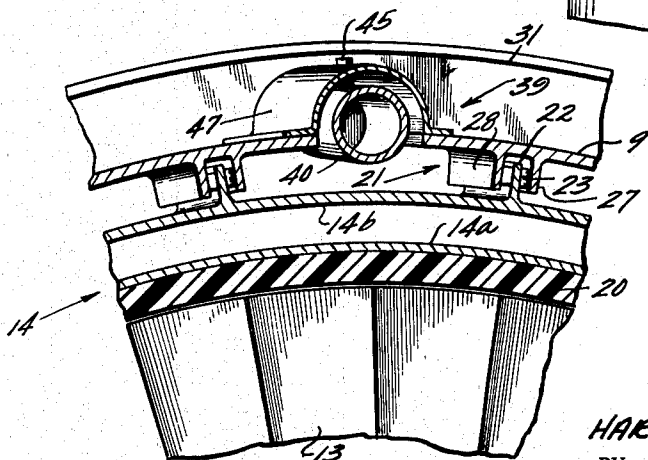
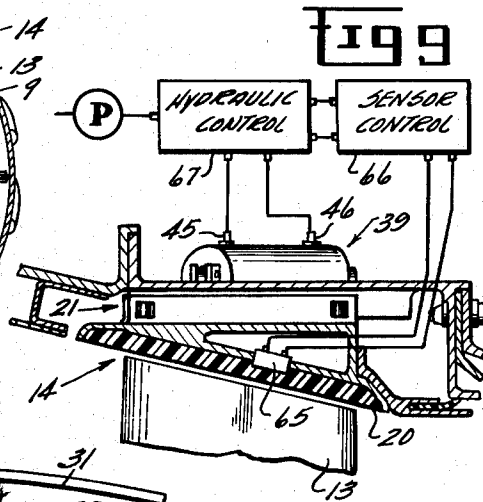
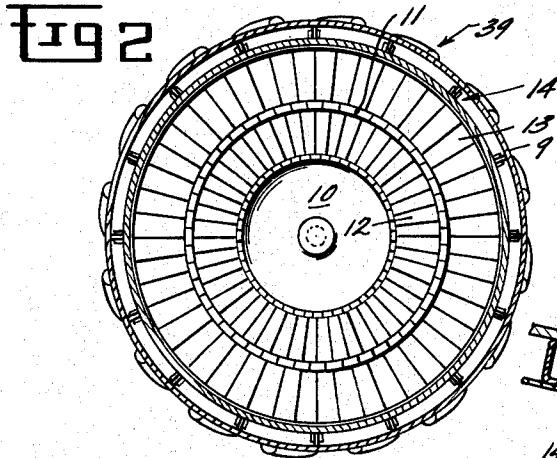
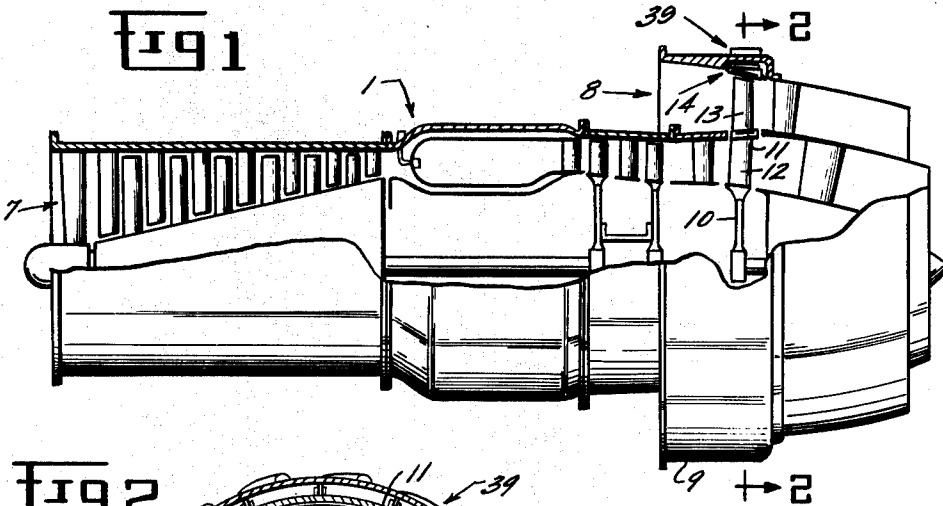
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3,227,418

VARIABLE CLEARANCE SEAL

Filed Nov. 4, 1963

3 Sheets-Sheet 1



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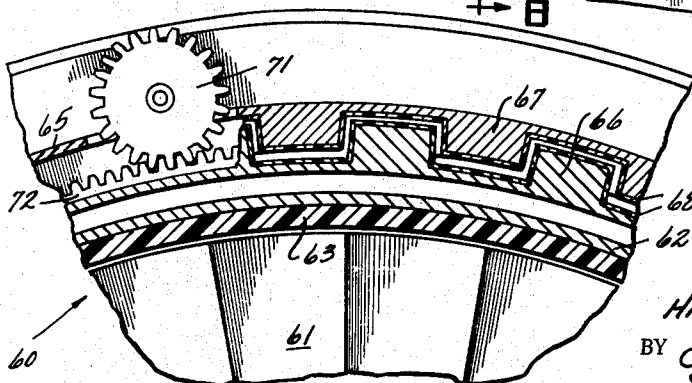
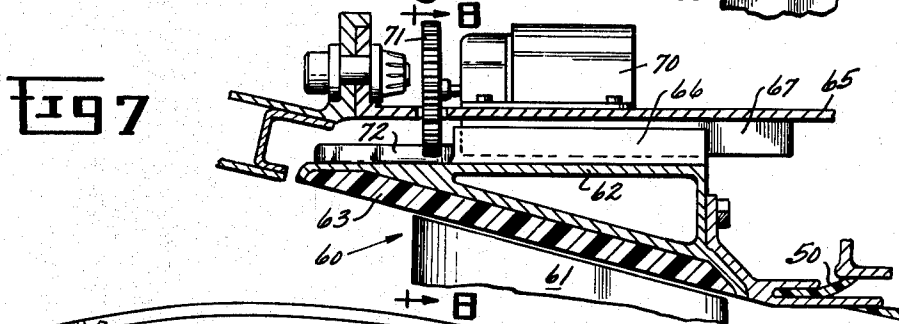
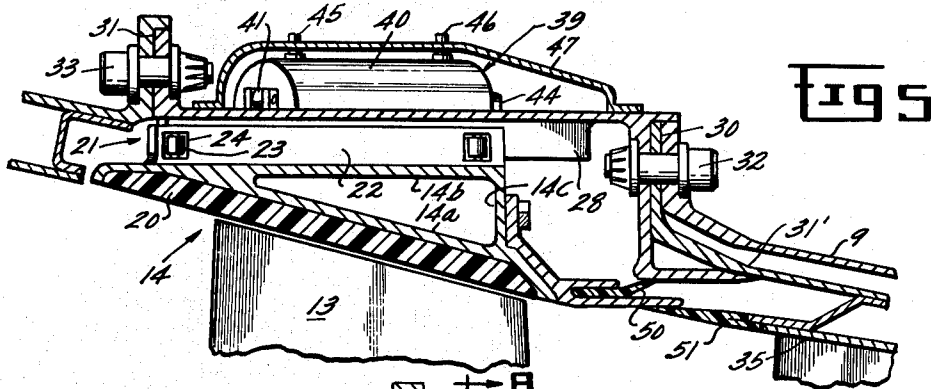
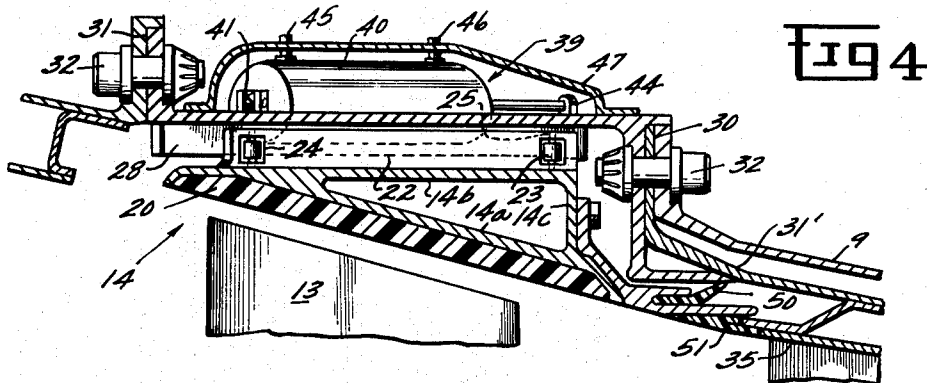
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VARIABLE CLEARANCE SEAL

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3 Sheets-Sheet 2



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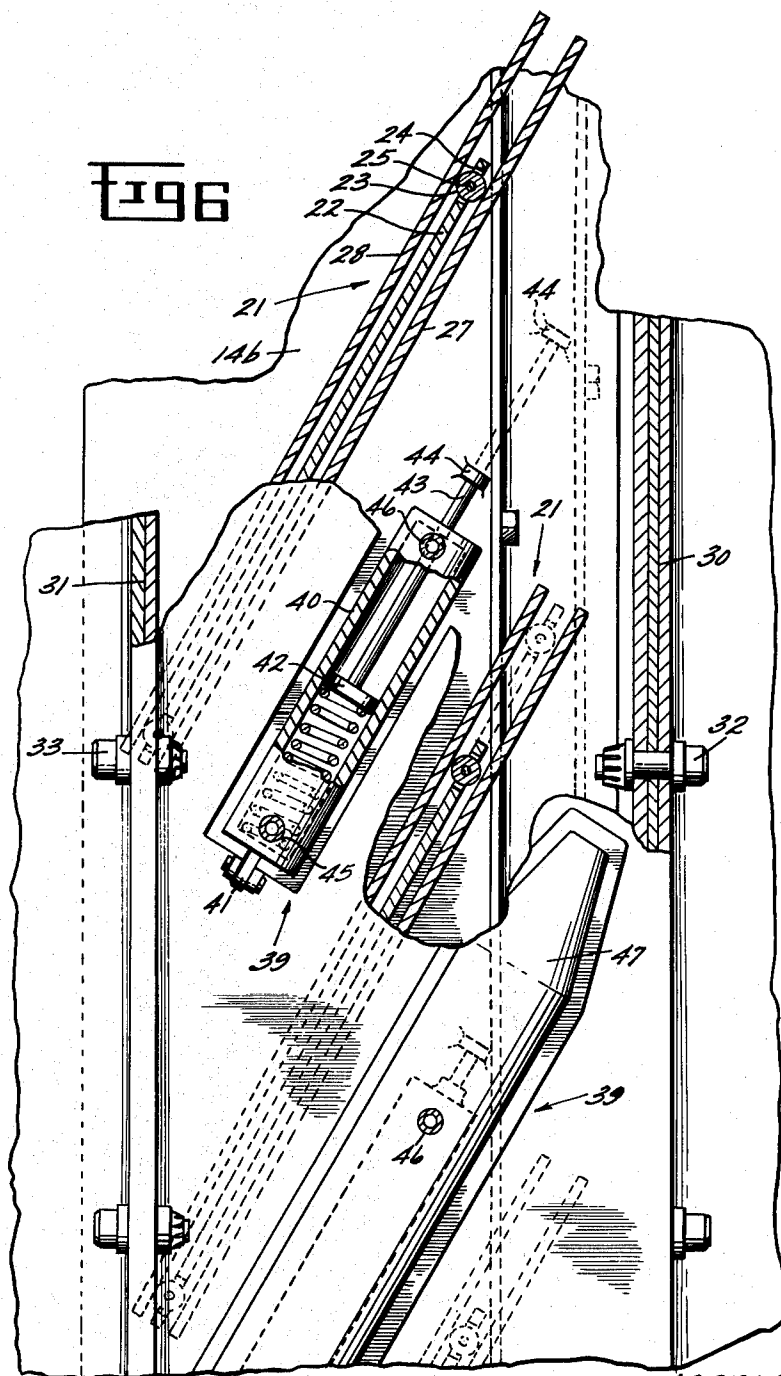
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VARIABLE CLEARANCE SEAL

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3 Sheets-Sheet 3



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3,227,418

VARIABLE CLEARANCE SEAL

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4 Claims. (Cl. 253—39)

This application is a continuation-in-part of application No. 222,327 filed September 10, 1962, now abandoned, of the same title and assignee.

This invention relates to a variable clearance seal and more particularly to a means for controlling seal clearance between the rotor blade tips of a turbomachine and the stationary seal or shroud.

In turbomachines and in other such apparatus it has been found to be extremely difficult to control the clearances between rotating parts and stationary assemblies, and particularly between the rotating blade tips and the stationary shrouds spaced from the outer ends of these tips. Controlling these clearances is made difficult because of manufacturing tolerances, also there is always the problem of differential thermal expansion between the rotating blade assembly and stationary shroud which necessitates the allowance for some spacing between the blades and the shroud. Wherein the blade and possibly the rotor itself is subjected to the high temperature of the gas stream on both sides, the shroud is subjected to such temperatures on only one side and generally is cooled by some type of cooling airflow on its outer side to maintain it at a lower temperature. This can result in the blade and disk assembly expanding radially more rapidly than the shroud, or the shroud contracting radially more rapidly than the blade and disk assembly, and since direct contact between the blade tips and the shroud must be avoided some spacing must be provided to allow for this transient and steady state differential expansion. However, such spacing allows leakage or gas flow around the blades between the blade tips and the shroud which naturally results in a less efficient turbomachine.

Some efforts have been expended to solve this problem by the use of honeycomb or other type seals located next to the blade tips and supported from the shroud to allow the blade tips to wear into the seal if contact results, to do away with the necessity for excessive radial clearances for differential thermal expansion, for stack up, for relative out-of-roundness, and for safety. However, this does not completely solve the problem since the clearance between such a seal and the blade tip is determined by the greatest differential thermal expansion therebetween and therefore any sudden thermal transient determines the seal clearance from that time until the engine is overhauled and the seal is again replaced. Blade tip clearance is therefore recognized as a primary problem in the manufacture of turbomachines and is one that is being further amplified as higher and higher efficiency engines are desired and as higher Mach engines are sought in the supersonic ranges. At such supersonic speeds, the ram air temperature rise in the compressor coupled with higher performance combustors subject the turbines to higher and higher temperatures resulting in greater thermal expansions of the rotor and blade assemblies thereby complicating this sealing problem even more.

It is therefore one object of this invention to provide a means for actively controlling the seal clearance between a rotating blade assembly and an adjacent stationary member or shroud.

It is a further object of this invention to provide a means for positioning a truncated cone shaped shroud supported to allow axial movement of the shroud to actively control the radial clearance between such shroud and the blade tips of a turbomachine rotor.

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In accordance with one embodiment of the invention there is provided a turbomachine assembly comprising a rotor having blades extending radially therefrom through a gas duct with a stationary shroud located at a spaced position from the outer tips of the blades forming a portion of the gas passage duct, such shroud being of a truncated cone shape and positioned with the blade ends at an angle with the axis of rotation and including support means allowing for axial movement of the shroud to effect an adjustment of the radial clearance between the blade tips and the shroud. A closed loop control may also be provided to position the shroud responsive to the sensed blade tip clearance.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. 1 is a side view in partial cross-section of one type of turbomachine in which the invention is employed,

FIG. 2 is a cross-sectional view of the turbomachine along the line 2—2 of FIG. 1,

FIG. 3 is an enlarged partial cross-section of the same turbomachine showing a first embodiment of the subject invention,

FIG. 4 is a cross-sectional view of the seal assembly showing the seal assembly fully open,

FIG. 5 is a cross-sectional view of the seal assembly showing the seal assembly in a minimum clearance position,

FIG. 6 is a top view partially in section, showing the actuators of the first embodiment,

FIG. 7 is a cross-sectional view of a second embodiment showing the seal closed,

FIG. 8 is a cross-sectional view along the line 8—8 of FIG. 7, and

FIG. 9 is a cross-sectional view of a third embodiment utilizing a clearance detector and control system to position the shroud and control the seal clearance.

Referring now to FIGS. 1 and 2, a turbojet 1 is illustrated of one type to which the subject invention may be applied. This turbojet is a fan-type generally described in U.S. Patent 2,999,631, Wollmershauser, entitled "Dual Airfoil" and assigned to the same assignee. Generally the turbojet comprises a gas generator 7 with a fan 8 comprising an outer casing 9, a rotor 10, with radially attached blades or buckets 11 comprising a turbine blade portion 12 and a compressor blade portion 13. An annular shroud 14 is supported from the outer casing and seals between the compressor blade 7 and the shroud. However differential thermal expansion exists between these blades and the shroud because the turbine blade portion of the rotor is exposed to the hot exhaust gases from the turbojet and the compressor blade portions are exposed only to cool secondary air making such sealing difficult to accomplish. It is the improvement of this sealing to which the subject invention is directed by providing a means for adjusting the clearance between the blade tips and shroud. Such adjustment must be accomplished in a precise manner as will be pointed out hereinafter in view of the relative small clearance being controlled when compared to the diameter of the rotor.

In FIG. 3 is illustrated the outer casing member 9, the compressor blades 13, shroud 14 and a seal 20 supported between this shroud and the tips of the rotor blades for sealing therebetween. This seal may be of the well known honeycomb or abradable type which, if contact results between the seal and the rotor blades such as that caused by differential thermal expansion, will abrade so that such contact will not harm the rotor blade tips and sealing will still be effected by the seal member. Shroud

member 14 is annular and as illustrated in FIG. 4, is triangular cross-sectioned with the side 14a being of a truncated cone configuration forming a gas passageway. As illustrated here, the invention is employed in a compressor wherein the passageway becomes smaller from front to rear due to the truncated cone configuration of the shroud, and the blade tips are positioned adjacent the shroud defining a similar truncated cone configuration when the rotor is rotated about the axis of rotation. The other sides of the shroud 14b and 14c complete the shroud assembly to provide a rigid box-like structure for proper sealing and structural rigidity.

To support the shroud there is attached to the sides 14b a track assembly 21 comprising elongated projections 22 extending helically along the shroud member 14b with rollers 23 attached thereto in openings 24 by a shaft 25 extending through the openings. Extending from the outer casing member 9 on either side of the projections 22 are a pair of co-operating projections 27 and 28 which contact the rollers 23 in a manner to provide a helical roller track to support the shroud 14 within the turbomachine and yet allow movement of the shroud within the turbomachine casing 9 along this helical track type support arrangement.

As illustrated in FIGS. 4 and 5, it may be seen that the outer casing 9 is made up of individual sections so that it may be separated at the flange joint 30 and 31 by removal of the bolt fasteners 32 and 33 for ease of removal of the shroud and seal assembly for maintenance, etc. It further may be seen by comparison of FIGS. 4 and 5 that differential axial movement between the shroud and rotor by axial movement of the shroud 14, because of its truncated cone shape, results in an adjustment of the radial clearance between the tip of the rotor blade 14 and the seal member 20. This is true since the blade tips and shroud are parallel and form equal angles with the axis of rotation so that relative movement closes the clearance therebetween uniformly. The track assemblies 21 described heretofore by which the shroud member is supported allows a continuous adjusting of the clearance between the blade tips and the seal. As further illustrated in these figures, other structural members such as the member 31' may be provided to add structural rigidity to the turbomachine casing while the inner casing member 35 may be supported from the outer casing member 9 to provide a stator vane support and an outer duct wall for the annular gas passage of the turbomachine.

Turning now to FIG. 6, it may be seen that in this embodiment the track assemblies 21 by which the shroud is supported are located at an angle with the axis of the turbomachine to form a helix. To move the shroud assembly, the actuators 39 are provided comprising a hydraulic cylinder 40 supported at one end by a bracket 41 extending between the casing member 9 and the cylinder end plate. Within the cylinder 40 is located a piston 42 with a shaft 43 attached thereto. The shaft 43 extends through one end of the cylinder 40 and is attached by suitable bracket means 44 to the shroud wall 14b. By selectively controlling the flow of hydraulic fluid into the inlets 45 and 46 the positioning of the piston 42 may be controlled and since the cylinder 40 is anchored to the outer casing 9, the movement of the piston 42 and piston rod 43 with respect to the cylinder 40 rotates the shroud 14 and moves it axially in a manner similar to a large nut on a multiple screw thread. However, with respect to a fixed axial reference point, shroud wall 14a also moves radially to change the seal clearance measurement equally along the axial length of the shroud and blade tip.

By locating the track assembly 21 at an angle with the turbomachine axis to form a screw thread type assembly it may be seen that axial movement of the shroud wall 14a results in radial movement thereof to control the seal clearance as illustrated better in FIGS. 4 and 5. By utilizing this screw thread assembly the stroke of the hy-

draulic actuator 40 may be longer to provide for finer adjustment of the position of the shroud and, even more importantly, to prevent cocking or wedging of the shroud as the shroud is moved or subjected to the pressures of the gas stream. The reason for this is that due to the cone shape of the shroud exposed to the axial gas passage in the turbomachine many forces, some non-uniform, are exerted on the shroud by the gas within the primary passage which bear on the shroud assembly and this screw thread feed prevents such action in a manner to allow smooth positioning of the shroud. Also, by arranging the screw feed on the shroud such that for reducing the clearance, the shroud must be rotated counter to the rotation of the rotor, the seal clearance mechanism is fail safe since any rub between the shroud and rotor will tend to rotate the shroud in a direction to increase seal clearance. Further, by positioning the shroud by this rotating helical movement rather than by strict axial movement, the actuators are synchronized to act together therefore a fewer number of actuators may be utilized for proper shroud positioning. However, it should be kept in mind that in certain applications it may be advantageous to actuate the shroud only axially with equally beneficial seal clearance adjustment. An outer shield 47 may be provided around the actuators to prevent outside matter from contaminating the mechanism.

FIGS. 4 and 5 show the two positions of the shroud, it may be seen that by supplying pressured hydraulic fluid to the actuator 40 the shroud may be moved axially to vary the clearance between the rotor blade tip 13 and the seal 20. For instance by supplying pressured fluid to the inlet 46, the shroud may be moved from the position illustrated in FIG. 4 to that of FIG. 5. As the shroud moves axially and radially, a seal 50 supported from the shroud 14 and a seal 51 supported from the duct wall 35 prevents the gas leakage from the duct at the downstream end of the shroud. While a void is left at the upstream edge of the shroud which could be sealed in the same manner, this void is sealed by the turbomachine casing member 9 to prevent any actual flow of gas through this void therefore the void has negligible effects on the primary flow stream. It is therefore obvious that there is provided a continuously adjustable seal around the outer periphery of the rotor blades to adjust the seal clearance to that desired for optimum performance of the turbomachine with the position of the shroud being controlled by some clearance sensing means which makes automatic operation possible.

Turning now to FIGS. 7 and 8 therein is illustrated a second embodiment of the invention employed in a turbomachine. Here the duct forming the gas passage 60 through which the rotor blades 61 project includes a shroud member 62 supporting a seal member 63. The shroud member 62 is of a similar triangular cross-section as in the previous embodiment. The shroud is supported from the outer casing member 65 by the projections 66 cooperating with similar projections 67 forming a screw thread arrangement extending from the outer casing 65 to form a toothed arrangement which may extend in a helix much in the same manner as the track assembly of the first embodiment. These teeth may be coated by a suitable lubricating material such as a lining 68 of a tetrafluoroethylene polymer type to reduce the friction between the members and thereby reduce the actuating forces necessary.

In this embodiment the actuating means consists of one or more fluid or electric motors 70 driving through a gear member 71 a large diameter gear 72 forming a drive similar to a rack and pinion gear drive on the shroud member to control the helical motion of the shroud member. As pointed out heretofore, because of the configuration of the projections 66 and 67 forming helical teeth, by moving the shroud 62 axially radial movement of the shroud member 63 is also effected thereby controlling the seal clearance between the seal member 63 supported

from the shroud 62 and the tips of the rotor blades 61. It may be seen that this embodiment provides a different yet equally advantageous method of supporting and actuating the shroud member to control the seal clearance.

In FIG. 9 is illustrated still another embodiment of the invention. As illustrated and described in FIGS. 1 through 6, the shroud 14 is movable by action of the hydraulic actuator 39. However, to control the actuator, a closed loop control system is employed comprising a clearance sensor 65, a sensor control 66 and associated connecting lines which through the hydraulic control 67 regulates the flow of hydraulic fluid to the actuator 40 to position the shroud and control the clearance. The sensor 65 may be one of several types, for instance one that either detects stresses or heat within the shroud which results from contact between the shroud 14 and blade tips 13 or one that detects the proximity of the rotor by magnetic fields, etc. The sensor control 66 receives the signal from the sensor 65 and in turn regulates the hydraulic control 67 to properly position the shroud through the actuator 40 controlling the supply of hydraulic fluid to the actuator.

It is obvious from the foregoing that herein is described a means for controlling seal clearances between a rotating and stationary member by allowing for continuous positioning of the stationary member for optimum seal clearance. While particular embodiments of the invention have 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. For instance, in some applications of the invention it might be advantageous to provide for differential axial movement between the shroud and rotor by providing for axial movement of the rotor instead of the shroud to vary the clearance therebetween, however this is considered within the scope of the invention.

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

1. An axial flow turbomachine comprising:

a cylindrical outer casing, said outer casing having means forming a plurality of helical grooves on the inner surface thereof;

an annular shaped shroud, said shroud fitting within said casing and having outer radially extending projections interfitting with said casing grooves to support said shroud, said shroud forming an axially extending gas passage having one end of a larger diameter than the other;

a rotor supported for rotation within said shroud, said shroud and rotor having their adjacent portions lying in straight parallel lines intercepting the axis of rotation of said rotor at an acute angle, such that upon rotation of either said lines define a truncated cone;

means to rotate said shroud, wherein by rotation said shroud is moved axially to vary the radial clearance between it and said rotor.

2. An axial flow turbomachine assembly comprising: an outer annular shaped shroud;

a rotor assembly supported for rotation around an axis of rotation within and spaced from said shroud, wherein adjacent edges of said rotor and said shroud

lying in straight parallel planes form an acute angle with and intercept said axis of rotation;

means to effect differential axial movement between said shroud and said rotor assembly; and

sensing means to detect the clearance between said shroud and said rotor assembly and control said differential axial movement.

3. An axial flow turbomachine assembly comprising:

a rotor having a plurality of radially extending blades supported thereon, said rotor blades having tip portions cut along straight lines angularly disposed with respect to the axis of rotation of the rotor so that upon rotation of the rotor said tip portions define a truncated cone;

an annular shroud member having an inner wall in the form of a truncated cone having a diameter larger than and cone angle equal to the truncated cone defined by said rotating rotor blade tip portions, said shroud member being disposed in a spaced, surrounding relation with respect to said blade tip portions to provide clearance between the shroud member and said tip portions;

means rotatable with respect to said axis and operable to support said shroud member within said turbomachine for axial movement relative to said blades, wherein said clearance between said blade tip portions and said shroud is varied radially as said shroud member moves axially.

4. An axial flow turbomachine comprising:

an outer cylindrically-shaped casing member, said casing member having internal screw threads thereon; an annular shroud having a truncated cone configuration and forming the outer boundary of a gas passage through said turbomachine;

means supporting said shroud in said casing including external screw threads on the shroud interfitting with said casing internal threads;

a rotor assembly located within said shroud in spaced relation therefrom and supported for rotation around an axis of rotation colinear with the turbomachine axis, said rotor assembly having outer end portions adjacent said shroud cut along straight lines parallel to said shroud and angularly disposed with respect to said axis of rotation so that upon rotation of the rotor assembly said lines define a truncated cone;

actuating means for rotating said shroud to cause said shroud to move axially with respect to said outer end portions of said rotor assembly, said rate of movement being controlled by said screw threads for varying the radial clearance between the shroud and said rotor assembly outer end portions.

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