April 16, 1963 — J. F. INGLESON — 3,085,398

VARIABLE-CLEARANCE SHROUD STRUCTURE FOR GAS TURBINE ENGINES

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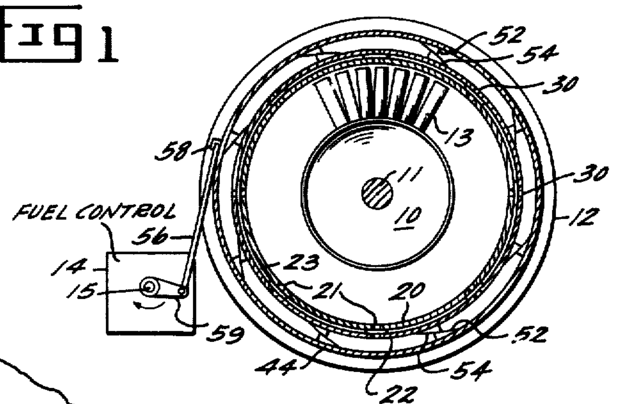
Fig 1



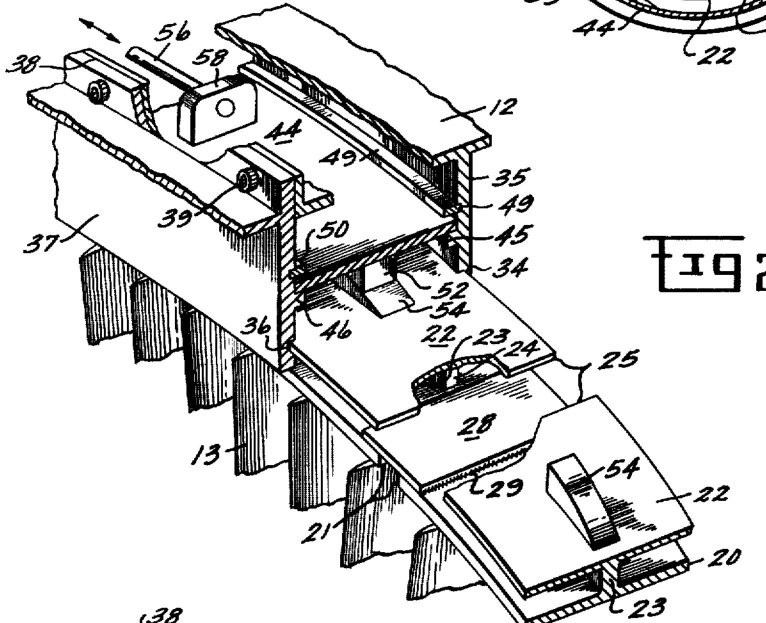


Fig 2

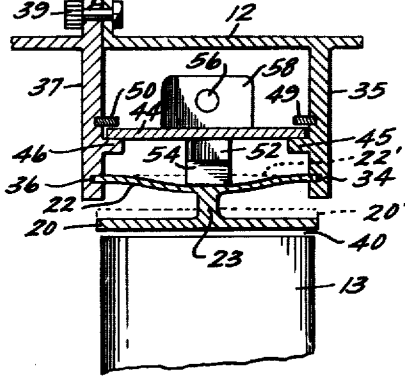


Fig 4

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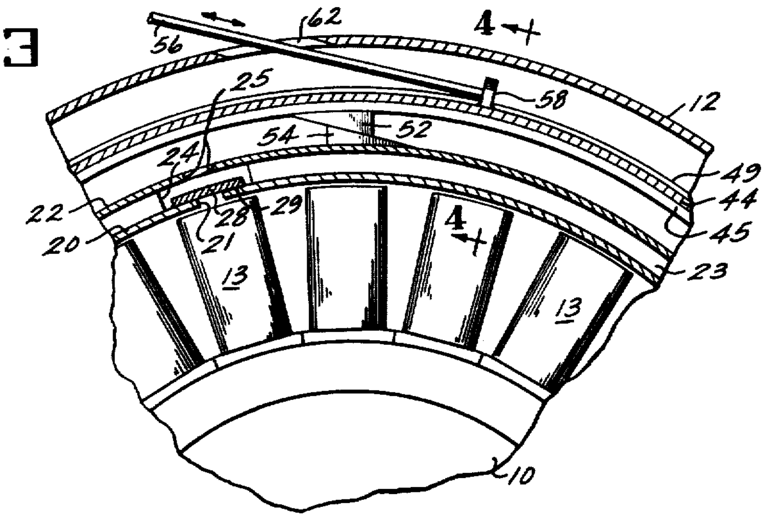
Fig 3



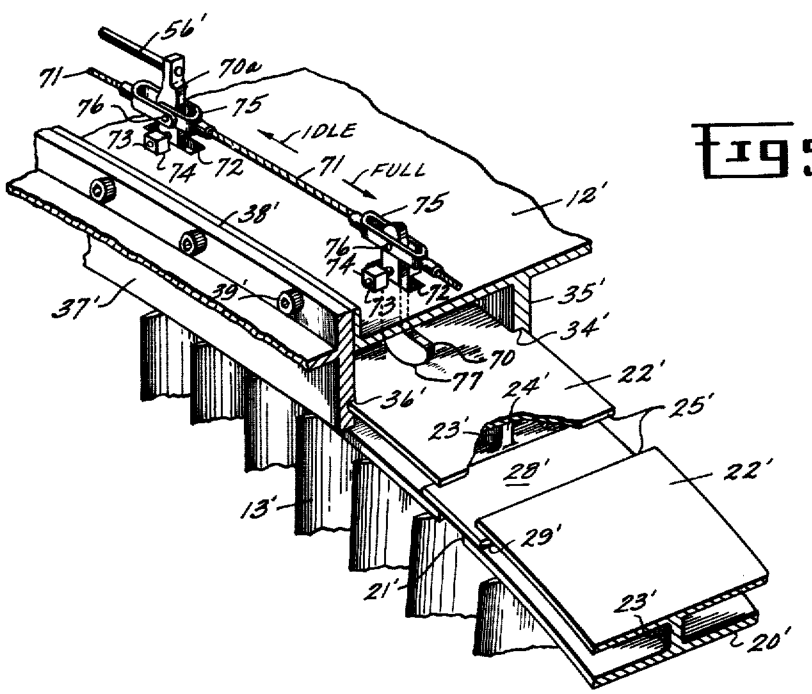


Fig 5

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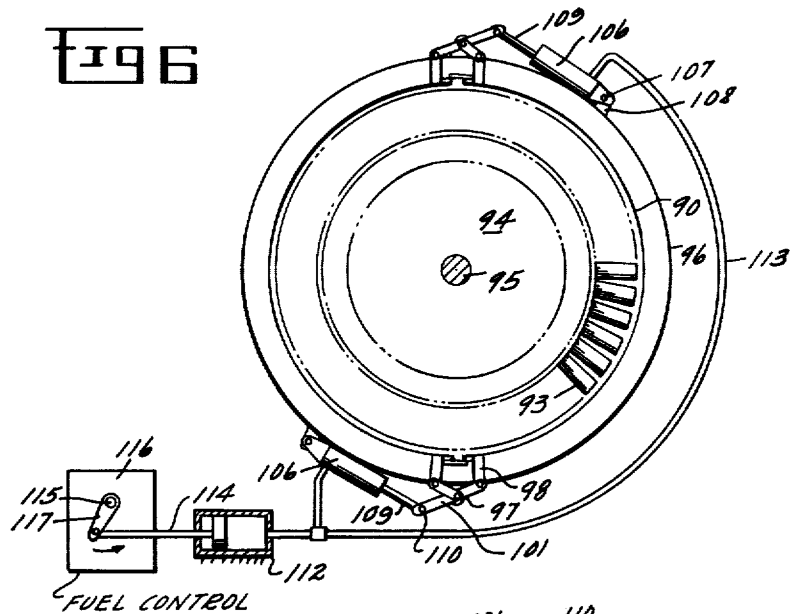
Fig 6



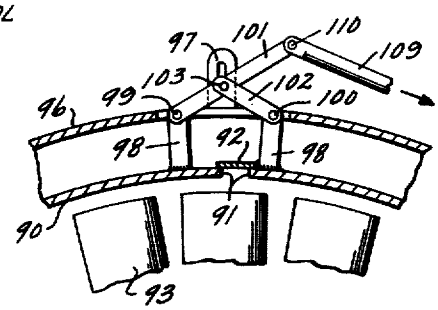


Fig 7

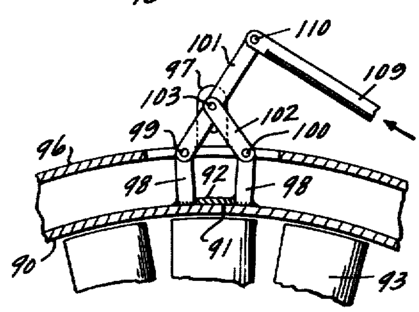


Fig 8

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VARIABLE-CLEARANCE SHROUD STRUCTURE FOR GAS TURBINE ENGINES

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8 Claims. (Cl. 60—39.32)

This invention relates to shroud structures for gas turbines, and more particularly to an improved structure for varying the clearance between the tips of the buckets of a turbine wheel and a shroud ring spaced circumferentially thereabout.

The tip clearance between the buckets of a turbine wheel and the surrounding shroud ring must be maintained at a minimum value to achieve satisfactory efficiency. Excessive clearance results in leakage of the operating fluid around the tips of the buckets. However, it is ordinarily found in practice that the shroud ring and the supporting casing exhibit thermal expansion and contraction to a greater extent, and at a more rapid rate, than does the turbine wheel. Sufficient clearance must therefore be provided to accommodate the most extreme conditions of relative thermal expansion and contraction which may be encountered, to avoid rubbing between the buckets and the shroud ring. The most severe condition occurs during a rapid engine shut-down or "throttle chop," when the shroud ring contracts very rapidly. It is necessary in conventional shroud structures to provide a wastefully large clearance in the normal operating condition of the turbine, if rubbing during a rapid shut-down is to be prevented. If the bucket tips are rubbed, increased clearance and leakage will occur during subsequent operation of the engine. An abradable shroud ring may be employed for intentional rubbing, but excessive leakage is not avoided by this expedient.

It is the primary object of my invention to provide an improved structure for varying the tip clearance between a turbine wheel and a surrounding shroud ring in compliance with the thermal condition of the parts, such as to afford reduced clearance without rubbing.

It is a further object of my invention to provide an improved structure for varying the diameter of a shroud ring to maintain a minimal clearance space about a turbine wheel under all conditions of relative thermal expansion of the shroud ring and the turbine wheel.

In general, I carry out my invention by providing a segmented shroud ring and arranging the segments for movement by linkage means to vary the diameter of the ring as a function of the rate of fuel flow to the turbine engine. The thermal conditions of the turbine wheel and shroud ring are responsive to the temperature of the working fluid supplied to the turbine, although with some retardation, and this temperature is directly controlled by the fuel flow rate. The "fuel flow rate" is a term commonly used in the art to indicate the throttle setting. Thus, it can be seen that the turbine temperature is directly controlled by the throttle setting. It is well known that the actual amount of fuel supplied to the combustor is a function of throttle setting as corrected by certain engine parameters such as, for example, compressor inlet temperature, compressor discharge pressure, and engine speed. This relationship between throttle setting and turbine temperature permits a definite tip clearance schedule to be maintained under widely varying thermal conditions of the parts, by controlling the clearance in accordance with the fuel flow rate or some function thereof, such as working fluid temperature.

According to a preferred embodiment of the invention, the segments of the shroud ring are carried by a segmented flexible support ring to form a composite ring,

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and cam means are provided for depressing the segments of the support ring and the shroud radially inwardly to decrease the clearance. The cam means are circumferentially spaced about the shroud ring, and are connected by a suitable linkage to means responsive to the fuel flow rate. These means preferably comprise the main fuel control of the engine. As the throttle of the fuel control is opened to increase the fuel flow rate, the shroud segments are depressed radially inwardly to decrease the turbine tip clearance. A reduction in fuel flow rate actuates the cam means to permit the flexible support ring to draw the shroud segments radially outwardly, thus compensating for the shrinkage of the shroud ring to prevent rubbing while maintaining a minimal clearance. Since the movement of the shroud segments occurs concurrently with the change in throttle setting, the adjustment anticipates the consequent relative expansion of the shroud and turbine wheel.

While the specification concludes with claims particularly pointing out and distinctly claiming the subject matter which I regard as my invention, it is believed that the aforementioned and other objects and features will be better understood and appreciated from the following detailed description of illustrative embodiments of the invention, referring to the accompanying drawings, in which:

FIG. 1 is a sectional end view of a gas turbine engine incorporating a first embodiment of the improved shroud structure;

FIG. 2 is a pictorial view of a fragmentary portion of the shroud structure;

FIG. 3 is a sectional end view of the parts shown in FIG. 2;

FIG. 4 is a sectional view taken along line 4—4 in FIG. 3, looking in the direction of the arrows;

FIG. 5 is a pictorial view of a fragmentary portion of a turbine engine incorporating another embodiment of the invention;

FIG. 6 is a sectional end view of a gas turbine engine incorporating still another embodiment of the invention;

FIG. 7 corresponds to FIG. 6, but shows a fragmentary portion of the shroud structure on an enlarged scale, with parts in a first adjusted position; and

FIG. 8 is a view similar to FIG. 7, but showing the parts in a second adjusted position.

Referring to FIGS. 1–4, a first embodiment of the invention is shown incorporated in a gas turbine engine which comprises a turbine wheel **10** rotatably mounted upon a shaft **11** within a casing **12**. The turbine wheel carries a row of turbine buckets **13** circumferentially spaced thereabout for expansion of a flow of working fluid to drive the wheel. The engine is provided with conventional fuel flow control means **14**, for regulating the rate of flow of fuel to a combustor (not shown) and thus controlling the temperature of the flow of working fluid supplied to the turbine. The fuel control includes a shaft **15**, whose rotary position is a function of the rate of fuel flow to the engine; for example, the shaft position may be controlled by the temperature of the working fluid as it enters the turbine, or in direct response to the fuel flow rate. The turbine engine may be of any well-known type suited to a particular application, and no further detailed description thereof is believed necessary.

In order to confine the flow of working fluid to the passages between the turbine buckets **13**, a shroud ring is customarily mounted in the casing, circumferentially spaced about the buckets to form an annular clearance space therebetween. It has been found in practice that upon a change in throttle setting and a consequent change in the temperature of working fluid supplied to the turbine, the turbine wheel and the shroud ring and casing expand or contract at different rates, altering the clearance space therebetween. In the event of a rapid reduction in fuel flow rate, known as a "throttle chop," the shroud ring and casing may contract so rapidly that rubbing of the tips of the buckets occurs, with the result that the clearance is subsequently increased, or that the buckets fail catastrophically. To avoid these eventualities, it is customary to provide sufficient clearance to prevent rubbing under the most extreme conditions of relative thermal expansion which are expected to be encountered. The increase in clearance in a normal operating condition is accompanied by excessive leakage of working fluid past the tips of the buckets, with a corresponding loss of efficiency.

According to the present invention, a shroud ring is segmented and arranged for adjustment of the radial positions of the segments as a function of the rate of fuel flow to the engine. By these means it is possible to maintain desired clearances under all operating conditions, regardless of the rapidity of change of the throttle setting.

In the embodiment of FIGS. 1–4, a shroud ring **20** is supported in a flexible support ring **22** by a circumferentially- discontinuous radially-extending web **23**, to form a composite ring. The shroud ring, support ring, and web are segmented by a plurality of circumferentially-spaced interruptions **21**, **24**, and **25**, respectively. The interruptions of the web are recessed from those of the shroud ring to accommodate a plurality of sealing plates **28**. Each of the plates **28** is brazed at **29** to a circumferential end of one of the segments of the shroud ring, and overlies the circumferential end of the adjacent segment in circumferentially slidable relation to prevent leakage of working fluid from the gas path through the space between the segments. The segments of the support ring are supported in flanges **35** and **37** of the casing **12**, being received in circumferentially-spaced relation in annular grooves **34** and **36** formed in the flanges, respectively. The composite ring is thus mounted in the casing for flexure of the segments of the support ring to vary the radial positions of the segments of the shroud ring.

The casing **12** is preferably split on a radial plane as at **38** to facilitate assembly of the shroud ring and the associated elements, but may assume any desired form, as will be understood by those skilled in the art. The casing sections are joined by a plurality of fasteners **39** following the assembly of the shroud structure therein. According to conventional practice, the casing may also be split upon a diametral plane passing through the axis of the shaft **11**, to facilitate assembly of the turbine wheel and additional elements of a rotor within a stator structure caried by the casing.

Linkage means are provided to adjust the radial dimension of an annular clearance space **40** between the shroud ring **20** and the tips of the blades **13**. These means include a control ring **44** which is mounted in circumferentially-slidable relation upon flanges **45** and **46** extending circumferentially about the flanges **35** and **37**, respectively. A pair of locking rings **49** and **50** are inserted in suitable annular recesses formed in the flanges **35** and **37**, respectively, to retain the control ring **44** against radial distortion with respect to the casing. A plurality of cams **52** are brazed or otherwsie suitably secured in circumferentially-spaced relation about the interior surface of the control ring, and each cam slidably engages a corresponding one of a plurality of cams **54**, which are fixed to the outer circumference of the support ring **22**. The longitudinal edges of the support ring have a force fit in the grooves **34** and **36**, to restrain the segments of the composite ring against rotation relative to the casing. Rotation of the control ring in a counter-clockwise direction, as viewed in FIGS. 1 or 3, urges the segments of the shroud ring radially inwardly toward the position shown in full lines in FIG. 4, against the bias of the flexible support ring **22**. Rotation in a clockwise direction allows the support ring to urge the segments radially outwardly toward the position shown in dotted lines at **20'** in FIG. 4.

The control ring **44** is drivingly connected with the shaft **15** of the fuel control **14** by means of a push-rod **56**, which is threaded into an ear **58** brazed to the control ring. A crank **59** is mounted upon the shaft **15** and pivotally connected to the push-rod in such a manner that an increase in the rate of fuel flow to the engine causes the arm to rotate in the direction shown by the arrow in FIG. 1, and to move the control ring in a counterclockwise direction to decrease the radial dimension of the clearance space **40**. The push-rod **56** passes through a suitable opening **62** (FIG. 3) formed in the casing to the fuel control. Upon a reduction in throttle setting, the push-rod is actuated to move the control ring in a clockwise direction, thus increasing the clearance space by permitting movement of the shroud ring **20** toward the retracted position **20'** (FIG. 4). In this manner, the clearance is adjusted as a function of the rate of fuel flow, in this case in inverse response to the temperature of the working fluid supplied to the turbine wheel. The movement of the shroud ring anticipates the relative thermal growth of the parts resulting from a change in working fluid temperature, and is effective to prevent rubbing of the shroud ring by the bucket tips even though a small clearance space is provided.

In the embodiment of FIGS. 1–4, a direct driving connection is established by the push-rod **56** between the fuel control **14** and the control ring **44**. In certain applications, it may be found that a delayed response to an increase or a decrease in throttle setting, or both, is preferable. For this purpose, the push-rod **56** may be actuated by means which are responsive to the temperature of an element of the shroud structure, rather than the fuel flow rate. The temperature of the parts of the shroud structure is a delayed function of the fuel flow rate. Alternatively, a delayed response to movement of the shaft may be obtained by modifying the linkage to include various well-known mechanical expedients, such as lost-motion linkages, multilated gear drives, etc.

A delayed response to changes in throttle setting may prove quite necessary where it is found that a diminution of the clearance space immediately upon an increase in throttle setting, which anticipates an increase in the temperature of the parts, results in rubbing of the bucket tips. At the same time, an increase of the shroud diameter upon a throttle chop, in anticipation of the thermal shrinkage of the shroud ring, may be desired as a safety factor. To accommodate these diverse response rates, time delay or lost-motion means may be arranged to be operative only upon an increase in the throttle setting, while a direct response ensues upon a decrease in throttle setting. Various mechanical means for securing these relationships will readily occur to those skilled in the art. It should also be noted that the specific form of the cams **52**, **54** may be varied to afford any desired programmed relationship between the magnitude of the clearance space and the fuel flow rate.

Referring to FIG. 5, a modification is shown in which the linkage means drivingly connecting the fuel flow control means with the shroud ring comprises a plurality of cams **70**, **70*a***, rotatably mounted directly in the casing, and inter-connected for joint actuation by links **71** rather than by a circumferential control ring. Parts similar to those in the embodiment of FIGS. 1–4 are similarly numbered, with prime superscripts. One of the cams **70*a*** is formed with a radial extension for threaded engagement with a push rod **56'** for actuation of the cams by suitable fuel flow control means (not shown). Each cam extends interiorly of the casing through one of a plurality of circumferentially-spaced slots **72**, and is pivotally mounted by means of a pin **73** received in a pair of blocks **74** brazed on the exterior surface of the casing adjacent to the corresponding slot. A pair of yokes **75** is pivoted at 76 upon each cam exteriorly of the casing, so that actuation of the push rod 56′ rotates each of the cams 70 or 70*a* about its pivot 73. A cam surface 77 of each of the cams is arranged to slidably engage the periphery of the support ring 22′ at the approximate axial and circumferential center of a segment thereof. Actuation of the push rod 56′ in the direction shown by the arrow marked "full" reflexes the segments of the shroud ring radially inwardly to decrease the shroud clearance, while actuation in the direction of the arrow marked "idle" permits the flexible support ring 22′ to withdraw the segments of the shroud ring radially outwardly to provide an increased clearance. The operation of the shroud structure is otherwise similar to that shown in the embodiment of FIGS. 1–4.

In FIGS. 6–8, a simplified embodiment of the improved shroud structure is shown, in which cam means are omitted from the actuating linkage, and the flexible support ring is eliminated from the structure of the shroud ring. The shroud ring 90 is shown divided into only two segments by means of circumferential interruptions 91; however, it may be divided into as many segments as desired. A sealing plate 92 is brazed upon the circumferential end of a segment at each interruption, and overlies the circumferential end of the adjacent segment in circumferentially-slidable gas-sealing relation. The shroud ring is spaced about a row of turbine buckets 93 mounted upon a turbine wheel 94 which is rotatably supported by a shaft 95. A surrounding casing 96 is provided with a plurality of stanchions 97 for supporting the segments of the shroud ring in spaced relation about the buckets 93. A supporting post 98 is brazed or otherwise suitably secured upon each segment adjacent to each circumferential interruption 91 thereof. Adjacent pairs of posts 98 are pivotally connected at 99 and 100 to a link 101 and a link 102, respectively, and the links are pivotally secured at 103 upon the stanchion 97. In this manner, the links support the segments of the shroud ring and are rotatable about the pivot 103 to adjust the clearance space about the buckets 93; this adjustment is accompanied by variation of the circumferential spacing between the segments. The segments should be formed to afford a circular configuration in the position of minimum clearance as shown in FIG. 8, in order to afford the least possible leakage without rubbing. In the maximum-clearance position of the segments shown in FIG. 7, the shroud will therefore be non-circular, and the clearance will vary slightly over the periphery of the turbine wheel. It will be apparent that a more uniform clearance may be established by dividing the shroud ring into a greater number of segments.

For controlling the clearance of the shroud ring as a function of the fuel flow rate, I provide an hydraulic actuator 106 for each linkage, and pivotally mount the actuators at 107 upon ears 108 secured to the casing. A drive rod 109 of each actuator is pivotally secured to a link 101 at 110. A piston-pump 112 is connected by means of a branch conduit 113 to each of the actuators in parallel, and an actuating shaft 114 of the pump is drivingly connected to the shaft 115 of a fuel flow control means 116 by an arm 117. An increase in the rate of fuel flow to the engine is accompanied by rotation of the arm 117 in the direction shown by the arrow, causing the pump 112 and the actuators 106 to drive the push rods 109 in the direction shown by the arrow in FIG. 8, thus decreasing the area of the clearance space about the turbine wheel. Conversely, a decrease in the flow rate causes the push rod 109 to be drawn in the direction of the arrow in FIG. 7, increasing the area of the clearance space. The operation of the shroud structure is otherwise similar to that described in the previous embodiments.

While I have described specific embodiments of my invention for purposes of illustration, it should be understood that my invention is not limited to the specific details of construction and arrangement thereof therein illustrated, and that changes and modifications may readily occur to those skilled in the art without departing from the true spirit and scope of my invention. I aim in the appended claims to cover all such changes and modifications.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In a gas turbine engine, a turbine wheel, fuel flow control means for regulating the temperature of a flow of working fluid to said turbine wheel, a segmented shroud ring, means adjustably supporting said shroud ring circumferentially about said turbine wheel to form a variable annular clearance space thereabout, and linkage means drivingly connecting the segments of said shroud ring with said fuel flow control means to adjust said clearance space in opposition to the normal clearance variation resulting from the relative thermal characteristics of said turbine wheel and said shroud ring, said clearance space being varied as a function of the rate of fuel flow supplied to the gas turbine engine by said fuel flow control means.

2. In a gas turbine engine, a turbine wheel, fuel flow control means for regulating the temperature of a flow of working fluid to said turbine wheel, a segmented shroud ring, means supporting said shroud ring circumferentially about said turbine wheel for adjustment of the radial positions of the segments thereof with respect to said turbine wheel to form a variable annular clearance space about said turbine wheel, and linkage means drivingly connecting the segments of said shroud ring with said fuel flow control means to adjust said clearance space in opposition to the normal clearance variation resulting from the relative thermal characteristics of said turbine wheel and said shroud ring, said clearance space being varied as a function of the rate of fuel flow supplied to the gas turbine engine.

3. In a gas turbine engine, a casing, a turbine wheel rotatably mounted in said casing, fuel flow control means for regulating the temperature of a flow of working fluid to said turbine wheel, a segmented shroud ring, a segmented flexible support ring mounted in said casing, said support ring supporting the segments of said shroud ring circumferentially about said turbine wheel in radially adjustable relation thereto to form a variable annular clearance space thereabout, and linkage means drivingly connecting the segments of said support ring with said fuel control means and arranged for flexure of said support ring to adjust said clearance space in opposition to the normal clearance variation resulting from the relative thermal characteristics of said turbine wheel and said shroud ring, said clearance space being varied as a function of the rate of fuel flow supplied to the gas turbine engine.

4. The combination recited in claim 3, in which said shroud ring and said support ring are circumferentially spaced apart, together with a circumferentially-discontinuous web connecting each of the segments of said shroud ring with a corresponding one of the segments of said support ring.

5. In a gas turbine engine, a casing, a turbine wheel rotatably mounted in said casing, fuel flow control means for regulating the temperature of a flow of working fluid to said turbine wheel, a segmented shroud ring, means movably supporting said shroud ring in said casing circumferentially about said turbine wheel for adjustment of the radial positions of the segments thereof to form a variable annular clearance space about said turbine wheel, cam means arranged for movement to adjust the radial positions of said segments, and linkage means drivingly connecting said cam means with said fuel flow control means to adjust said clearance space in opposition to the normal clearance variation resulting from the relative thermal characteristics of said turbine wheel and said shroud ring, said clearance space being varied as a func-

tion of the rate of fuel flow supplied to the gas turbine engine.

6. In a gas turbine engine, a casing, a turbine wheel rotatably mounted in said casing, fuel flow control means for regulating the temperature of a flow of working fluid to said turbine wheel, a segmented shroud ring, a segmented flexible support ring mounted in said casing, said support ring supporting the segments of said shroud ring circumferentially about said turbine wheel in radially adjustable relation thereto to form a variable annular clearance space thereabout, cam means arranged for movement to flex said support ring, and linkage means drivingly connecting said cam means with said fuel flow control means to adjust said clearance space in opposition to the normal clearance variation resulting from the relative thermal characteristics of said turbine wheel and said shroud ring, said clearance space being varied as a function of the rate of fuel flow supplied to the gas turbine engine.

7. In a gas turbine engine, a casing, a turbine wheel rotatably mounted in said casing, fuel flow control means for regulating the temperature of a flow of working fluid to said turbine wheel, a segmented shroud ring, a segmented flexible support ring mounted in said casing, said support ring supporting the segments of said shroud ring circumferentially about said turbine wheel in radially adjustable relation thereto to form a variable annular clearance space thereabout, a control ring supported for circumferential movement in said casing, cam means arranged for movement to flex said support ring, said cam means comprising a plurality of circumferentially-spaced pairs of cams, the members of each pair of said cams being mounted on said control ring and said support ring, respectively, and being slidably engaged to flex the segments of said support ring upon circumferential movement of said control ring, and linkage means drivingly connecting said fuel control means to said control ring for circumferential movement thereof to adjust said clearance as a function of the rate of fuel flow supplied to the gas turbine engine.

8. In a gas turbine engine, a casing, a turbine wheel rotatably mounted in said casing, fuel flow control means for regulating the temperature of a flow of working fluid to said turbine wheel, a segmented shroud ring, a segmented flexible support ring mounted in said casing, said support ring supporting the segments of said shroud ring circumferentially about said turbine wheel in radially adjustable relation thereto to form a variable annular clearance space thereabout, a plurality of cams pivotally mounted in circumferentially-spaced relation about said casing, each of said cams slidably engaging a corresponding segment of said support ring for flexure thereof, and linkage means drivingly connecting said fuel flow control means to said cam means for pivotal movement of said cams to adjust said clearance as a function of the rate of fuel flow supplied to the gas turbine engine.

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