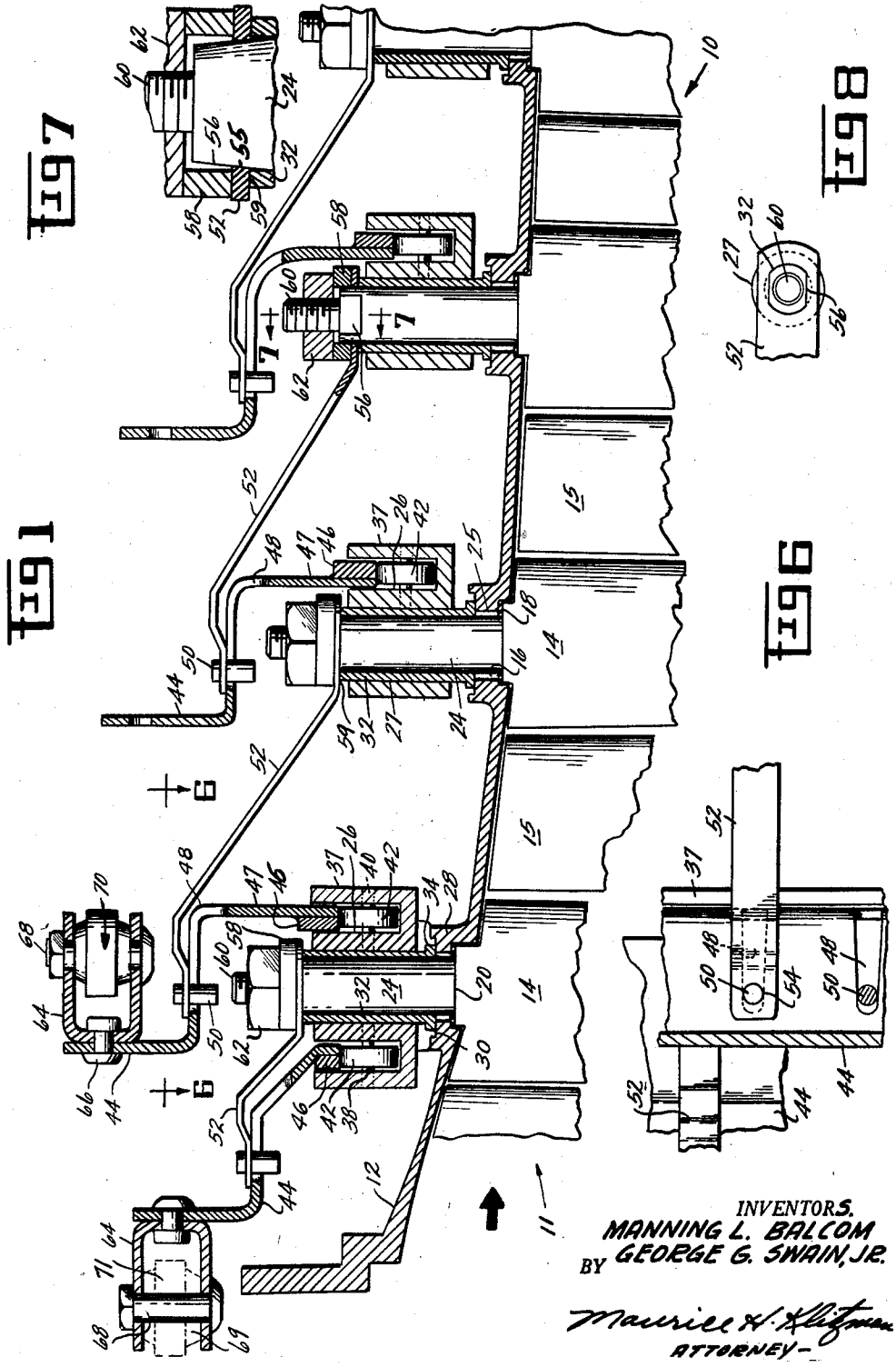
May 10, 1960 M. L. BALCOM ET AL 2,936,108

COMPRESSOR

Filed April 29, 1957 3 Sheets-Sheet 1



INVENTORS.
MANNING L. BALCOM
BY GEORGE G. SWAIN, JR.

Maurice H. Klitzman
ATTORNEY-

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COMPRESSOR

Filed April 29, 1957 3 Sheets-Sheet 2

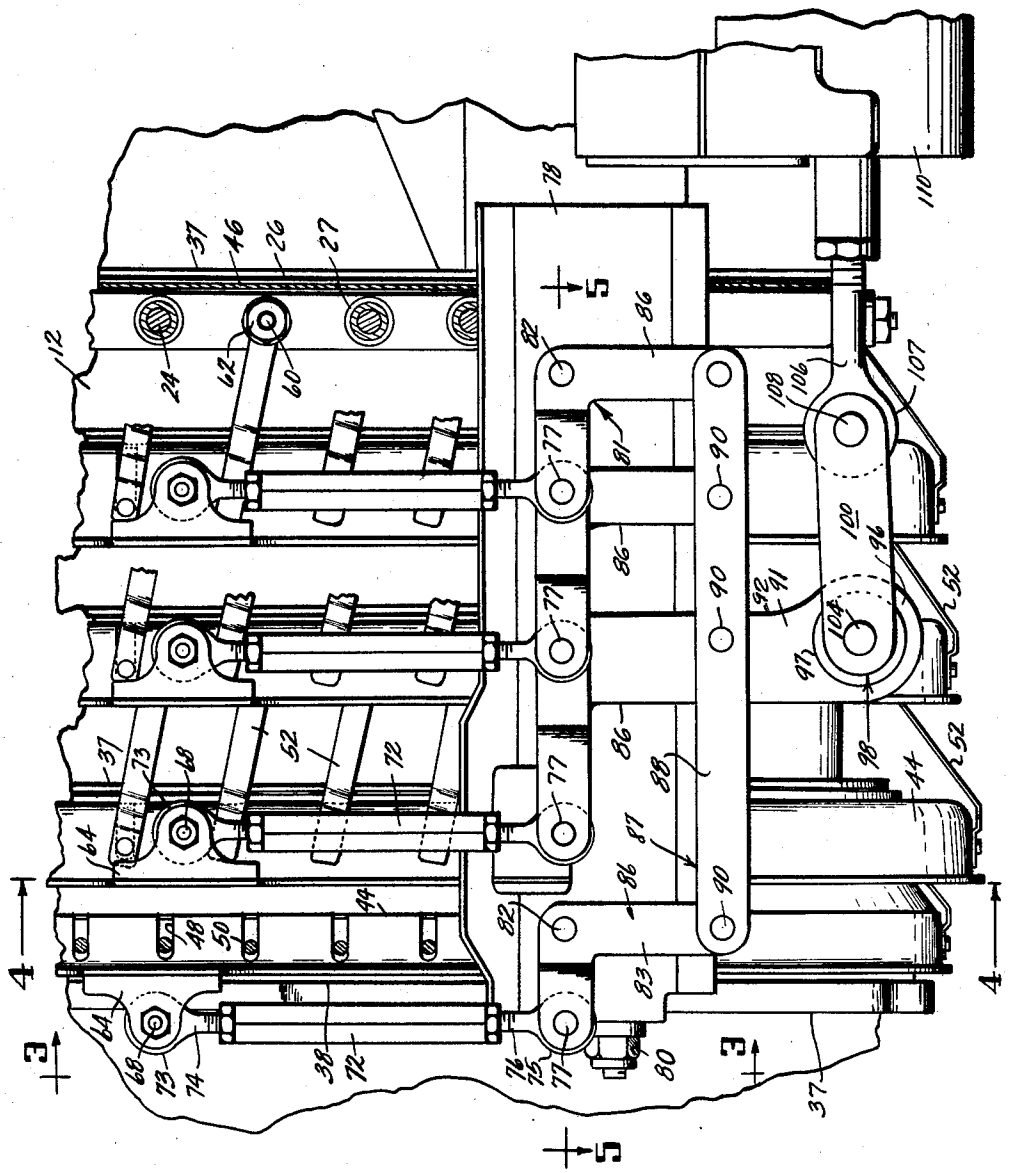


Fig 2

INVENTORS.
MANNING L. BALCOM
BY GEORGE G. SWAIN, JR.
Maurice H. Klitzman
ATTORNEY.

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Fig 5

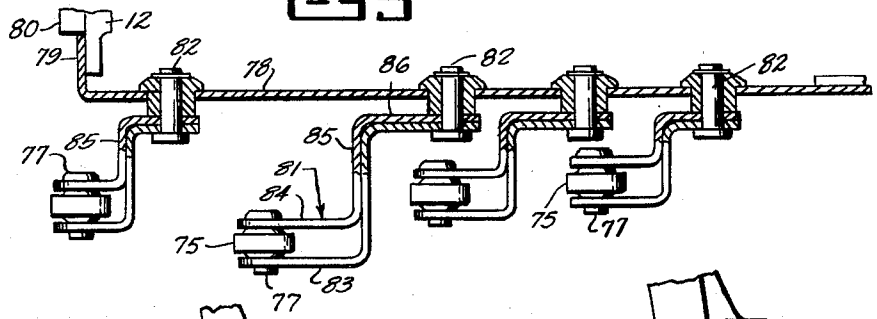
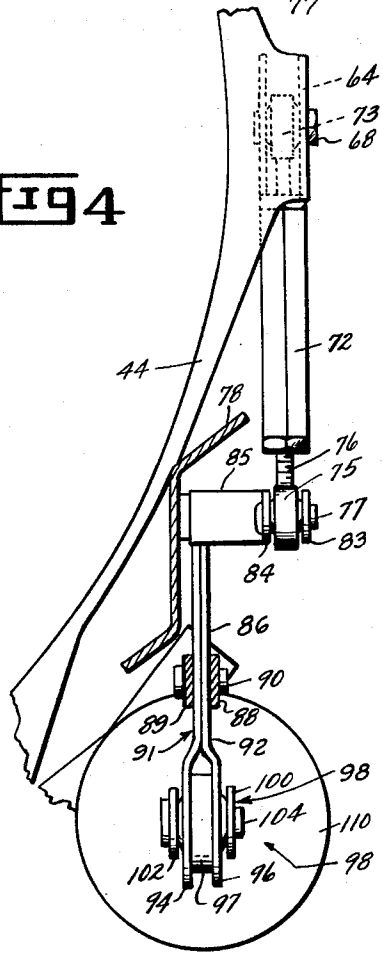


Fig 4



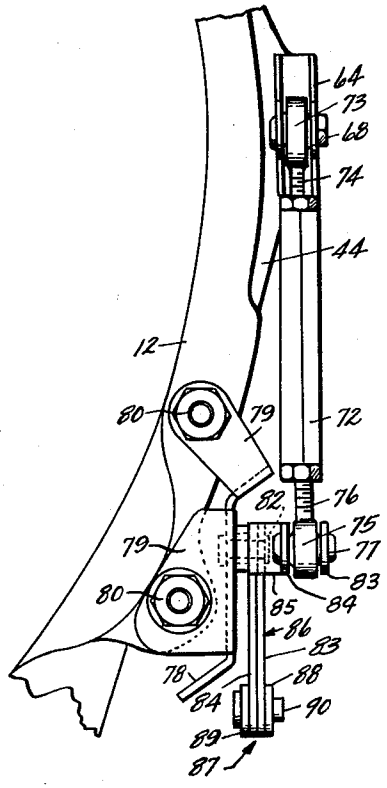


Fig 3

INVENTORS.
MANNING L. BALCOM
BY GEORGE G. SWAIN, JR.
Maurice A. Klitzman
ATTORNEY

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2,936,108

COMPRESSOR

Manning Longley Balcom, Melrose, and George Gilbert Swain, Jr., Marblehead, Mass., assignors to General Electric Company, a corporation of New York

Application April 29, 1957, Serial No. 655,755

3 Claims. (Cl. 230—114)

This invention relates to a gas turbine (turboshaft) engine which is provided with an axial flow compressor, and in particular, to a means for simultaneously varying the position of several rows of stator vanes in the compressor of a turbojet engine.

More power can be obtained from a gas turbine engine by providing a higher pressure ratio compressor for the engine. However, whenever a conventional high pressure ratio compressor with fixed stator vanes is used, stall characteristics occur during various part speed conditions. This is due to the fact that when a compressor is designed for a high speed, high pressure operating condition, the stator vanes are designed to have a particular angle of attack to give the most efficient operation at that particular operating condition. During starting or at some part speed condition, the angle of attack of the front rows of vances will become mismatched from the rows of vanes in the rear of the compressor if the stator vanes are fixed, and, thereby create stall. In other words, at the part speed or starting condition, the rear stages cannot take the quantity of air that is being passed to it by the front stages. Accordingly, back pressure is built up so as to choke the compressor. In order to prevent this stall characteristic from occurring, adjustable stator vanes can be provided so that at the starting or part speed condition the front stages can be closed down with respect to the rear stages and thereby provide the correct airfoil orientation angle for the particular velocity of flowing air. By this means, the operating characteristics of the compressor are improved under certain operating conditions since the direction and quantity of air flow is changed to correspond to the angle of attack of the stator vanes. This change in air flow has a direct bearing on the stall characteristics of an axial flow compressor. A compressor having variable stator vanes overcomes the tendency of poor performance at the off design operating conditions by merely adjusting the angle of attack of the stator vanes of the front rows so as to match the characteristics with the back end rows. The position or angle of attack of the stator vanes for the various operating conditions can be scheduled as a function of engine speed and pressure.

By making an engine construction heavy enough from a structural standpoint, the approach to the stall region of a compressor will not significantly effect its operation. For example, the approach to the stall region of a compressor excites or creates pressure surges which result in large vibrations in the structural components of the compressor. If the structural members are sufficiently heavy, they can withstand these large vibrations. However, a gas turbine engine having a good power to weight ratio results in an air frame having the capability of either carrying more gas or more pay load. A heavy structurally built jet engine can not obtain this good power to weight ratio. However, in order to provide the best power to weight ratio of a jet engine it is very important that the engine be made as light as possible. The problem of approaching a stall region then takes on added significance.

In small aircraft gas turbines the power to weight ratio is particularly significant. For example, small gains in weight saving result in greater weight saving percentage for a small engine as compared to the same saving for large engines.

In small engines particularly, the space requirement is at a premium. For example, the rows of stator vanes of an axial flow compressor for small aircraft gas turbines are positioned so close together that it is difficult to locate the linkage for adjusting the stator vanes. It is an object of this invention to provide a lightweight mechanical linkage arrangement for adjusting the rows of stator vanes of an axial flow compressor for a small aircraft gas turbine, which is capable of operating in a minimum amount of space without any loss of accuracy or significant play between the parts.

Not only is the degree of accuracy a requirement in positioning and controlling the angular setting of the rows of variable stator vanes in relatively small compressors, but provision must be made to minimize backlash and error which result from the effect of necessary manufacturing tolerances and differential thermal growth between the components. In other words, in a small compressor of the type contemplated the lever arm lengths and the bellcranks are so small that small movement or play will result in a relatively great angular movement of the vanes. Therefore, any error in machining or stack-up of manufacturing tolerances as well as differential thermal growth between the components would normally have an uncontrollable effect on the angular position on the stator vanes.

Accordingly, it is another object of this invention to provide a mechanical linkage arrangement for adjusting the rows of stator vanes which is arranged in such a manner as to eliminate backlash or lost motion between the parts and to provide the necessary accuracy and control of the angular setting of the rows of stator vanes of an axial flow compressor.

In a casing of a small aircraft gas turbine, and in particular the compressor for the turbine, the circumference of the casing is so small that the openings required for each of the vanes in a row of stator vanes are so close together that the mechanism for adjusting the vanes can not be connected to the vanes at the casing. For example, the lever arm normally fastened to the base of a stator vane would interfere with the lever arm of an adjacent stage. It is, therefore, a further object of this invention to provide means for securing the lever arms of a linkage arrangement for varying the stator vanes to the base of the stator vane at a location remote from the compressor casing.

In a small aircraft gas turbine engine, radial thermal expansion of the compressor casing would normally be transferred to the actuating mechanism for adjusting the rows of stator vanes of the compressor and thereby incorporate an error into the actuating mechanism. Such an error would not provide for the best angle of attack for the stator vanes. Prior art adjusting mechanisms have not been successful in minimizing or eliminating this error. It is, therefore, still a further object of this invention to provide a support ring for supporting an actuating ring, which support ring is not subject to the radial thermal expansions of the compressor.

It is a more specific object of this invention to provide a support ring for supporting the actuating ring and stator vanes, which support ring is positioned and constructed in such a manner as to permit radial thermal expansion of the compressor casing and radial movement of the shafts of the vanes with respect to the support ring without transmitting such movement to the support ring, and to provide a stable support for the actuating ring.

Briefly stated, in accordance with one aspect of our invention, we provide stator vanes with elongated shafts

extending loosely through openings in the walls of a compressor casing, together with clyindrical spacers in which the shafts are received and secured to support the vanes radially. The ends of the shafts of each stage of vanes are secured to lever arms, drivingly connected for relative thermal expansion with an actuating ring. An actuating ring for each stage is circumferentially spaced about the casing outwardly of the shafts of a preceding stage of vanes, so that a minimum axial length is required for the adjusting mechanism. In order to locate and support the actuating rings, and to prevent transmission to them of thermal expansion of the casing and vane shafts, we mount a support ring in circumferentially spaced relation about each stage of vanes. The support ring receives the spacers and shafts of that stage in a circumferentially spaced row of openings formed therein, in radially slidable relation. Each actuating ring is rotatably mounted in a circumferential groove in the support ring associated with the preceding stage, upon bearing means carried thereby; however, an actuating ring for an initial stage of vanes is preferably carried by the support ring associated with the same stage. By these means, the actuating rings and support rings are not subjected to thermal expansion of the engine elements, but the actuating rings are given adequate support to sustain vane adjustment forces.

Further objects and advantages of our invention will become apparent in the light of the accompanying specification and drawing wherein similar parts are referred to by the same number and wherein:

Figure 1 is a cross sectional view of the compressor for an aircraft gas turbine showing the stator vanes and part of the mechanical linkage arrangement for adjusting the stator vanes.

Figure 2 is a plan view showing the external mechanical linkage arrangement for adjusting the actuating rings which extend circumferentially about the compressor casing.

Figure 3 is a view taken on lines 3—3 of Figure 2.

Figure 4 is a side view taken on lines 4—4 of Figure 2.

Figure 5 is a cross sectional view taken on lines 5—5 of Figure 2.

Figure 6 is a view taken on lines 6—6 of Figure 1.

Figure 7 is a view taken on lines 7—7 of Figure 1.

Figure 8 is a fragmentary view of a lever arm and shaft.

Referring to the figures, and in particular to Figures 1 and 2, the numeral 10 generally refers to an axial flow compressor for an aircraft gas turbine. The compressor is provided with an inlet 11 and a compressor casing 12. A row of stator vanes is shown at 14 of which there can be any number. Of this number, all or a portion of the rows may be made adjustable. Adjacent to one row of stator vanes is a row of rotor blades 15 of which there can be any number of rows. The casing 12 is provided with a plurality of circular openings 16. Each of the circular openings are provided with a seat 18. The base of each blade 14 is provided with a bearing surface 20 adapted to be journaled on one of the seats 18. Positioned between the bearing surface 20 and the seat 18 is bearing sheet material commonly referred to as polytetrafluoroethylene. The purpose of the bearing material is to provide substantially frictionless movement between the seat 18 and the bearing surface 20. Also, the bearing sheet material requires no lubricant and acts as an air seal to prevent leakage of high pressure air from within the compressor. Extending radially outwardly from the base of each of the adjustable stator vanes 14 is a shaft 24 which fits loosely in the opening 16 as shown by the space 25.

Due to the fact that a compressor casing of a small aircraft gas turbine is of such small circumference, and that a large number of blades in a row are required for high pressure operation, the openings 16 must be positioned close together. Lever arms or the like secured to the shafts 24 at the compressor casing would interfere with adjacent lever arms. Therefore, the shafts 24 extend radially outwardly from the casing for a substantial distance to permit the mechanical linkage such as lever arms to be fastened thereto. However, the shafts 24 must be supported against pivoting away from a radial position under the influence of the moment of force produced by the impact of fluid on vanes 14. For this purpose a support ring 37 is provided with a plurality of openings 27 equal in number to the openings 16. In view of the stack-up of machining tolerances, the openings 27 will be misaligned from the openings 16. Therefore, the openings 16 are made oversize to loosely receive shafts 24.

In view of the fact that the openings 16 are made oversize, the problem arises as to how the bending loads may be transmitted from the shafts 24. This is accomplished by providing a built-up portion 28 around the openings 16 upon which is milled a recess or flat surface 30 so as to form a seat. Extending through each of the openings 27 in the support ring 37 is a spacer or sleeve 32. The spacer 32 is flared outwardly to form a shoulder 34 adapted to seat on the surface 30. Any bending loads of the shaft 24 is taken in the spacer 32 and transmitted to the support ring 37. The spacer 32 provides a means for positively locating the actuating mechanism radially and the actuating ring in an axial direction.

In order to isolate the support rings 37 from the compressor casing 12 and stator vanes 14 so as not to be subject to radial thermal expansions thereof, the support ring is slidably mounted on spacers or sleeves 32, with the spacers abutting recesses 30 formed on the compressor casing. This construction permits the spacers to move with the thermal expansion of the compressor casing, and the sliding fit permits the spacers 32 to move radially within the support ring without affecting the support ring. This arrangement isolates the support ring 37 from the compressor casing and provides a stable support for the actuator ring. This construction also prevents the thermal expansion of the compressor casing and stator vanes from creating an error in the actuating mechanism.

In addition, since there are several vanes in each row, those of shafts 24 which are horizontally inclined maintain the support ring 37 in a vertical direction, and those of shafts 24 which are vertically inclined maintain the support ring in a horizontal direction. The support ring 37 can be dimensioned with respect to the shafts so as to be positioned at a particular radial location with respect to the compressor casing 12 without being directly connected to it, and can be regarded as being floating.

Each of the support rings is provided with an annular groove 26. However, this is true for each of the rows of adjustable vanes with the exception of the first row which must provide for its own actuator support ring. In that case a second annular groove 38 is shown on the opposite side from the annular groove 26.

Extending through the actuator support ring 37 transversely of the annular grooves 26 and 38 are a plurality of fixed shafts 40. These fixed shafts have anti friction roller bearings 42 mounted thereon in order to support one of a plurality of actuating rings 44. The actuating rings 44 are shown as being substantially Z-shaped with one end mounted on the anti friction bearings 42 so as to be capable of rotational movement with substantially no friction. A ring 46 is shown welded, or the like, to the vertical portion 47 of each actuating ring 44 to provide a wide base to enable the actuating ring to take the loads, maintain its stabliity and axial alignment.

Referring also to Figure 6, the actuating ring 44 contains a tapered cam slot 48, the purpose of which will be more fully hereinafter explained. A follower pin is shown at 50 for movement within each tapered slot 48. A lever arm 52 is provided for drivingly connecting each shaft 24 with an actuating ring 44. The follower pin 50 is secured in an opening 54 of the lever arm 52 by welding or the like. In order to maintain a close sliding fit between the marginal edges of the cam slot 48 and

the follower 50, to eliminate any lost motion between the edges of the slot and the follower 50, to eliminate harmful binding, and yet maintain the required accuracy for positioning the stator vanes, the slot is tapered. The taper is necessary since the actuating ring 44 moves about an arc of a circle and the follower 50 in a plane tangent to the arc of the circle. This condition will result in the follower pin 50 becoming more out of alignment with respect to the cam slot thereby requiring a gradually enlarged slot as the angle of travel increases from its neutral or zero position. Therefore, the taper provides for a gradually increasing larger slot with increase in angle of travel.

As best seen in Figures 7 and 8, each shaft 24 is formed at its protruding end with two flat tapered sides 56, and with a threaded stud 60 extending from the shaft. An opening 55 is formed in an end of each lever arm 52 to conform with sides 56, and is fitted over shaft 24 with an interference fit, thereby reducing the possibility of lost motion between these elements. A washer 58 is shown extending over each shaft 24 and engaging the lever arm 52. A nut 62 is threaded on the threaded stud 60 so as to engage the washer 58. An abutment surface 59 of spacer 32 locates the radial position of the lever arm 52 with respect to the compressor casing 12.

Referring again to Figures 1 and 2, the lever arms 52 are secured to the shafts 24 of the vanes 14 in a sprung condition so as to bear against the actuating ring 44. This enables the casing along with the vanes to expand radially without losing the snug fit and without the follower 50 being separated from the cam slot 48.

In order to actuate the actuator ring 44 in an arc of a circle about the compressor casing, a clevis 64 is shown fixed to the actuating ring 44 by a rivet or the like 66. Actuator means are connected to this clevis for actuating the actuating ring. This actuator means includes a pin and nut arrangement 68 extending through the clevis 64. Mounted on the pin and nut arrangement 68 is a self aligning uniball bearing 70. In general, the uniball bearing consists of a ball 69 and socket 71 with an opening extending through the ball 69 to receive pin and nut 68.

The uniball bearing 70 is secured within one end of a turnbuckle 72 at the eye 73 to permit the turnbuckle and the pin 68 to move in different planes without binding, as best seen in Figures 2 and 3. The eye 73 is provided with a stud 74 which is fitted into the main portion of the turnbuckle 72 to provide a means for zeroing-in and adjusting the angle of attack of the row of stator vanes. This turnbuckle takes care of the build-up of manufacturing tolerances and thereby eliminates the manufacturing inaccuracy on the angle of attack of the stator vanes as a result thereof. Another eye 75 is integrally secured to a stud 76 on the other end of the turnbuckle 72. Another pin and nut arrangement along with a self aligning uniball bearing is shown at 77 with the uniball being mounted in the eye 75. This arrangement is similar in construction to the self aligning uniball bearing 70 and the nut arrangement 68 as shown in Figure 1.

Fixed to the compressor casing 12 (Figures 2, 3, 4, and 5) is a longitudinally extending actuator support member 78 having brackets 79 secured to the front end of the casing such as by bolt and nut arrangements as shown at 80. Mounted on the actuator support member 78 are a plurality of bellcranks generally designated 81. These bellcranks 81 are pivotally mounted by pins as shown at 82. Referring to Figure 5, bellcranks 81 are constructed of two similar portions, referred to as the outer bellcrank member 83 and an inner bellcrank member 84 with the inner and outer members being spot welded or bolted together in any well known manner.

The inner and outer bellcrank members 83 and 84 being secured together act as a unitary bellcrank. This construction permits the use of relatively thin lightweight material while still retaining the necessary structural strength to carry the forces transmitted to adjust the vanes without harmful buckling. Each bellcrank 81 terminates with outer bellcrank member 83 spaced from the inner bellcrank member 84 for additional strength and to receive the eye 75 therebetween as shown in Figure 3. A uniball bearing is mounted in the eye 75 and is pivotally scured to the bellcrank by the pin shown at 77 extending through the ball of the uniball.

The bellcranks 81 are stepped down or offset as shown at 85 to provide sufficient clearance for the other linkage such as the turnbuckle 72 and bellcrank pivot points 82. The offset 85 permits one bellcrank to overlie an adjacent bellcrank.

The other leg 86 of the bellcranks 81 terminates with the outer member 83 and the inner member 84 in abutting relationship rather than being spaced. Each of the legs 86 of the bellcranks 81 are pivotally interconnected by an interconnecting link 87 so that all of the bellcranks are adjusted in unison. The interconnecting link 87 (Figures 2 and 3) is constructed of an outer portion 88 to fit over the outer bellcrank member 83 and an inner portion 89 adapted to fit under the inner bellcrank member 84. The legs 86 of the bellcranks are pivotally secured to the interconnecting link 87 by pins or rivets 90. The distance from the pin 90 to the pivot 82 on each of the bellcranks is the same so that during movement of the interconnecting link 87 each of the bellcranks travel through the same angle. However, the distance on each of the bellcranks 81 from the pivot 82 to the pin at 77 can be the same, or, can vary from one row of vanes to another depending on the space requirements, the length of the lever arms 52, and the angle through which the row of vanes should travel. For example, the space at one row may not be sufficient to permit as long a distance as may be desired. Also, space requirements may require that the lever arms be shorter. Therefore, in order to provide the correct angle of travel for the vanes, the distance between the pivot 82 and the pin 77 can be increased or decreased as desired. Further, the operating conditions of the compressor may be such as to require a much larger angle of travel for one row of vanes than another row of vanes. To provide for the larger angle of travel, the lever arms 52 and the distance on the bellcrank between points 82 and 77 can be increased.

In order to provide for simultaneous actuation of bellcranks 81, one such bellcrank is formed with an extended leg portion 92, best shown in Figures 2 and 4, and forms a master bellcrank generally designated 91. The inner and outer legs 94 and 96 of the extended leg portion 92 are spaced from each other so as to accommodate a uniball bearing 97 similar to that shown in Figure 5.

An actuating link 98 is shown formed by inner and outer members 102 and 100, one positioned on each side of the uniball bearing 97 and arms 94 and 96. A pin 104 extends through the ball portion of the uniball 97 and the legs 94 and 96 of the master bellcrank 91, in addition to the inner link member 102 and the outer link member 104. This pin can be in the form of a rivet or bolt and nut arrangement. The actuating link 98 is secured to an adjustable piston rod 106, as best seen in Figure 2. This connection is made by providing the piston rod 106 with an eye 107 at the one end so as to receive a uniball bearing therein. A pin 108 extends through the inner link member 102 and the outer link member 100 in addition to the uniball bearing so as to secure the parts together. The pin can be either in the form of a rivet or a nut and bolt arrangement.

In order to actuate the piston rod 106, the piston rod is mounted in an actuating cylinder 110. By proper control mechanism the actuating cylinder can be made to operate the piston rod in response to the parameters of compressor and power turbine speed, inlet temperature, compressor discharge pressure, and engine control lever position. Whenever the speed, and pressure varies, to

indicate the approach to the stall region of the engine, a signal is transmitted to the actuator cylinder to thereby actuate the piston rod **106** for actuating the linkage arrangement. Each row or stage of vanes will be adjusted to any desirable angle over a relatively wide range. It is readily apparent from the construction proposed and described above that it is applicable to small engine applications wherein lightweight parts are utilized with a high degree of accuracy which is required for axial flow compressors.

When the piston rod **106** is actuated, the master bellcrank **91** is placed in motion. Since the interconnecting link **87** interconnects the master bellcrank with the other bellcranks **81**, pivoting of the bellcranks about the pivot pins at **82** is thereby initiated. The distance from the pivotal point **82** of the center of the bolt and nut arrangement to the center of the self aligning uniball bearing at **77** can be the same or vary from stage to stage on each of the bellcranks. This length serves two functions, in that, from an operating consideration it might be desirable to vary the lengths of the distances between the points at **77** and **82** to vary the rows of vanes unequally; or where space considerations require that the distance between points **82** and **77** of the bellcranks be of different lengths for the various rows of vanes while operating conditions require that the angle of travel of the stator vanes must be equal, the lever arms **52** can be made of a length to cooperate with the length of the bellcranks to adjust the rows of stators through equal angles.

The uniball at the various connections permits the various member to be pivoted in different planes while still permitting a tight connection between the members. Therefore, since each of the bellcranks are actuated simultaneously their motions are transmitted to each of the actuating rings **44** through the turnbuckles **72**. This motion is then transmitted to the levers **52** so that the vanes **14** are pivoted to the correct angle of attack to meet the required operating conditions.

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

1. A compressor comprising a casing, a rotor mounted for rotation about an axis within said casing and forming a gas path therebetween, rows of stator vanes extending across said gas path, rows of rotor blades mounted on said rotor axially spaced from said rows of stator vanes and extending across said gas path, a plurality of support rings circumferentially spaced about said casing, each of said stator vanes having a shaft extending radially and loosely through a wall of said casing and through one of said support rings, a plurality of spacer means each rotatably supporting said shaft of one of said stator vanes in said casing, said spacer means received in radially slidable relation in said support rings for supporting said support rings in circumferentially spaced relation to said casing and cooperating with said support rings to locate the circumferential positions of said stator vanes about said casing, a plurality of lever arms each secured to one of said shafts, and a plurality of adjusting rings drivingly connected for relative thermal expansion with said lever arms for rotating said shafts and said stator vanes, said support rings supporting said adjusting rings in circumferentially spaced relation to said casing for rotation about said axis, such that radial movement of said stator vanes and spacer means caused by thermal expansion thereof is not transmitted to said support rings and said adjusting rings.

2. A compressor comprising a casing, a rotor mounted for rotation about an axis within said casing and forming a gas path therebetween, rows of stator vanes extending across said gas path, rows of rotor blades mounted on said rotor axially interposed between said rows of stator vanes and extending across said gas path, support rings circumferentially spaced about said casing, each of said stator vanes having a shaft extending radially and loosely through a wall of said casing, said support rings formed with a plurality of radial openings each receiving one of said shafts of said stator vanes, a plurality of sleeves each disposed in one of said radial openings and receiving one of said shafts rotatably for radial support thereof, and a plurality of adjusting rings drivingly connected for relative thermal expansion with said shafts for rotational adjustment of said stator vanes, said support rings supporting said adjusting rings in circumferentially spaced relation to said casing for rotation about said axis, said sleeves received in radially slidable relation in said openings for supporting said support rings in circumferentially spaced relation to said casing, such that said sleeves transmit bending loads from said vanes to said support rings, and radial movement of said stator vanes and sleeves caused by thermal expansion thereof is not transmitted to said support rings and said adjusting rings.

3. A compressor comprising a casing, a rotor mounted for rotation about a longitudinal axis of said casing and forming a gas path therebetween, first and second axially spaced rows of stator vanes extending across said gas path, axially spaced rows of rotor blades mounted on said rotor axially interposed between said rows of stator vanes and extending across said gas path, a plurality of shafts each affixed to one of said vanes and extending radially through a wall of said casing, first and second support rings circumferentially spaced about said casing, said first and second support rings formed with a plurality of radial openings loosely receiving said shafts of said first and second rows of vanes, respectively, a plurality of sleeves each received in radially slidable relation in one of said openings and receiving one of said shafts, said sleeves radially supporting said shafts in said casing for rotation about axes radial to said casing, said sleeves supporting said support rings for radial expansion relative thereto, at least one actuating ring circumferentially spaced about said casing, a plurality of lever arms drivingly connecting said actuating ring for relative thermal expansion with said shafts of said second row of vanes, said actuating ring being supported upon said first support ring for rotation about said axis to rotatively adjust said second row of vanes, whereby radial thermal expansion of said casing and said vanes is not transmitted to said support rings and said actuating ring.

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