Oct. 21, 1958 R. H. CAMPBELL 2,857,092

VARIABLE COMPRESSOR VANES

Filed May 25, 1951 4 Sheets-Sheet 1

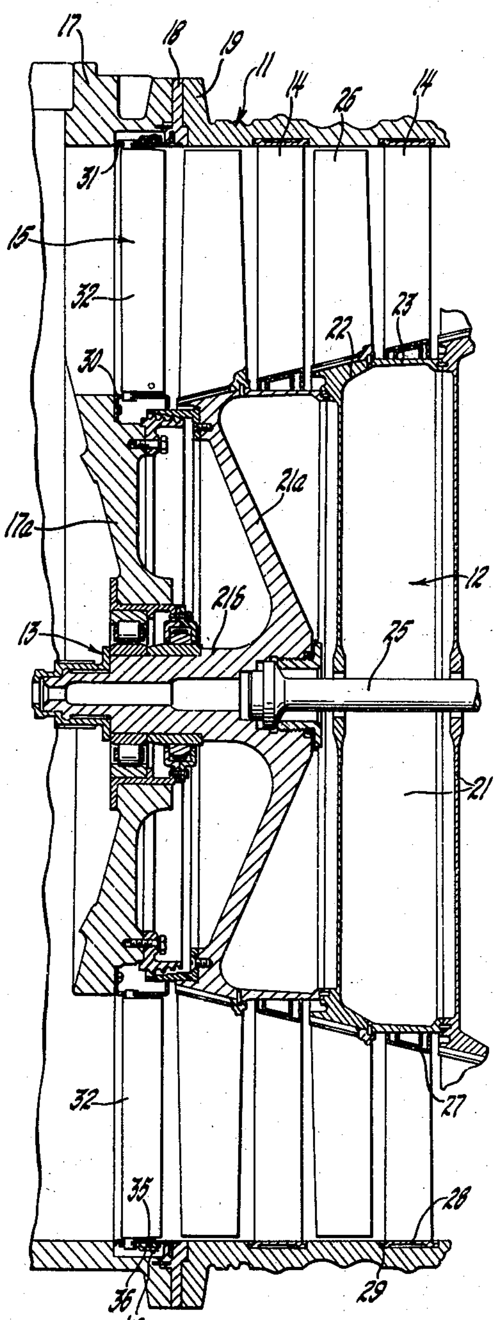

Fig. 1

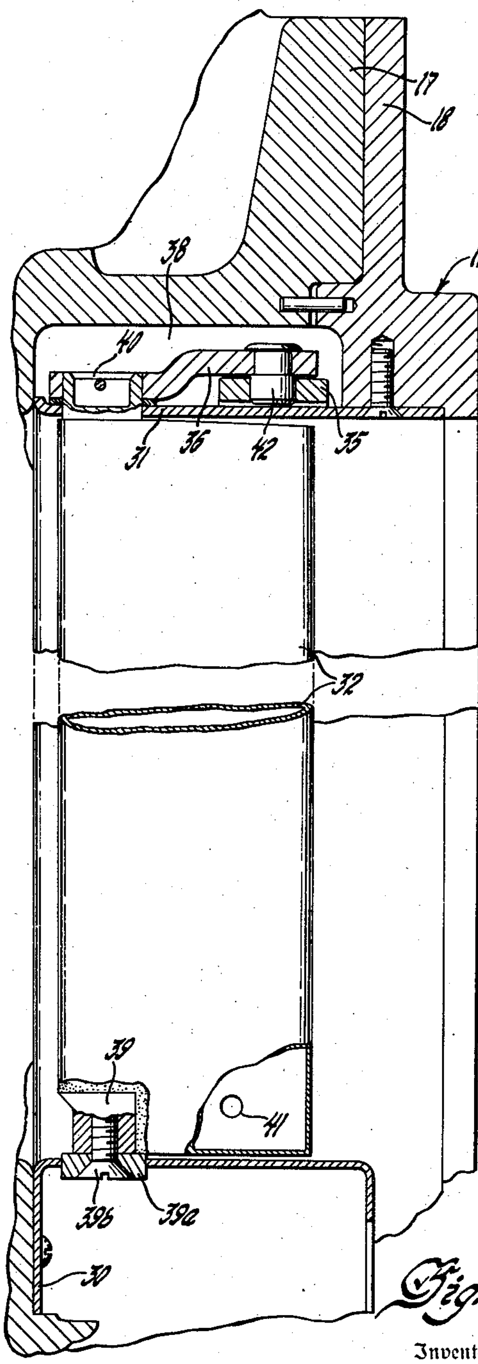

Fig. 2

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VARIABLE COMPRESSOR VANES

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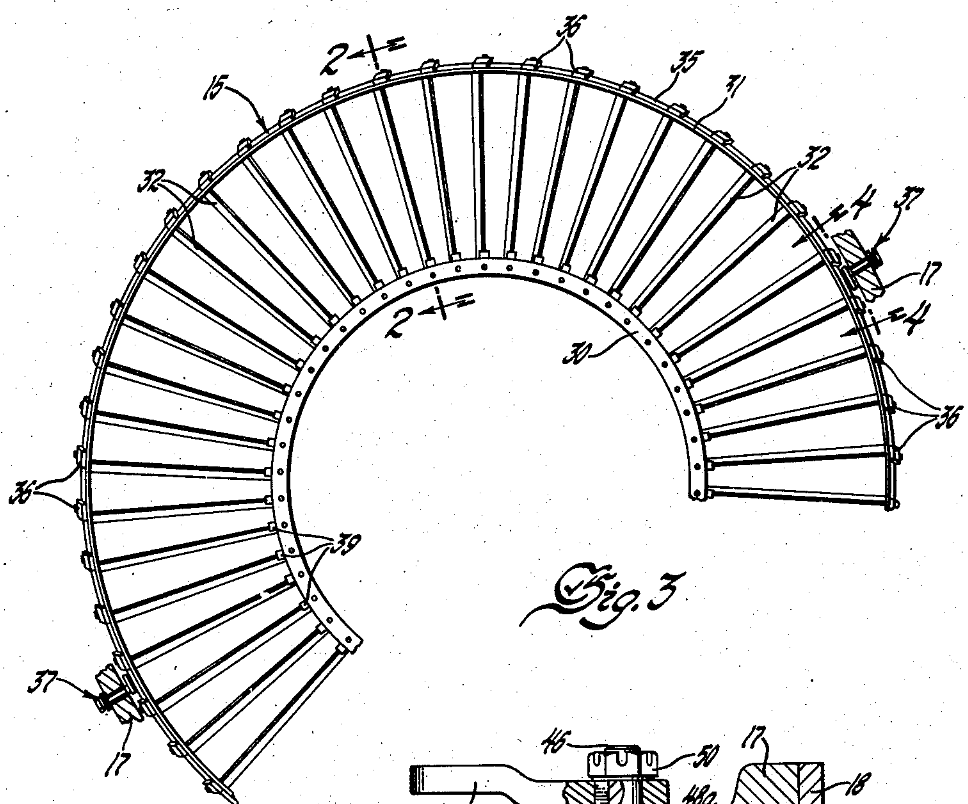

Fig. 3

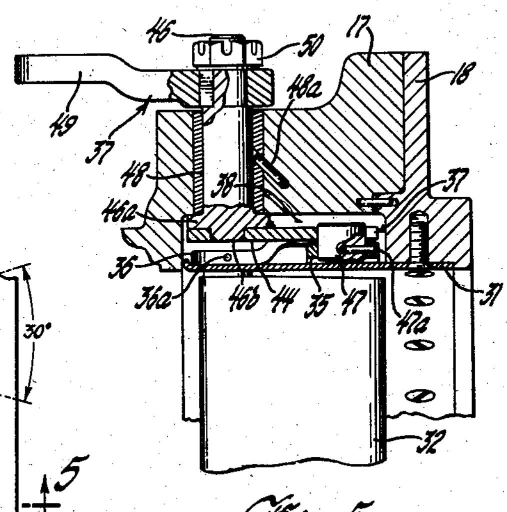

Fig. 5

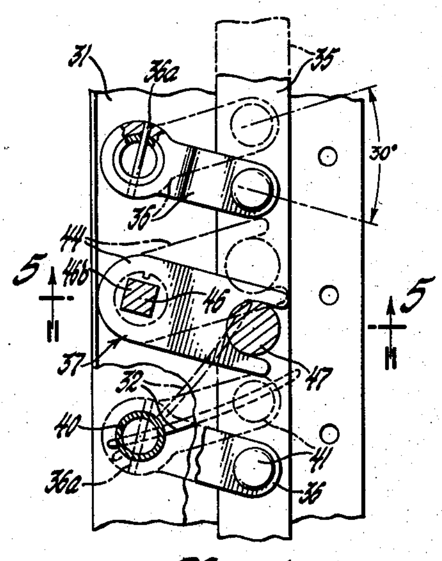

Fig. 4

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VARIABLE COMPRESSOR VANES

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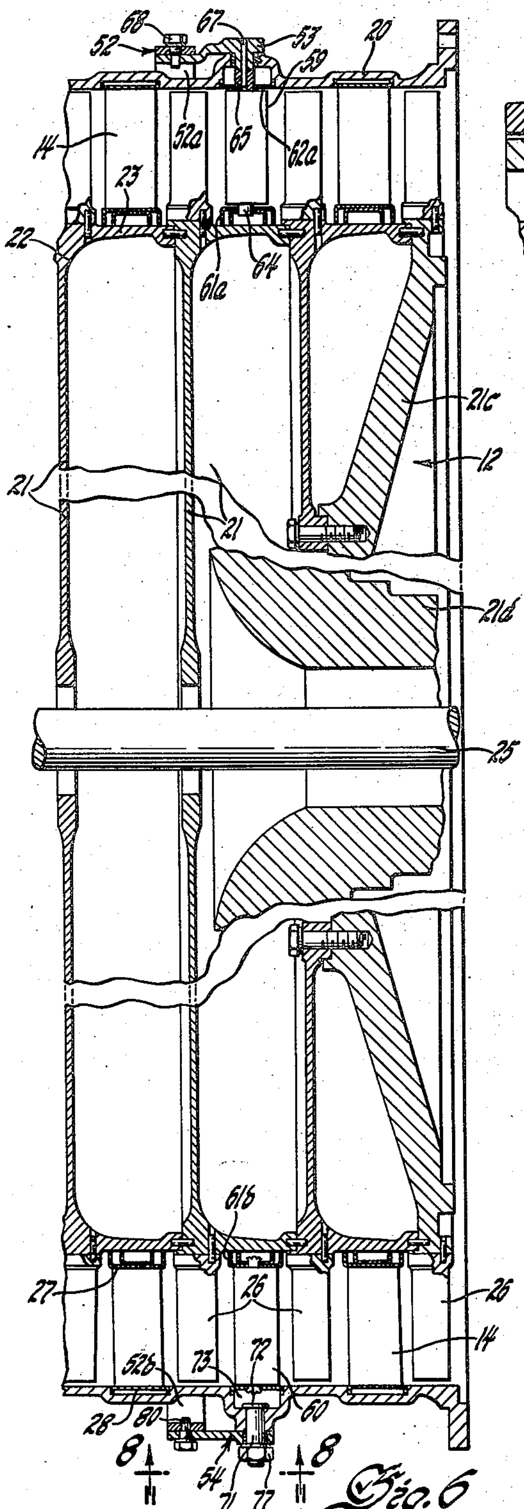

Fig. 6

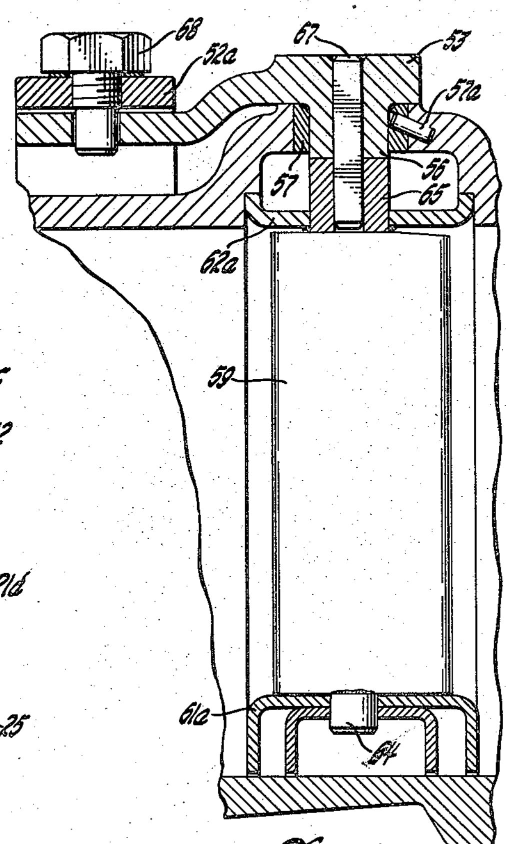

Fig. 7

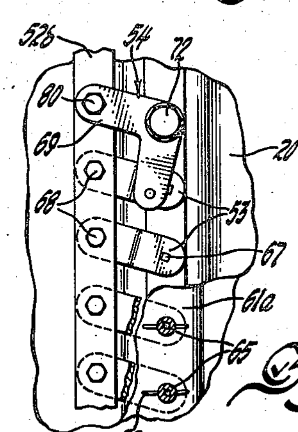

Fig. 8

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VARIABLE COMPRESSOR VANES

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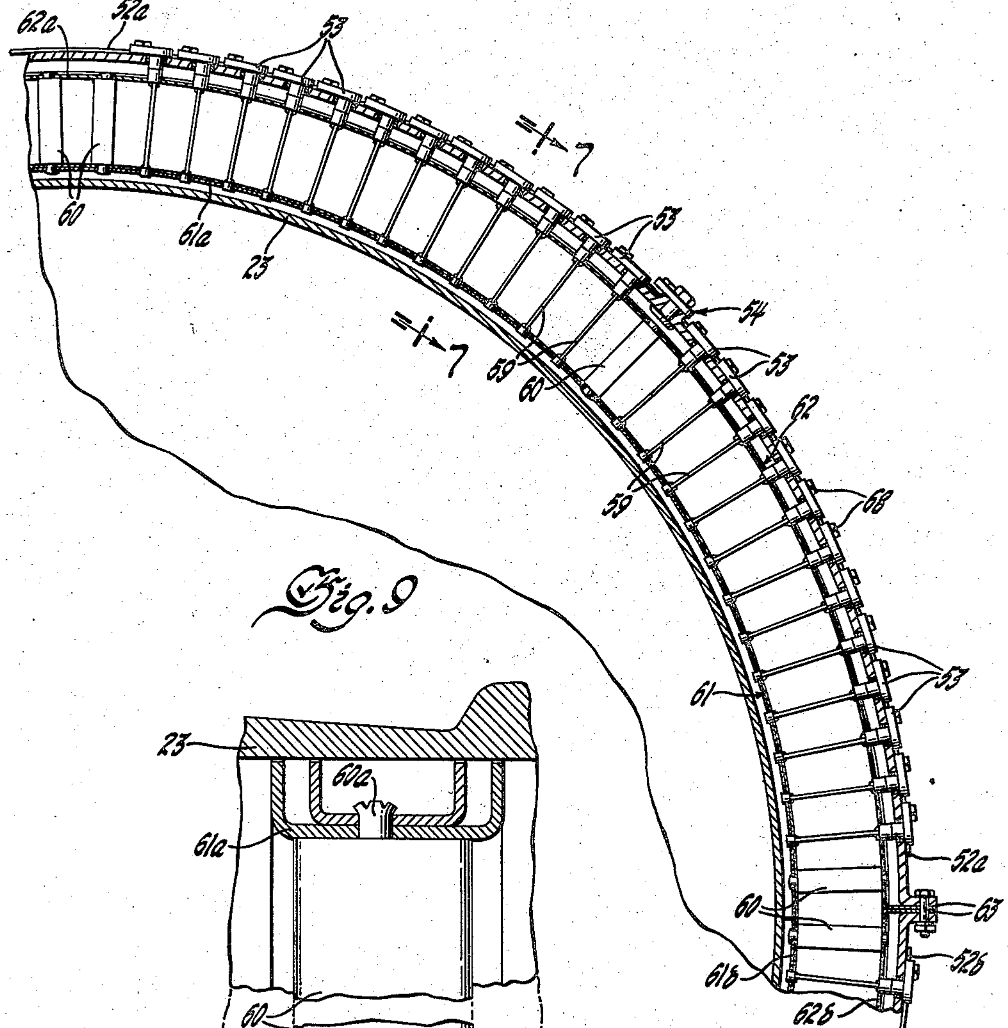

Fig. 9

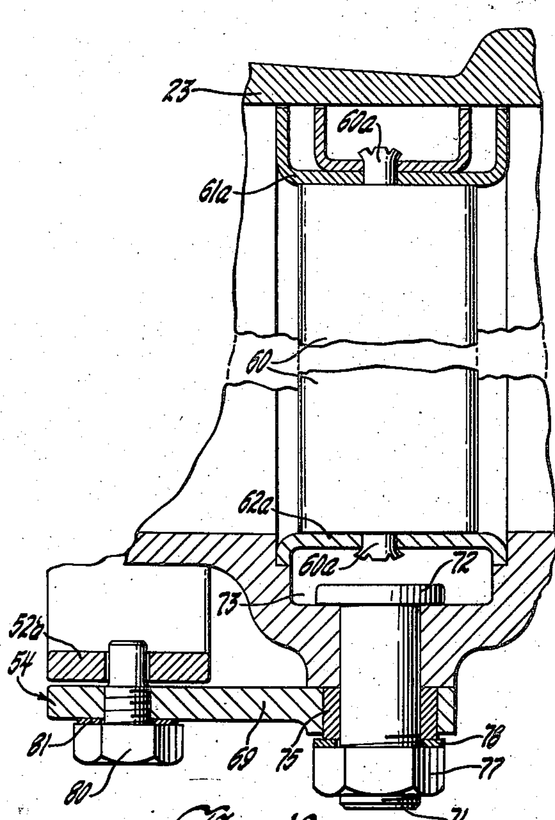

Fig. 10

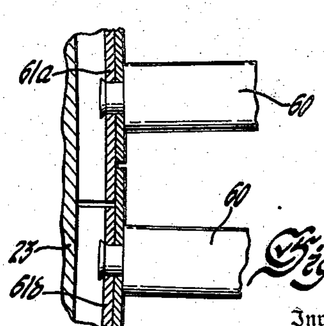

Fig. 9a

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VARIABLE COMPRESSOR VANES

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Application May 25, 1951, Serial No. 228,159

2 Claims. (Cl. 230—114)

This invention relates to axial flow fluid dynamic machines including multi-stage compressors and the like and, more particularly, to multi-stage machines of this type suited for use in aircraft gas turbine engines, for example. The invention aims generally toward improving the operation and performance of axial-flow compressors under off design operating conditions thereof, and has as an objective the provision of suitable means adapted to be compactly embodied in such machines for the accomplishment of these general ends.

In accordance with one embodiment of the invention the inlet guide vanes of an axial-flow compressor are so constructed as to be pivotable about a radial axis by means of suitable vane actuating apparatus compactly associated therewith, thereby to obviate a stalled condition likely to occur in the early stages thereof particularly during starting and low speed operation.

In accordance with another embodiment of the invention a number of the stator blades in one of the later stages of an axial-flow compressor are so constructed as to be pivotable about a radial axis by means of suitable blade actuating apparatus compactly associated therewith, thereby to obviate an undesirable surge condition which may be encountered in the low or intermediate speed ranges.

The nature of the present invention and other objects, features and advantages thereof will be apparent from a consideration of the following detailed description and drawings, in which:

Figure 1 is a longitudinal sectional view of the inlet end of a multi-stage axial-flow compressor which includes apparatus constructed in accordance with one embodiment of the invention;

Figure 2 is a sectional view taken in the plane 2—2 of Figure 3;

Figure 3 is a transverse elevation of part of the structure of Figure 1;

Figure 4 is a plan view of a fragmentary portion of Figure 3 taken substantially in the direction 4—4 thereof;

Figure 5 is a partial sectional view of the apparatus of Figure 1 taken substantially in the plane 5—5 of Figure 4;

Figure 6 is a longitudinal sectional view of the discharge end of a multi-stage axial-flow compressor which includes apparatus constructed in accordance with another embodiment of the invention;

Figure 7 is a sectional view taken in the plane 7—7 of Figure 9;

Figure 8 is a bottom plan view of a fragmentary portion of Figure 6 taken substantially in the direction 8—8 thereof with parts broken away and in section;

Figure 9 is a transverse elevation of part of the structure of Figure 6;

Figure 9*a* is detail of a part of Figure 9; and

Figure 10 is a sectional view of a part of the apparatus of Figure 6.

Referring to the drawings, Figure 1 is a sectional view of the inlet end of a multi-stage axial-flow compressor

which includes apparatus constructed in accordance with one embodiment of the invention for varying the angle of incidence of the entrance guide vanes thereof.

The compressor is contained within a cylindrical stator casing **11** and includes a rotor **12** carried by the main shaft assembly **13**, stator vanes **14** mounted in the casing, and an entrance guide vane assembly **15** associated with the inlet of the compressor. The casing assembly comprises a forward frame **17**, a ring-like spacing member **18**, and the forward section of the compressor casing proper **19**, all of which are rigidly fastened together by bolts or the like (not shown) passing through outward extensions of the joining surfaces thereof. The central portion of the forward frame **17** includes a circular disk **17*a*** supported therein by radial support struts (not shown) which serve as a front bearing support for the rotor shaft **13**.

The compressor rotor **12** comprises a plurality of axially aligned drum-shaped wheels or disks **21** and a wheel **21*a***, the latter having a forwardly extending hub **21*b*** thereon which constitutes a stub shaft of the rotor. The forward portion of the periphery of each disk is constituted by a thickened rim **22** and the rearward portion, which may be integrally formed therewith, by a spacer ring **23**. A tie bolt **25** rigidly secures the disks together, thereby providing a unitary rotatable structure. The rotor blades **26** are disposed in dovetail slots arranged around the circumference of each rotor disk.

The stator is composed of two semi-cylindrical sections bolted together. The stator blades **14** are fixed in inner and outer shroud rings **27** and **28** respectively, which are semi-circular. The inner shroud rings **27** are of double channel cross-section to form an effective pressure seal between compressor stages. The outer shroud rings **28** are securely mounted in dovetail grooves **29** circumferentially disposed around the inner surface of the compressor casing.

The inlet guide vane assembly **15** is contained within the forward frame **17** of the housing assembly and is an annular structure formed by a pair of cylindrical concentric shroud rings **30, 31** between which the inlet guide blades or vanes **32** are mounted. The outer and inner shroud rings are secured to the inner surface of the spacing member **18** and to the central disk **17*a*** of the forward frame **17**, respectively, by screws as shown in Figures 1, 2 and 5.

The inlet guide vanes **32** are hollow and are so constructed as to be pivotable about radially disposed axes, thereby providing a variable entrance for accomplishment of the ends set forth hereinabove. The apparatus for varying the pitch of the entrance guide vanes comprises an adjustable control ring **35**, a plurality of vane actuating levers or follower arms **36**, and a pair of ring actuating members **37**, the latter being shown in Figures 3, 4, and 5.

Figure 2, which is an enlarged fragmentary portion of Figure 1, illustrates in section the adjustable control ring **35** and one of the follower arms **36** of the entrance guide vane varying apparatus. The control ring **35**, which may be a welded steel band, is concentrically disposed about the outer shroud ring **31** of the annular entrance guide vane assembly and may be contained within a recess **38** located toward the rear and within the interior of the forward frame **17**.

Cylindrical extensions **39, 40** serving as pivots about which the inlet guide vanes may be rotated are located at both ends of each vane near the leading edge thereof and extend through aligned openings in the outer and inner shroud rings as shown in Figure 2. The outer pivot extensions **40** are welded to the outboard end of the entrance guide vanes and are hollow for the purpose of allowing air to be blown through the latter members, A small opening 41 located near the inboard end of the hollow guide vanes serves as an exit port for air blown therethrough. The inner pivot extensions 39 are welded to the inboard end of the entrance guide vanes and further comprise a washer 39*a* held thereon by a screw 39*b* as shown.

The vane actuating levers or follower arms 36, contained within the recess 38, are detachably secured to respective outer pivots 40 by pins 36*a* (Figures 4 and 5) and extend to the adjustable control ring 35, the connection to the control ring being made through a connecting pin 42 which is fitted in the end of each follower arm and passes through an axially aligned opening in the control ring, as shown.

Associated with the control ring 35 are a pair of the afore-mentioned ring actuating members 37 (Figures 3 and 5) which extend into the forward frame 17 to engage the control ring at two points spaced approximately 180 degrees apart about the circumference thereof to effect rotational movement of the control ring. Each of the ring actuating members comprises a master arm 44 (Figures 4 and 5) mounted on a radial shaft 46. The outer end of the master arm 44 has a clevis formed therein which engages an actuating pin 47 detachably secured in place by a pin 47*a* in the ring 35. In accordance with the present embodiment of the invention the follower and master arms are so proportioned as to allow free movement of the guide vanes through an arc of, say, 30 degrees.

Each shaft 46 is mounted in a bearing bushing 48 that is retained in an opening in the forward frame 17 by a pin 48*a* and extends through the compressed casing. A shoulder 46*a* located at one extremity of the shaft 46 is contained within the recess 38 within the interior of the forward frame 17 and has suitably mounted on a rectangular axial projection 46*b* thereof the above-mentioned master arm 44. An actuating arm 49, shown partially in cross-section in Figure 5, is keyed to a reduced portion of the shaft 46 exterior to the compressor casing and is held thereon by means of a castellated nut 50. The arms 49 may be coupled to suitable power actuators (not shown) or may be linked to a manual operating lever to rotate the control ring a desired amount.

By locating the adjustable control ring and the follower arms of the vane varying apparatus within the stator casing, the invention affords a compact construction without increasing the overall diameter of the compressor structure. Mounting the pivotable stator vanes in an annulus formed by concentric inner and outer shroud rings eliminates undesired radial displacement thereof were the pivotable vanes otherwise mounted. The invention has the further advantage that a balanced and uniform movement may be imparted to the adjustable control ring by actuation thereof at at least two points.

Figure 6 is a sectional view of the discharge end of a multi-stage axial-flow compressor (which may be the compressor the inlet end of which has been described) which includes apparatus constructed in accordance with another embodiment of the invention for varying the pitch of stator vanes of one of the stages thereof. The compressor comprises a rotor 12 which includes a plurality of drum-shaped disks 21 and a wheel 21*c*, the latter having a rearwardly extending hub 21*d* which constitutes a stub shaft of the rotor. Rotor blades 26 coact with stator blades 14 mounted in a rear casing section 20 split longitudinally into two semi-cylindrical sections. The rear casing section 20 is generally similar to the forward casing section 19.

In accordance with the present embodiment of the invention a number of the stator blades contained in one of the stator stages, say, in the next-to-last stage of the compressor, are so constructed as to be pivotable about radially disposed axes passing therethrough for accomplishment of the ends set forth hereinabove. The apparatus for varying the pitch or angle of incidence of the stator blades is disposed principally without the compressor casing, but is otherwise generally similar to that described in connection with Figures 1–5 inclusive and comprises an adjustable control ring assembly 52, a plurality of blade actuating levers or follower arms 53, and ring actuating members 54.

Figure 7, which is an enlarged fragmentary portion of Figure 6, illustrates in section the adjustable control ring assembly 52 and one of the follower arms 53 of the stator blade varying apparatus. The control ring assembly is of a split construction and is formed preferably by at least two nearly semi-circular arcuate strips 52*a*, 52*b* (Figure 9), disposed closely around the exterior of the rearward section 20 of the compressor casing so as not to substantially increase the diameter of the overall compressor structure. Each of the follower arms 53 has a cylindrical extension or hub 56 formed at one end thereof, the hub being mounted in a bearing bushing 57 which is retained by a pin 57*a* in an opening in the compressor casing. The pivotable stator blades 59 are mounted in an annulus formed by concentric inner and outer shroud ring assemblies 61, 62 respectively, each of which is formed by a pair of semi-circular bands. The outer shroud bands are secured within a grooved slot extending circumferentially about the interior of the compressor casing and may be further supported by bolts (not shown) extending through the casing. Outwardly extending tabs 63 (Figure 9) formed at each end of the semi-circular outer shroud bands are bolted together between the flanges of the two-piece compressor casing. The inner shroud bands 61*a*, 61*b*, which have a double channel cross-section, may be suitably held together by overlapping the respective channel sections thereof as shown in Figure 9*a*. Cylindrical extensions 64, 65 serving as pivots, about which the pivotable stator blades may be rotated, are welded to the inner and outer ends, respectively, thereof. A pin 67 having a square cross-section passes through aligned openings in the hub end of the follower arm and the outer or outboard pivot 65 of the pivotable blades and may be welded to the follower arm so as to lock these members together as shown in Figure 7. The opposite end of the follower arm is positioned within the control ring assembly to form a support therefor and is coupled thereto by means of a partially threaded stud bolt 68 having an unthreaded lower portion which passes loosely through an axially aligned opening in the follower arm.

In accordance with the invention as exemplified herein, the control ring assembly 52 has associated therewith preferably two pairs of the aforementioned ring actuating members 54, only one member of one pair of which is shown in Figures 8 and 9. The ring actuating members, one of which is shown in Figs. 8 and 9, are displaced equally from the central portion of each half section of the control ring and are located at four points spaced substantially 90 degrees apart about the circumference of the casing.

Each of the ring actuating members comprises a pivotable bell crank 69 (Figures 8 and 10) mounted on a shaft 71 formed by a partially threaded bolt which is fitted in and passes through an opening in the compressor casing, the head 72 of the bolt being contained within a recess 73 that is circumferentially disposed about the interior of the compressor casing. The bell crank is journalled about an exterior portion of the shaft 71 on a bearing bushing 75 retained on the shaft by a nut 77 and washer 78 as shown. A partially threaded stud bolt 80 having a washer 81 thereon passes through a threaded opening in one arm of the bell crank and an aligned opening in the control ring section 52*b* to form a loose coupling therebetween. Rotational movement may be simultaneously imparted to each section of the control ring assembly in accordance with a force applied to the other arm of each bell crank by suitable external means (not shown). In accordance with the specific embodiment of the invention the follower arms and ring actuating members are so proportioned as to allow free movement of the pivotable stator blades through an arc of, say, 20 degrees.

The manner in which the stationary stator blades **60** of the variable stator stage are mounted between the concentric shroud rings is illustrated in Figures 9 and 10, the former figure further illustrating the position of the variable stator blades relative to the fixed blades in one extreme position of the blade varying apparatus. Six of the stator blades, for example, in each half section of the variable stator stage are shown stationary. The stationary blades support the inner shroud bands **61***a*, **61***b* from the outer shroud bands **62***a*, **62***b* and are fixedly mounted therebetween by upset or peened tangs **60***a* which are located at both ends of each blade and pass through aligned openings in the inner and outer shroud bands as shown in Figure 10. The separation without the compressor casing between a pair of adjacent follower arms **53** connected to respective pivotable blades **59** surrounding a stationary blade affords a convenient location for the mounting of the ring actuating members **54** as illustrated in Figure 9.

Although at least one pair of ring actuating members are employed to effect rotational movement of the control ring in the arrangements shown herein, it is apparent that a single control ring actuating member could be employed with a continuous control ring structure if desired. The control ring, in addition, may be composed of any number of sections. Furthermore, the vane actuating apparatus can be used at any stator stage or plurality of stator stages of an axial-flow machine of the character described. Numerous other arrangements may be derived by those skilled in the art without departing from the spirit and scope of the invention.

I claim:

1. In an axial flow compressor, a stator casing, an annular inlet guide mounted in said casing and including an outer shroud band, an inner shroud band and a plurality of hollow inlet guide vanes pivotally mounted therebetween, said stator casing having an annular recessed portion forming with one of said shroud bands an annular air chamber within said casing, each of said hollow vanes having a hollow pivot communicating with the interior thereof and extending through one of said shroud bands into said chamber, an actuating lever for each of said pivots within said chamber, an actuating ring within said chamber pivotally connected to the actuating lever of each of said pivotable vanes and supported from said levers free of said one of said shroud bands and said stator casing, actuating means extending into said chamber and connected to said actuating ring for movement thereof, said chamber being of substantially the same extent axially of said casing as said inlet guide, said actuating ring being of substantially the same diameter as the said one of said shroud bands and constituting with said vane actuating levers a compact actuating mechanism within said chamber having substantially the same axial extent as said inlet guide, each of said inlet guide vanes having an opening therein spaced from said hollow pivot to provide an air passage for each vane extending from said air chamber through the pivot, the interior of the vane and out through said opening.

2. In an axial flow compressor, a stator casing, an annular inlet guide mounted in said casing and including an outer shroud band, an inner shroud band and a plurality of hollow inlet guide vanes pivotally mounted therebetween, said stator casing having an annular recessed portion forming with the outer shroud band an annular air chamber within said casing, each of said hollow vanes having a hollow pivot communicating with the interior thereof and extending through said outer shroud band into said chamber, an actuating lever for each of said pivots within said chamber, an actuating ring within said chamber pivotally connected to the actuating lever of each of said pivotable vanes and supported from said levers free of said outer shroud band and said stator casing, actuating means extending into said chamber and connected to said actuating ring for movement thereof, said chamber being of substantially the same extent axially of said casing as said inlet guide, said actuating ring being of substantially the same diameter as said outer shroud band and constituting with said vane actuating levers a compact actuating mechanism within said chamber having substantially the same axial extent as said inlet guide, each of said inlet guide vanes having an opening therein spaced from said hollow pivot to provide an air passage for each vane extending from said air chamber through the pivot, the interior of the vane and out through said opening.

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