April 22, 1958 M. J. BRUNNER 2,831,627

AXIAL FLOW COMPRESSOR APPARATUS

Filed Jan. 15, 1954 2 Sheets-Sheet 1

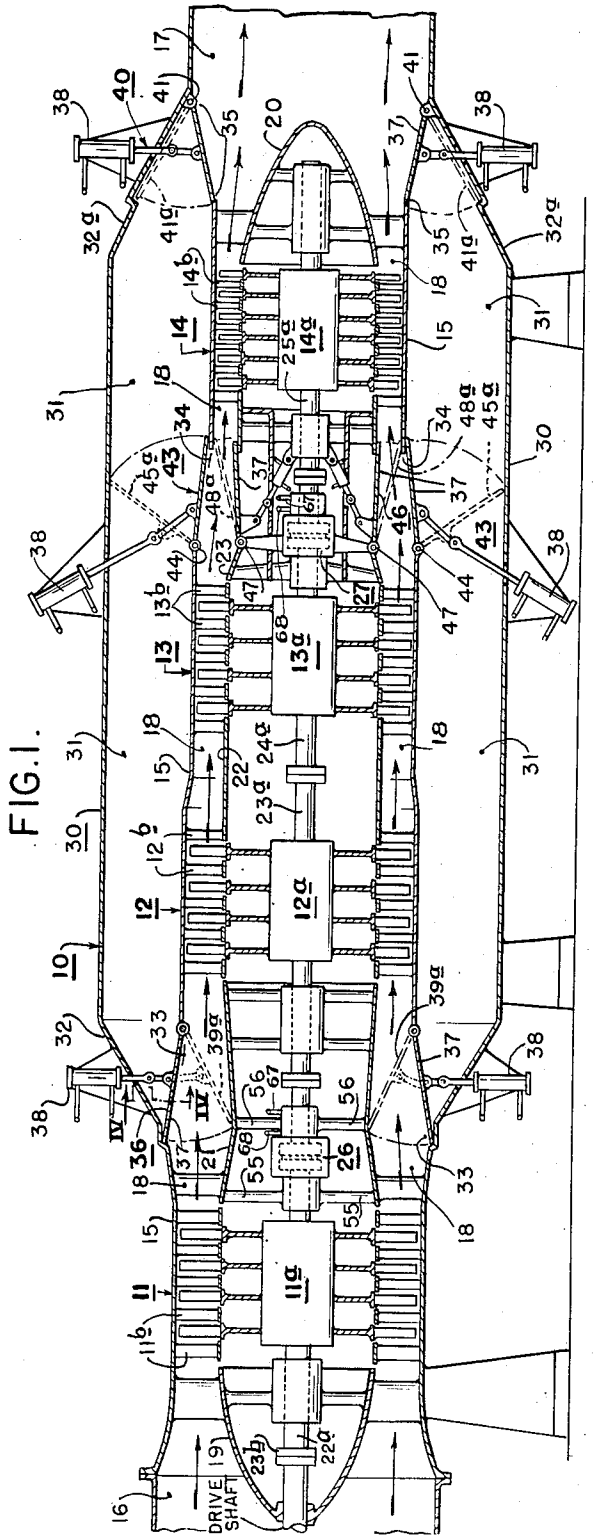


FIG. 1.

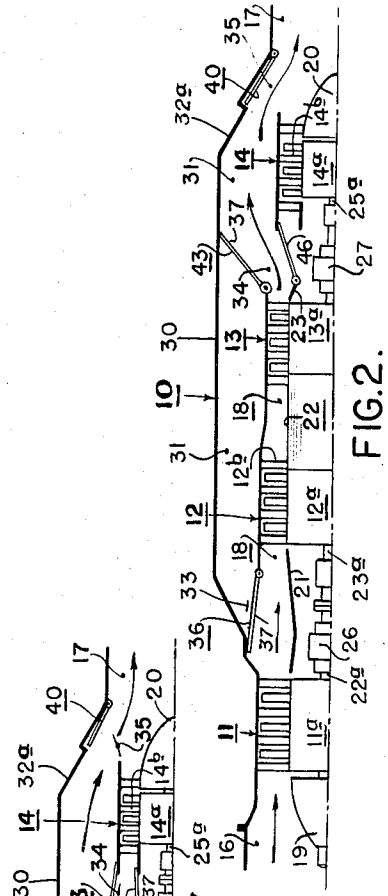


FIG. 2.

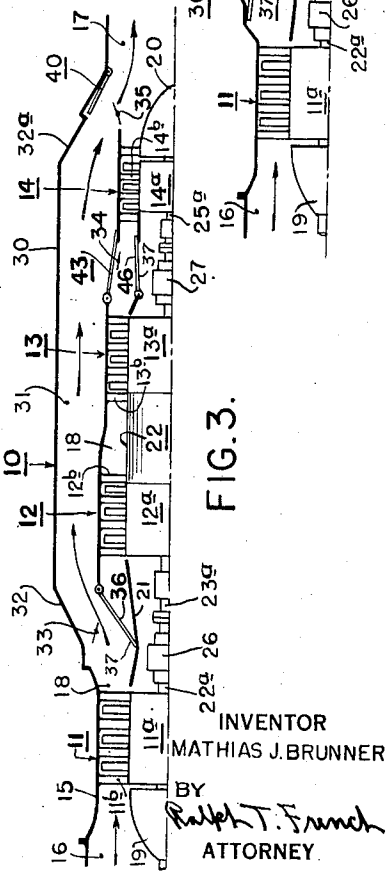


FIG. 3.

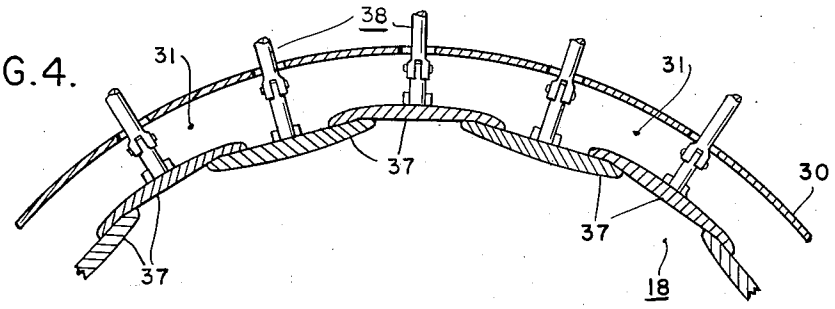
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AXIAL FLOW COMPRESSOR APPARATUS

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FIG.4.



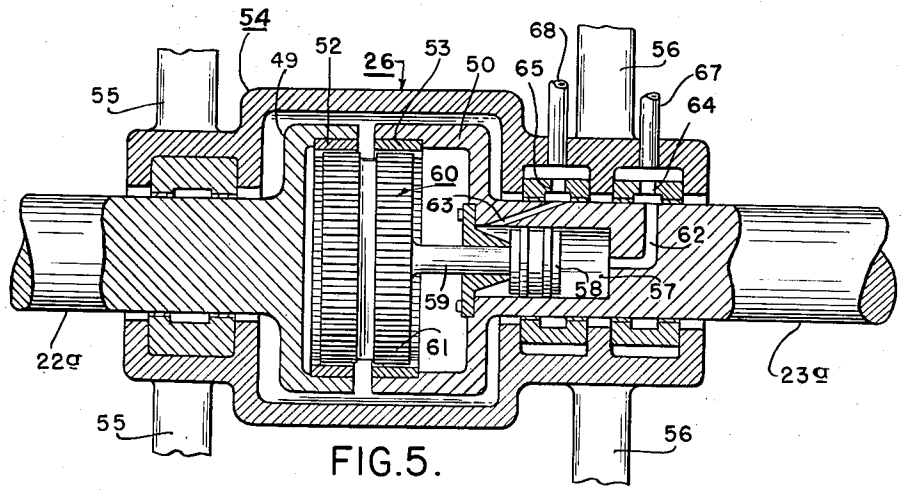


FIG.5.

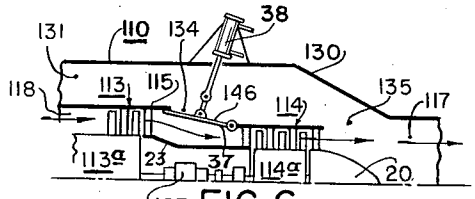


FIG.6.

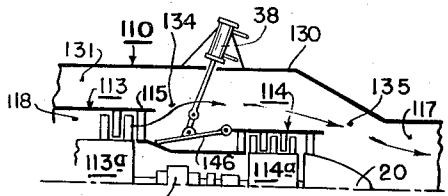


FIG.7.

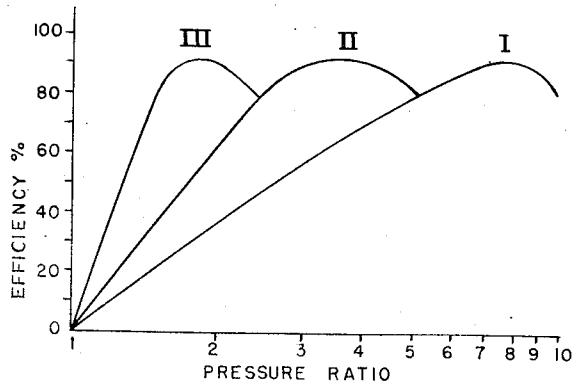


FIG.8

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AXIAL FLOW COMPRESSOR APPARATUS

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Application January 15, 1954, Serial No. 404,292

4 Claims. (Cl. 230—114)

This invention relates to axial flow compressors, more particularly to multi-stage, axial flow compressors for providing air or other gaseous fluids under pressure, and has for an object to provide a compressor of the above type having improved performance characteristics under various operating conditions.

In many applications, a multi-stage compressor operating under substantially constant inlet flow and rotational speed conditions is required to perform under various air outlet to air inlet pressure ratio conditions, including low pressure ratio conditions as well as the high pressure ratio conditions for which the compressor is designed. However, most conventional multi-stage compressors of the above type perform at peak efficiency only under high pressure ratio conditions, their efficiency decreasing to a low value under low pressure ratio conditions.

In view of the above, it is a further object of the invention to provide a multi-stage, axial flow compressor of the above type operable at high efficiency under various air outlet to air inlet pressure ratio conditions, including high pressure ratio conditions and low pressure ratio conditions.

It is another object of the invention to provide a multi-stage axial flow compressor of the above type which is compact in design, requires a minimum of space for installation and lends itself to economies in cost of manufacture.

In accordance with the invention, there is provided an axial flow compressor having a plurality of multi-stage air compressing sections. Each of the sections is provided with a bladed rotor and the usual complementary stationary blading. The rotors are connected in tandem by individually disconnectible coupling mechanisms, so that one or more sections may be utilized to compress the air as required by the air outlet to air inlet pressure ratio condition to be maintained. A continuous air passage extending from the downstream end of the low pressure section to the discharge outlet of the compressor is provided with a plurality of valves operable to divert the pressurized air around the sections in which the rotors are disconnected, thereby preventing "windmilling" of the disconnected rotors and eliminating attendant operating losses.

The above and the objects are attained by the invention as will be apparent from the following description taken in connection with the accompanying drawings, forming a part of this application, in which:

Fig. 1 is a schematic longitudinal vertical sectional view of a wind tunnel compressor incorporating the invention, the compressor being illustrated in operative condition for maximum pressure ratio performance;

Fig. 2 is a further simplified schematic view of the compressor taken on a smaller scale and showing the compressor in operative condition for intermediate pressure ratio performance;

Fig. 3 is a schematic view similar to Fig. 2, but showing the compressor in operative condition for low pressure ratio performance;

Fig. 4 is a greatly enlarged fragmentary sectional view taken on line IV—IV of Fig. 1;

Fig. 5 is an enlarged axial sectional view of one of the disconnectible coupling mechanisms;

Fig. 6 is a fragmentary schematic view showing another embodiment of the invention;

Fig. 7 is a fragmentary schematic view similar to Fig. 6, but showing the compressor in another operative condition; and

Fig. 8 is a chart showing representative efficiency curves attained with the invention.

Referring to the drawings in detail, especially Fig. 1, the invention is embodied in a multi-stage axial flow compressor **10** of the type utilized to provide pressurized air to a wind tunnel or the like (not shown). The compressor is provided with a plurality of multi-stage air compressing sections, namely, a low pressure section **11**, intermediate pressure sections **12** and **13**, and a high pressure section **14**, disposed in axial alignment with each other within a tubular shell structure **15**. The compressing sections **11**, **12**, **13** and **14** are provided with multi-stage bladed rotors **11***a*, **12***a*, **13***a* and **14***a* and complementary bladed stators **11***b*, **12***b*, **13***b* and **14***b*, respectively. The rotors are disposed in tandem with each other and together with the shell **15** define a primary annular air flow passage **18** extending from a flared air inlet end portion **16** to a flared air outlet end portion **17**. To provide for smooth air flow characteristics, a stationary fairing member **19** is mounted at the inlet end of the compressor, while a similar stationary fairing member **20** is mounted at the air outlet end **17**. Also, stationary core members **21**, **22** and **23** are axially interposed between the air compressing sections **11**, **12**, **13** and **14** respectively.

The rotors **11***a*, **12***a*, **13***a* and **14***a* are provided with shafts **22***a*, **23***a*, **24***a* and **25***a*, respectively, connected in tandem with each other. The rotor **11***a* is connected at the left end, to a source of power (not shown) having substantially fixed angular velocity, by a flange **23***b* provided on its shaft **22***a*. The rotors **12***a* and **13***a* are permanently coupled to each other by complementary flanges carried on the shafts **23***a* and **24***a*. The rotor **12***a* is connected to rotor **11***a* by means of a remotely controlled disconnectible coupling mechanism **26**. Similarly, the rotor **13***a* is connected to rotor **14***a* by a second remotely controlled disconnectible coupling mechanism **27**.

As thus far described, the compressor operates in the following manner. When the rotor **11***a* is connected to the source of power, air enters the air inlet end **16** and is driven through the air compressing sections **11**, **12**, **13** and **14**, traversing the primary passage **18** and being progressively increased in pressure before being discharged through the outlet end **17**. Obviously, with all of the compressing sections connected to each other, the pressure ratio of the air at the outlet end to the air at the inlet end attains a maximum value.

In accordance with the invention, a secondary compressor shell member **30** encompassing the main shell **15** and extending from a zone immediately downstream of the compressing section **11** to the air outlet **17** provides a secondary air passage **31** of annular shape. The secondary shell **30** is provided with front and rear frusto-conical portions **32** and **32***a*, respectively, which extend inwardly and are joined to the shell **15** and the outlet member **17**. Axially spaced annular openings **33** and **34** are provided in the shell **15** for permitting communication between the primary passage **18** and the secondary passage **31**, and a third annular opening **35** is provided in the outlet member **17** for permitting communication between the secondary passage and the discharge outlet.

A valve mechanism generally indicated **36** is provided

for covering and uncovering the opening 33. The valve mechanism 36 may be of the iris type provided with an annular array of leaves 37 hinged at one end and disposed in overlapping relation to each other, as shown in Fig. 4. Each of the leaves 37 may be independently actuated by separate hydraulic actuators 38 of the well known piston and cylinder type. The hydraulic actuators 38 may be anchored to the shell 30 in any desired manner and may be connected to the leaves 37 by means of pivoted links.

As shown in Fig. 1, the valve mechanism 36 is disposed in covering relation with the opening 33 and by actuation of the hydraulic actuators 38, the leaves 37 may be moved radially inwardly to uncover the opening 33 and block the central passage 18 as indicated by the dotted lines 39*a*.

A second valve mechanism 40, generally similar to the valve mechanism 36 described above, is provided at the outlet end 17 for covering and uncovering the opening 35. In this instance, the leaves 37 are shown in covering relation with the opening 35 and are movable radially outwardly about hinge pins 41 to uncover the opening 35, the retracted position being indicated by the dotted lines 41*a*.

A third valve mechanism 43 of the iris type, similar to the valve mechanism 36 and operable by a separate set of hydraulic actuators 38, is provided intermediate the sections 13 and 14. The leaves 37 of the valve mechanism 43 are hinged at 44 and, as shown, are in covering relation with the opening 34. Upon actuation by the hydraulic actuators 38, the leaves 37 may be swung radially outwardly to the dotted position 45*a*, thereby uncovering the annular opening 34 and blocking the secondary passage 31 immediately upstream of the opening 34.

A fourth valve mechanism 46, also similar to the valve mechanism 36, is provided for controlling that portion of the primary passage 18 extending through the section 14. As shown in Fig. 1, the leaves 37 are disposed in a position in which the passage 18 through section 14 is open. However, the leaves 37 may be swung radially outwardly about hinge pins 47 to the dotted position 48*a* thereby blocking the primary passage at section 14 and diverting air flow through the opening 34 into the secondary passage 31.

As will be later described, the valve mechanisms 36, 40, 43 and 46 may be operated in various combinations to direct air flow through the compressor by various routes involving the primary passage 18 and the secondary passage 31.

The coupling mechanism 26 may be of any desired type, for example, the hydraulically actuated type shown in Fig. 5, comprising opposed spaced flange members 49 and 50 connected to the shafts 22*a* and 23*a*, respectively. Each of the flanges 49 and 50 has ring gear members 52 and 53, respectively, firmly imbedded therein. The flanges 49 and 50 are rotatably supported within a liquid-tight housing 54 rotatably supporting the shafts 22*a* and 23*a* and supported in the shell 15 by means of struts 55 and 56. The flange 50 is provided with a central bore or cylinder 57 within which is disposed a piston 58 having a shaft 59 extending axially therefrom in the direction of the flange 49. A gear member 60 of about the same pitch diameter as those of the ring gears 52 and 53 is rigidly attached to the end of the shaft 59 and is provided with a relatively wide tooth face 61 axially slidable into and out of engagement with the ring gear 52, although always maintained in engagement with the ring gear 53. Thus, when the gear 60 is in the position shown in Fig. 5, the flanges 49 and 50 are connected to each other by the gear 60 and the shaft 22*a* is drivingly connected to the shaft 23*a*. The shaft 23*a* has a pair of orifices 62 and 63 communicating with the cylinder 57 at opposite sides of the piston 58. Each of the orifices is in registry with annular ports 64 and 65 which, in turn, are connected to hydraulic lines 67 and 68, respectively, so that, regardless of the angular position of the shaft 23*a*, the orifices 62 and 63 are always in registry with the ports 64 and 65.

To engage the coupling members 49 and 50, hydraulic fluid is admitted through the line 67 and orifice 62 into the right side of the cylinder 57, thereby moving the gear 60 to the left into engagement with the ring gear 52. When it is desired to disconnect the coupling members 49 and 50, hydraulic fluid is admitted through the line 68 and orifice 63 to the left-hand side of the cylinder 57 and exhausted from the right-hand side of the cylinder, thereby moving the gear 60 to the right and out of engagement with the ring gear 52.

The coupling mechanism 27 may be identical to the coupling mechanism 26 described above, the only difference being that it serves to connect shaft 24*a* to shaft 25*a*. Hence, it needs no further description.

Operation

When it is desired to operate the compressor under maximum outlet to inlet pressure ratio conditions, the compressing sections 11, 12, 13 and 14 are connected to each other by means of the disconnectible couplings 26 and 27. Thus, with power of constant angular velocity, the air drawn through the inlet 16 is progressively compressed by the compressing sections 11, 12, 13 and 14 as it flows through the primary passage 18 to the discharge outlet 17, as shown in Fig. 1.

When it is desired to operate the compressor under intermediate outlet to inlet pressure ratio conditions, as indicated in Fig. 2, the coupling 26 is retained in the engaged position while the coupling 27 is actuated to the disengaged position. Under these conditions, the compressing section 11 is drivingly connected to the compressor sections 12 and 13, while the compressor section 14 is disconnected. Also, the valve mechanism 36 is retained in the position in which the leaves 37 are disposed in their maximum radially outward position and cover the opening 33. The valve mechanism 43 is actuated so that its leaves 37 are disposed in their maximum radially outward position, blocking the secondary passage 31 and uncovering opening 34, while the valve mechanism 46 is actuated so that its leaves 37 are in their maximum radially outward position, blocking the primary passage 18 through the compressing section 14. The valve mechanism 40 is actuated to the position in which its leaves 37 are in their maximum radially outward position in which the opening 35 is uncovered. With the valves disposed in the positions mentioned above, air is drawn into the inlet 16, through the compressing sections 11, 12 and 13 by way of the primary passage 18 and is then deflected radially outwardly through the secondary passage 31 to the discharge outlet 17. With this arrangement, the air attains a pressure which is proportionately less than when all of the compressing sections are in driving relation therewith. It will be noted that the leaves of the valves 36, 43, 46 and 40 are so positioned that the air in passing through the compressor from inlet to outlet flows through a smoothly contoured route and does not encounter abruptly deflecting surfaces. Also, it will be noted that when the compressing section 14 is out of the compressing circuit, the air flow is directed about the compressing section 14, so that the rotor 14*a* thereof is not subjected to "windmilling."

When it is desired to operate the compressor under low air outlet pressure to air inlet pressure ratio conditions, as indicated in Fig. 3, the coupling 26 is actuated to disconnect the shaft 23*a* from shaft 22*a* of the compressing section 11, thereby rendering the compressing sections 12, 13 and 14 inoperative, so that the air is compressed by the compressing section 11 alone. The valve mechanism 36 is actuated to the position in which the opening 33 is uncovered and the central passage 18 is blocked in the zone intermediate the compressing sections 11 and 12. Also, the valve mechanism 40 is retained in the position in which the opening 35 is un-

covered, while the valve mechanism **43** is actuated to cover the opening **34**. Since the primary passage **18** downstream of the rotors **12** and **13** is out of the air flow circuit, the valve mechanism **46** may be left in the position shown in Fig. 2 or may be actuated to the position shown in Fig. 3. It will now be seen that air entering the inlet **16** passes through the compressing section **11**, through the primary passage **18**, and is then diverted radially outwardly by the valve mechanism **36**, through the secondary passage **31**, and is finally admitted to the discharge outlet **17** through the opening **35**. Here again, it will be noted that the flow of the air passing through the compressor follows a smooth path and that the rotors **12***a*, **13***a* and **14***a*, which are in the inactive state, are bypassed by the air flow so that "windmilling" of these rotors is eliminated.

In Fig. 8 there is shown a chart illustrating the efficiency characteristics of the compressor under various pressure ratios. The efficiency and pressure ratio values are shown for a typical compressor incorporating the invention. Curve I illustrates the efficiency of the compressor when all of the compressing sections are connected together to pressurize the air to maximum pressure ratio values. Curve II illustrates the efficiency curve when sections **11**, **12** and **13** are connected together for pressurizing the air to an intermediate pressure ratio value, while curve III illustrates the efficiency of the compressor when the compressing section **11** is operated alone to pressurize the air to a low pressure ratio value.

From an inspection of the above curves I, II and III, it will be noted that with the invention disclosed herein the compressor may be operated at approximately peak efficiencies for any pressure ratio within the limits of operation. The locations of the maximum efficiency peaks of the curves are determined by the particular design of the compressor and the number of sections connected in driven relation with the power supply. It will also be noted from further inspection of curve I that, when all of the compressing sections are utilized to provide pressurized air of various pressure ratios including the intermediate pressure ratios and the low pressure ratios, the efficiency of the compressor falls rapidly proportionately to the pressure ratio of the air outlet to the air inlet.

Although not specifically shown and described, the valve mechanisms **36**, **40**, **43** and **46** may be operated in unison or in succession and may be positioned before power is applied to the rotor **11***a*. Also, the couplings **26** and **27** may be actuated conjointly with or separately from the valve mechanisms. In the embodiment shown, the couplings **26** and **27** are actuated while the rotor is stationary.

Although one particular valving arrangement has been shown and described in connection with Figs. 1 through 5, other valve arrangements for diverting the flow through the various air passages in the compressor may be utilized in accordance with the invention.

The fragmentary schematic sectional views shown in Figs. 6 and 7 illustrate the invention incorporated in a compressor **110** which is generally similar to the compressor **10** heretofore shown and described and differs therefrom only in the arrangement of the iris valves. It is to be understood that those portions of the compressor not illustrated in these views may be the same as in the first embodiment.

Referring to Figs. 6 and 7 in detail, the compressor **110** has an intermediate air compressing section **113** and a high pressure section **114** provided with rotors **113***a* and **114***a*, respectively, connected to each other in tandem by a coupling mechanism **127**. The rotors **113***a* and **114***a* are disposed within a main tubular shell **115** and together therewith define a primary air passage **118** of annular shape.

A secondary shell **130** surrounds the main shell **115** and provides a secondary air passage **131**. It will be understood that the primary passage **118** and the secondary passage **131** extend in upstream direction, in a manner similar to that described in the first embodiment, to a zone immediately downstream of the low pressure section (not shown in this embodiment). The secondary shell **130** extends downstream beyond the high pressure section **114** and an outlet opening **135** of annular shape is provided connecting the secondary passage **131** with the outlet end portion **117** of the compressor. The primary passage **118** also has its outlet in communication with the outlet end portion **117**.

An annular opening **134** is provided in the main shell **115** in a zone intermediate the compressing sections **113** and **114**. An iris valve mechanism **146** is arranged in such a manner that when moved by the hydraulic actuator **38** to the outwardly extended position shown in Fig. 6, the annular opening **134** is blocked and the primary passage **118** is unblocked, while when moved to the inward position shown in Fig. 7, the opening **135** is unblocked and the primary air passage **118** is blocked at the inlet to the compressing section **114**.

It will now be seen that when the valve mechanism **146** is in the position shown in Fig. 6 and the rotor **114***a* is connected to the rotor **113***a* by the coupling **127**, the pressurized air flowing downstream through the section **113** in the primary passage **118** is delivered to the section **114** where it is further pressurized before being delivered to the outlet of the compressor.

Referring to Fig. 7, when the valve **146** is in the position shown therein, and the rotor **114***a* is uncoupled from the rotor **113***a* the pressurized air passing through the section **113** is diverted through the opening **134** into the secondary passage **131**, and delivered to the outlet **117** through the opening **135**. Thus, it will be seen that when the section **114** is in deactivated condition, the pressurized air is diverted about it to the outlet, thereby avoiding the "windmilling" action of the rotor **114** as previously described.

With this arrangement, the valve mechanism **40** and the valve mechanism **37**, utilized in the first embodiment, are eliminated, thereby simplifying the design and manufacture of the compressor and providing economies in the manufacture.

It will now be seen that the invention provides a compressor which is adaptable to various pressure ratio requirements and operable at substantially high efficiencies throughout its operating range. It will further be noted that the control is readily effected by power actuated remotely controlled apparatus.

The invention may be readily applied to compressors having more or less air compressing sections than those shown in the illustrated embodiment.

Also, although a compressor of large physical dimensions suitable for wind tunnel installations has been shown for illustrative purposes, the invention may be readily applied to compressors of considerably smaller size suitable for other applications, without departing from the spirit or scope of the invention.

While the invention has been shown in several forms, it will be obvious to those skilled in the art that it is not so limited, but is susceptible of various other changes and modifications without departing from the spirit thereof.

What is claimed is:

1. In a multi-stage axial flow air compressor, a tubular shell, a plurality of bladed rotors disposed in said shell and together therewith defining a main annular air passage, said rotors including first and second rotors for providing low and high pressure sections, respectively, for the flow of air axially through said annular air passage, said rotors being disposed in tandem with each other, coupling means between said first and second rotors for selectively interconnecting and disconnecting the same, means for connecting said first rotor to a source of power, whereby said second rotor is driven only when connected

to said first rotor by said coupling means, means providing a secondary air passage in bypass relation with said annular passage around said second rotor, said secondary passage means having an opening communicating with said annular passage at a zone intermediate said first and second rotors, and means including a valve selectively movable to first and second positions, said valve covering said opening in said first position, and said valve blocking said annular passage at said zone and uncovering said opening in said second position.

2. In an axial flow air compressor, a plurality of multi-stage air compressing sections, each of said sections comprising a bladed rotor and complementary bladed stators, said rotors being disposed in tandem with each other, tubular means encompassing said rotors and stators and together therewith defining a primary annular air passage, said rotors including first and second rotors, coupling means between said first and second rotors for selectively interconnecting and disconnecting the same, means for connecting said first rotor to a source of power, whereby said first rotor is in driving relation with said second rotor, means including a tubular shell providing a secondary annular air passage in bypass relation with the portion of said primary air passage extending through said second rotor, said secondary passage means having an annular opening communicating with said primary passage at a zone intermediate said first and second rotors, and means for diverting air flow through said secondary passage including a valve selectively movable to first and second positions, said valve covering said annular opening in said first position, and said valve blocking said primary passage at said zone and uncovering said annular opening in said second position.

3. In a multi-stage axial flow air compressor, a tubular shell, a plurality of bladed rotors disposed in said shell and together therewith defining a main annular air passage, said rotors including first and second rotors for providing low and high pressure sections, respectively, for the flow of air axially through said annular air passage, said rotors being disposed in tandem with each other, coupling means between said first and second rotors for selectively interconnecting and disconnecting the same, means for connecting said first rotor to a source of power, whereby said second rotor is driven only when connected to said first rotor by said coupling means, means including a tubular member encompassing said tubular shell and providing a secondary air passage of annular shape in bypass relation with said main annular passage around said second rotor, said secondary passage means having an annular opening communicating with said main annular passage at a zone intermediate said first and second rotors, and means including a valve selectively movable to first and second positions, said valve covering said opening in said first position, and said valve blocking said main passage at said zone and uncovering said opening in said second position, said valve comprising an annular array of movable leaf members disposed in overlapping relation to each other.

4. In an axial flow air compressor, a plurality of multi-stage air compressing sections, each of said sections comprising a bladed rotor and complementary bladed stators, said rotors being disposed in tandem with each other, tubular means encompassing said rotors and stators and together therewith defining a primary annular air passage, said rotors including first and second rotors, coupling means between said first and second rotors for selectively interconnecting and disconnecting the same, means for connecting said first rotor to a source of power, whereby said first rotor is in driving relation with said second rotor, means including a tubular shell providing a secondary annular air passage in bypass relation with the portion of said primary air passage extending through said second rotor, said secondary passage means having an annular opening communicating with said primary passage at a zone intermediate said first and second rotors, means for diverting air flow through said secondary passage including a valve selectively movable to first and second positions, said valve covering said annular opening in said first position, and said valve blocking said primary passage at said zone and uncovering said annular opening in said second position, a member defining a main outlet passage communicating with said primary passage, said secondary passage means extending to said main outlet passage member and having a second opening communicating with said main outlet passage, and second valve means for selectively covering and uncovering said second opening.

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