

Oct. 7, 1952

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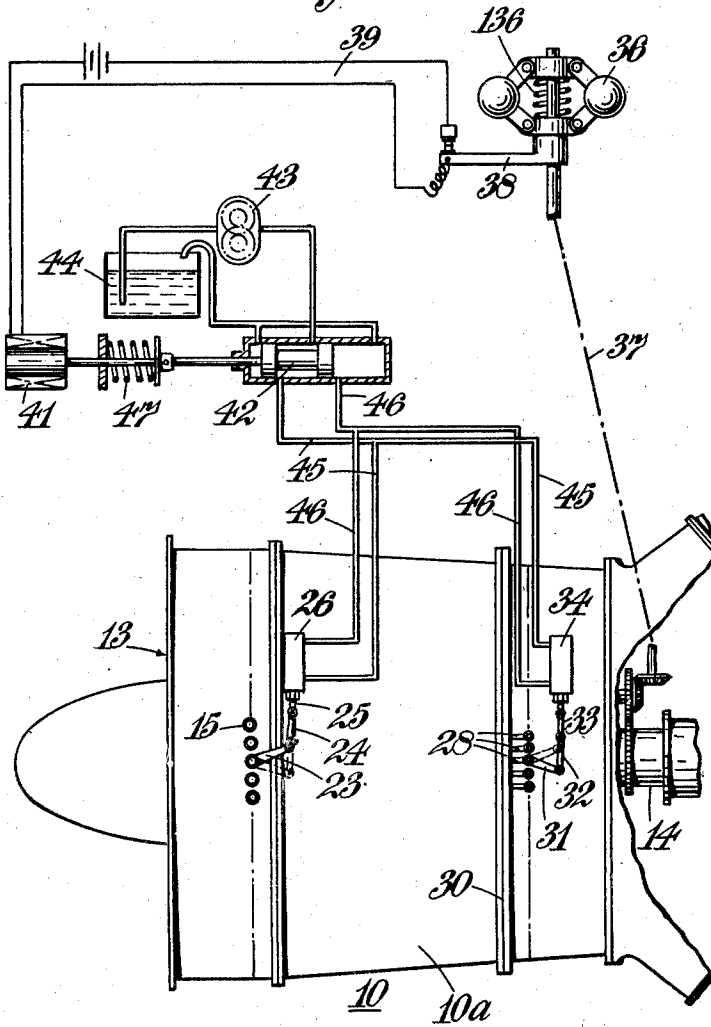
2,613,029

AXIAL FLOW COMPRESSOR REGULATION

Filed June 1, 1948

2 SHEETS—SHEET 1

Fig. 1.



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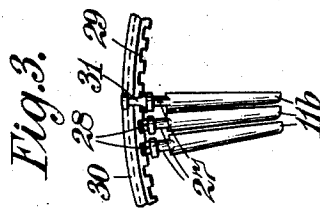
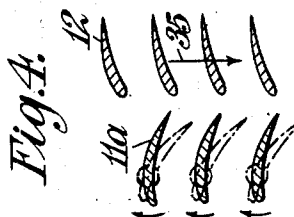
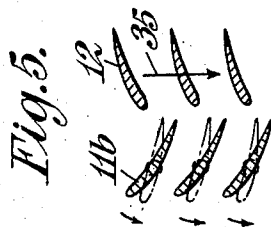
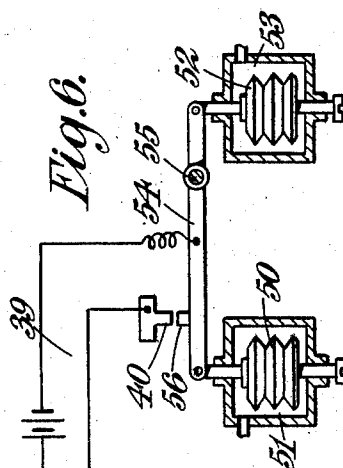
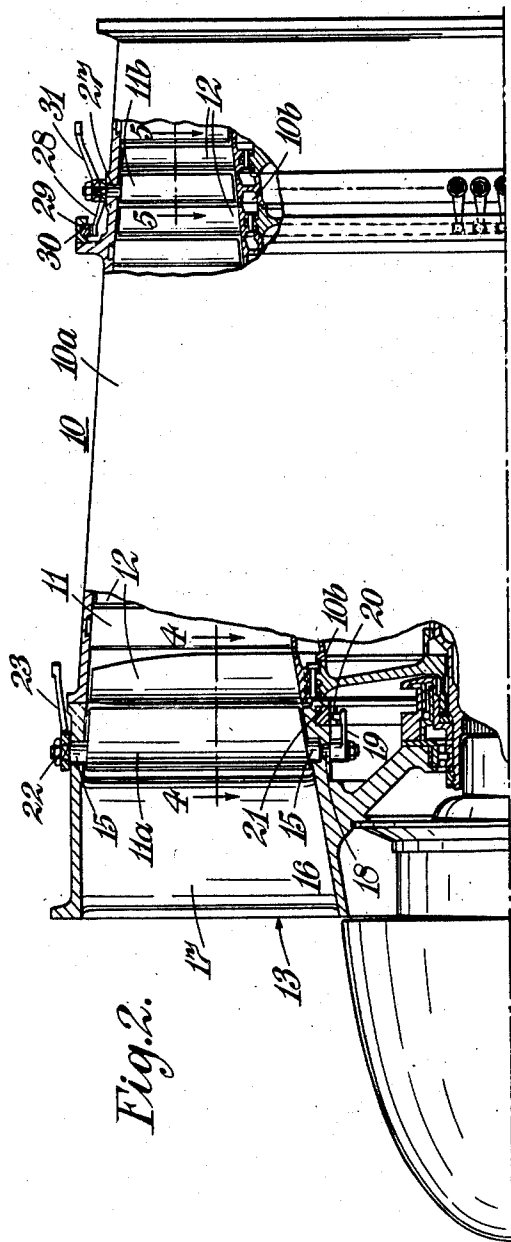
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2,613,029

AXIAL FLOW COMPRESSOR REGULATION

Filed June 1, 1948

2 SHEETS--SHEET 2



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2,613,029

AXIAL FLOW COMPRESSOR REGULATION

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Application June 1, 1948, Serial No. 30,330
In Great Britain June 4, 1947

11 Claims. (Cl. 230—114)

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This invention relates to multi-stage axial-flow compressors and has for its object to provide such a compressor with a wide speed-range of operation.

It is usual to design such a compressor to run efficiently at a particular rotational speed or at a condition dependent on rotational speed, and this involves designing the blades, so that all the stages can be ideally matched to give a selected, for instance constant, axial velocity of the fluid to be compressed, from entry to exit at the particular rotational speed or condition dependent on rotational speed.

The term "rotational speed" covers either the actual rotational speed of the compressor or the corrected rotational speed of the compressor i. e. the actual rotational speed divided by the square root of the absolute temperature at the inlet to the compressor, since, as is well known in the art, a compressor may be designed to operate efficiently at a selected value of the actual rotational speed or of the corrected rotational speed or of a condition dependent on either one of these two speeds.

The angle of incidence at which the rotor-blades operate, for any given speed of rotation, is determined by the axial velocity of the fluid and the direction of swirl given to it by the stator blades.

At rotational speeds below the designed speed, when the pressure rise per stage is less than the designed pressure-rise, there will tend to be an accelerating flow from entry to exit due to the designed overall density-ratio not being achieved. This acceleration appears as a reduction of the axial velocity of the fluid at the entry and an increase at the exit.

Where the axial velocity of the fluid is lower than the designed axial velocity, the angle of incidence becomes positive and so high that the blades run in a stalled condition, and where the axial velocity is higher, the blades run at a negative angle of incidence and therefore do not contribute their share of the stage pressure-rise.

At rotational speeds above the designed speed, when the pressure-rise per stage is greater than the designed pressure-rise, there will tend to be a decelerating flow from entry to exit due to the design overall density-ratio being exceeded; this deceleration appears as an increase of the axial velocity at entry and a decrease at exit. These conditions are therefore opposite to what occurs when the rotational speed is below the designed speed as described above.

The object of this invention is to provide for adjusting the rotational swirl of the fluid to suit

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any variations in the axial velocity of the fluid which arise from changes in the speed of the rotor from the designed speed.

The primary object of the present invention is to provide a construction of multi-stage axial-flow compressor in which the flow conditions are controlled in such a manner as to maintain a high efficiency of compression throughout a wide range of rotational speed.

According to the present invention, a multi-stage axial-flow compressor is arranged in a plurality of sections each comprising a plurality of stages, and is provided with a row of adjustable-pitch stator-blades at the entry to each section to vary the rotational swirl of the fluid leaving them and entering the section, and so to avoid the difficulties mentioned above and provide a multi-stage axial-flow compressor having a wide speed-range of operation and good efficiency at low speeds and at starting.

According to a feature of the invention, the means for adjusting the pitch of the adjustable-pitch stator blades may be connected with a device sensitive to the speed of the compressor, so that the pitch of the blades is adjusted to a predetermined setting for any compressor-speed other than the designed speed.

According to another feature of this invention, the means for adjusting the pitch of the adjustable-pitch stator blades may be connected with a device sensitive to an operating variable which varies as a unique function of rotational speed. Thus in some constructions according to the invention the means for adjusting the pitch of the adjustable pitch stator blades may be connected with a device sensitive to the ratio between the inlet and discharge pressures of the compressor, since this ratio varies as a unique function of corrected rotational speed.

Some embodiments of the invention will now be described by way of example, reference being made to the accompanying drawings in which,

Figure 1 is a diagrammatic plan of a multi-stage axial compressor and means for varying the pitch of the adjustable stator blades,

Figure 2 is a side elevation of part of the compressor with parts in section to show the manner in which the adjustable stator blades are supported,

Figure 3 is a scrap view showing means for adjusting the pitch of one row of stator blades,

Figure 4 is a diagrammatic section on the line 4—4 of Figure 2 illustrating the manner of pitch adjustment of the entry stator blades of one section of the compressor,

Figure 5 is a corresponding view on the line

5—5 for the blades of a second section of the compressor, and

Figure 6 illustrates diagrammatically a modified control for varying the pitch of the stator blades.

Referring to Figures 1 to 5, there is illustrated a multi-stage axial-flow compressor 10 which is suitable for an aircraft gas-turbine engine, having a stator casing 10a carrying a plurality of rows of stator blades 11 and a rotor 10b carrying a corresponding series of rows of rotor blades 12, the rows of blades 11 and blades 12 alternating from the inlet 13 of the compressor to the outlet therefrom. The rotor 10b is driven through a shaft 14 which in aircraft gas-turbine engines usually extends between the compressor rotor and a turbine rotor.

The compressor is divided into a number of sections each comprising a plurality of stages, each stage comprising a row of stator blades 11 and a row of rotor blades 12, and the entry row of stator blades of each section are adjustable in pitch for the purpose above described. Thus in the construction illustrated, the compressor is divided into low pressure and high pressure sections of which the first-stage stator blades 11a are the adjustable entry blades for the low pressure section and the seventh stage stator blades 11b are the adjustable entry blades of the high pressure section.

Each blade 11a is formed at each end with a trunnion 15, the outer trunnion engaging in a bearing in the compressor casing 10a and the inner trunnion being engaged in a bearing in a stationary annular front bearing housing 16 supported within the casing 10a by the inlet guide vanes 17. Each of the inner trunnions 15 has a pin-like extension 18 projecting within the housing 16 and having secured on it a rocker arm 19. Each rocker arm has an upstanding pin 20 at its end to engage with a notch in a ring 21. The ring 21 is rotatively mounted in the housing 16 and is internally notched, there being one notch for each pin 20 and thus for each of the stator blades 11a. Thus it will be seen that if the ring 21 is rotated, the arms 19 will be rocked and the blades 11a rotated about their lengthwise axes to adjust their pitch.

The following arrangement is adopted to rotate the internally-notched ring 21. The outer trunnion 15 of one of the blades 11a has a squared extension 22 projecting outside the compressor casing 10a and this extension has secured on it a lever 23 connected by a link 24 to the ram 25 of a hydraulic jack 26. Telescoping of the jack 26 will rock the lever 23 to rotate the blade 11a carrying it and this rotation will be transmitted to the ring 21 through the associated arm 19.

Each blade 11b is mounted to rotate about its lengthwise axis by being supported in the casing 10a through a trunnion 27 on its outer end. Each trunnion 27 has secured to it an arm 28 which engages by its free end in an internally-notched ring 29 rotatively mounted in an internally-recessed flange 30 on the casing 10a. One of the arms 28 has a rearward extension 31 which is connected by a link 32 to the ram 33 of a hydraulic jack 34. Telescoping of the jack 34 will rock the lever 28, 31 causing the ring 29 to rotate relative to the casing 10a, thereby rocking the remaining arms 28 and causing the blades 11b to rotate about their lengthwise axes to adjust their pitch.

Referring more particularly to Figures 1, 4 and 5, the means for controlling the pitch is

such that if the compressor speed is below a preselected speed the pitch of the blades 11a and 11b is adjusted by the jacks 26, 34 respectively to occupy the chain-line positions indicated while for normal running at above the preselected speed the blades occupy the full-line position. The direction of rotation of the rotor is indicated by arrow 35.

The control means comprises a centrifugal device 36 driven by any suitable drive 37 from the shaft 14. The centrifugal device produces a force which is a function of compressor speed and this force is opposed by the spring 136. The centrifugal device carries a contact arm 38 and it is arranged that when the preselected compressor speed is reached an electrical circuit 39 is completed by the contact on arm 38 engaging a fixed contact 40 thereby energising a solenoid 41. The solenoid controls a piston valve 42 controlling the flow of liquid through a hydraulic circuit between a pump 43 and the jacks 26, 34. The pump 43 draws liquid from the reservoir 44 and when the solenoid 41 is energised the pressure fluid is delivered to the jacks through pipes 45 holding the levers 23, 31 in their full-line position (Figure 1) which corresponds to the full-line positions of the blades 11a, 11b (Figures 4 and 5), whilst when the solenoid is de-energised the pipes 46 leading to the opposite ends of the jacks 26, 34 are connected to the pressure fluid and the levers 23, 31 occupy their chain line positions. A spring 47 is provided to urge the piston valve 42 to the right as viewed in the drawings on de-energization of the solenoid 41.

It will be seen that at speeds below the preselected speed, the inlet blades 11a are adjusted to increase the swirl caused by them in the direction of rotation 35 of the rotor blades 12, whilst the inlet blades 11b to the second section are adjusted to a position in which the swirl they cause in the direction of rotation of the rotor blades 12 is described.

This arrangement ensures that stalling of the compressor at low rotational speeds does not occur.

The preselected speed at which adjustment of the blades 11a, 11b occurs corresponds to a given ratio between the pressures at the compressor inlet 13 and at the compressor outlet and this fact is employed in an alternative controller to the centrifugal device 36 and spring 136.

Referring to Figure 6, the alternative controller comprises two pressure sensitive capsules, one 50 of which is enclosed in a chamber 51 connected to the compressor inlet and the other 52 of which is enclosed in a chamber 53 connected to the compressor delivery. The capsules operate on a pivoted beam 54, the pivot 55 for which is closer to the end of the beam connected to capsule 52 than to the other end. Assuming that the capsules are of equal effective area, then the beam will be rocked to close the circuit 39 by contact 56 engaging fixed contact 40, when the ratio of the outlet pressure to inlet pressure exceeds the ratio of the longer beam arm to the shorter beam arm and this occurs at a predetermined speed of the compressor. Closing of the contacts 40, 56 controls adjustment of the pitch of blades 11a, 11b in the manner described with reference to Figures 1, 4 and 5.

The invention is not limited to the constructions above described. The compressor may be divided into more than two sections having the first row of stator blades adjustable in pitch; the higher the designed running speed and pressure

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ratio of the compressor, the greater is the change in pitch required to improve efficiency at low speeds. For instance a compressor designed to run at a high-speed may have adjustable rows of stator blades at the inlet stage, the second stage, seventh stage and tenth stage, the first two being increased in pitch at low speed and the two latter decreased in pitch.

Furthermore, instead of providing only two positions for the stator blades they may be made to occupy more than two positions or to be controlled by a follow-up mechanism between the governor and blades so that their pitch is varied in accordance with engine speed over a predetermined range of speed.

I claim:

1. A multi-stage axial flow compressor comprising a high pressure section and a low pressure section, each section comprising a plurality of stages, said compressor further comprising a stator casing; a row of stator blades at the entry to each said section; bearing means supporting the stator blades of each said row in said casing so as to be adjustable in pitch; motor means operative to rotate each row of stator blades in unison but in opposite directions; a power supply for said motor means; and power supply control means, including a device sensitive to the speed of the compressor, automatically to control the power to supply to said motor means to rotate the stator blades of said low pressure section to give an increased swirl in the direction of rotation of the compressor at low compressor speeds and to rotate the stator blades of said high pressure section to give a decreased swirl at low compressor speeds.

2. In a multi-stage axial-flow compressor of the class having a plurality of rows of stator blades adjustable in pitch, the combination with each of said rows of a jack to adjust in pitch in unison all the blades in the row from a first position to a second position, a source of fluid pressure, fluid connection between said source and said jack, a two-position control valve operative in its first position to connect one end of said jack with said source, and in its second position to connect the other end of said jack to said source, a loading device biasing said valve to one of said positions, a solenoid operative when energised to move said valve against said loading device to its other position, a source of electric power, an electric switch, electric connections connecting said solenoid, said source of electric power, and said switch in an electric circuit in series, and speed-sensitive means arranged to be sensitive to the rotational speed of said compressor and operative alternately to open and close said switch when said rotational speed passes through a selected value.

3. A combination according to claim 2, wherein a single source of fluid pressure and a single control valve are common to all the jacks.

4. In a multi-stage axial-flow compressor of the class having a plurality of rows of stator blades adjustable in pitch, the combination with each of said rows of a jack to adjust in pitch in unison all the blades in the row from a first position to a second position, a source of fluid pressure, fluid connection between said source and said jack, a two-position control valve operative in its first position to connect one end of said jack with said source and in its second position to connect the other end of said jack to said source, a loading device biasing said valve to one of said positions, a solenoid operative when en-

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ergised to move said valve against said loading device to its other position, a source of electric power, an electric switch, electric connections connecting said solenoid, said source of electric power and said switch in an electric circuit in series, and pressure-sensitive means sensitive to the ratio between the pressures from the inlet to the outlet of said compressor and operative alternately to open and close said switch when said ratio passes through a selected value.

5. A combination according to claim 4, wherein a single source of fluid pressure and a single control valve are common to all the jacks.

6. A multi-stage axial-flow compressor comprising a high pressure section and a low pressure section, each section comprising a plurality of stages, said compressor further comprising a stator casing, a row of stator blades at the entry to each said section, bearing means supporting the stator blades of each said row in said casing so that they are adjustable in pitch, first motor means to rotate the stator blades of the row at entry to the high pressure section, second motor means operative to rotate the stator blades of the row at entry to the low pressure section, a power supply for said motor means, speed-sensitive means sensitive to the compressor rotational speed, and servo means operated by said speed-sensitive means to place said power supply in connection with said first motor means to rotate said row of stator blades at entry to the low pressure section in the direction to increase their outlet angle relative to the axial direction and to place said power supply in connection with said second motor means to rotate said row of stator blades at the entry to the high pressure section in the direction to decrease their outlet angle relative to the axial direction, until the pitch of the blades of the two rows is adjusted in opposite senses to a predetermined setting depending on the speed of the compressor.

7. A multi-stage axial-flow compressor comprising a plurality of sections, each section comprising a plurality of stages, said compressor further comprising a stator casing, a row of stator blades at the entry to each said section, bearing means supporting the stator blades of each row in said casing so that they are adjustable in pitch, jack devices operative to rotate the stator blades of each row in unison, a supply of pressure fluid for said jack devices, a centrifugal device to produce a force which is a function of compressor rotational speed and increases with increase of said speed, means to oppose said force, an electric circuit arranged to be completed by said centrifugal device on overcoming said opposing force due to sensing a preselected speed of said compressor, a solenoid arranged to be energized on completion of said electric circuit, valve means arranged to be moved between two positions by said solenoid device, conduit means from said pressure fluid supply to said valve means and conduit means from said valve means to said jack devices to deliver pressure fluid to one end thereof when said valve is in one position and to deliver pressure fluid to the other end thereof when said valve is in the other position whereby the supply of pressure fluid to said jack devices is controlled when said rotational speed passes through said preselected speed to rotate the stator blades of said rows until the pitch of the blades of each row is adjusted to a predetermined pitch depending on said rotational speed.

8. A multi-stage axial-flow compressor comprising a plurality of sections, each section comprising a plurality of stages, said compressor further comprising a stator casing, a row of stator blades at the entry to each said section, bearing means supporting the stator blades of each row in said casing so that they are adjustable in pitch, motor means operative to rotate the stator blades of each row in unison, a power supply for said motor means, pressure-ratio-sensitive means comprising a pair of resilient pressure-sensitive capsules connected respectively to an inlet pressure and an outlet pressure of the compressor, and a pivoted beam arranged to be loaded in opposition by said capsules, an electric circuit arranged to be completed when a predetermined pressure ratio is sensed by said pressure-ratio-sensitive means and servo means operated on completion of said electric circuit to place said power supply in connection with said motor means to rotate the stator blades of said rows until the pitch of the blades of each row is adjusted to a predetermined setting dependent on the speed of the compressor.

9. A multi-stage axial flow compressor comprising a plurality of sections, each section comprising a plurality of stages, said compressor further comprising a stator casing, a row of stator blades at the entry of each section, bearing means supporting the stator blades of each row in said casing so that they are adjustable in pitch, motor means to rotate each row of said stator blades, means controlling said motor means to cause said rows of blades to rotate in unison but in opposite directions, and speed-sensitive means sensitive to the compressor rotational speed to operate said motor controlling means until the pitch of the blades is adjusted to a predetermined setting depending on the speed of the compressor.

10. A multi-stage axial-flow compressor comprising a plurality of sections, each section comprising a plurality of stages, said compressor further comprising a stator casing, a row of stator blades at the entry to each said section, bearing means supporting the stator blades of each row in said casing so that they are adjustable in pitch, motor means to rotate each row of said stator blades, means controlling said motor means to cause said rows of blades to rotate in

unison but in opposite directions, and a centrifugal device driven by the compressor to produce a force which is a function of compressor rotational speed and increases with increase of speed, a spring to oppose said force, said motor controlling means being operated when said force produced by the centrifugal device overcomes said spring so that the stator blades of said rows are rotated until the pitch of the blades of each row is adjusted to a predetermined setting depending on the speed of the compressor.

11. A multi-stage axial flow compressor comprising a power input shaft subject to variable driven speeds of rotation, a high pressure section and a low pressure section both driven by said shaft, each section comprising a plurality of stages, said compressor further comprising a stator casing; a row of stator blades at the entry to each said section; bearing means supporting the stator blades of each said row in said casing so as to be adjustable in pitch; motor means operative to rotate each row of stator blades in unison but in opposite directions; a power supply for said motor means; and power supply control means, including a device sensitive to the speed of the compressor, automatically to control the power supply to said motor means to rotate the stator blades of said low pressure section to give an increased swirl in the direction of rotation of the compressor at low compressor speeds and to rotate the stator blades of said high pressure section to give a decreased swirl at low compressor speeds.

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