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2,741,423

AXIAL-FLOW COMPRESSORS

Filed March 7, 1952

4 Sheets-Sheet 1

Fig. 1.

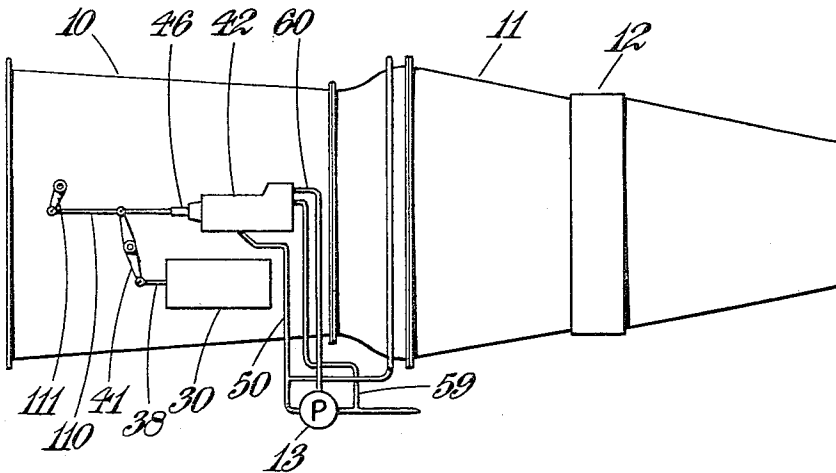
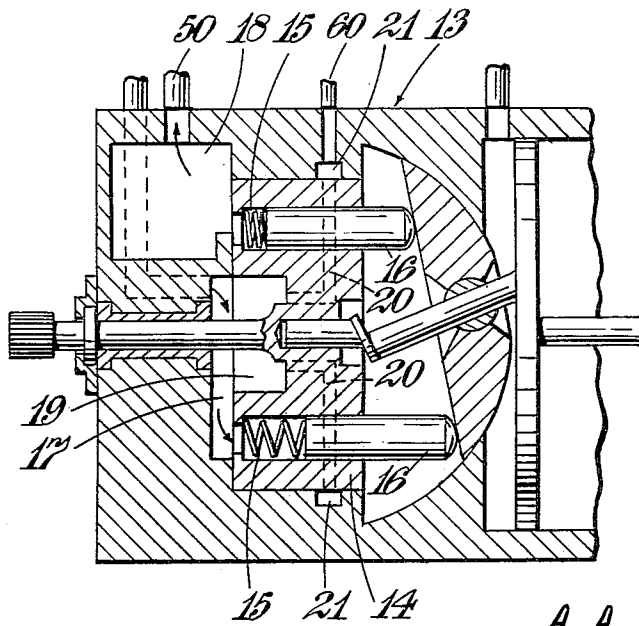


Fig. 2.



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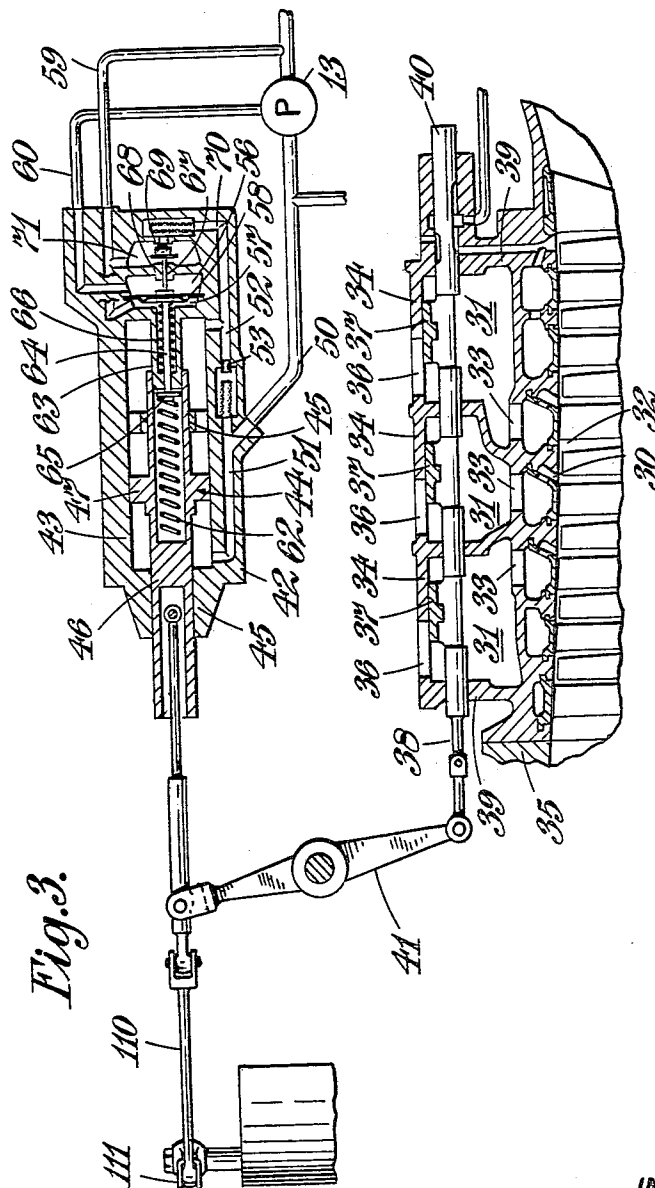
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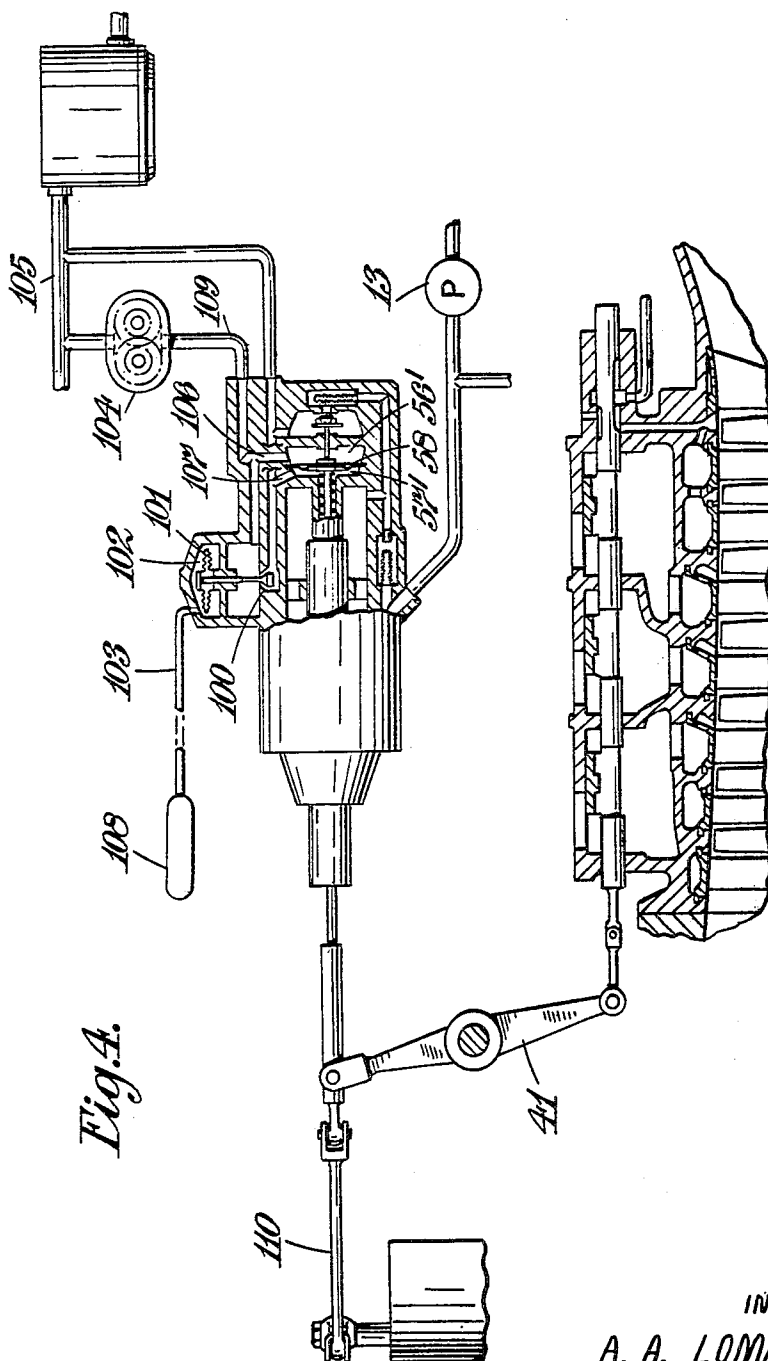
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4 Sheets-Sheet 3



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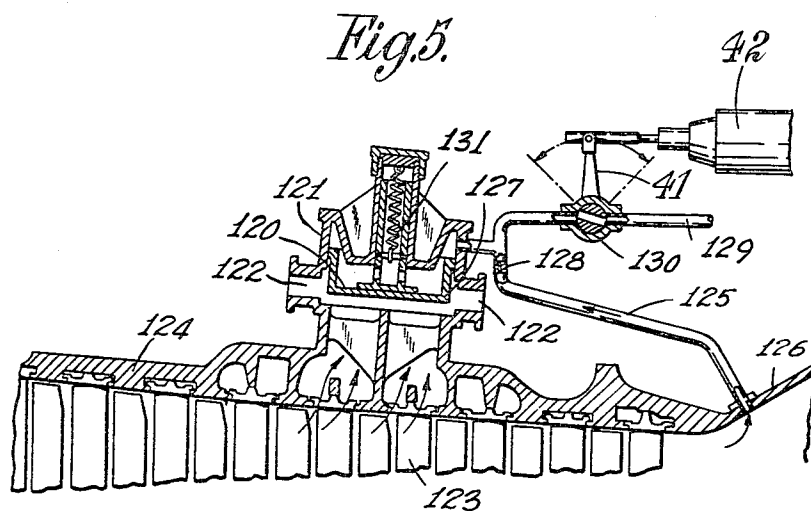
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AXIAL-FLOW COMPRESSORS

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AXIAL-FLOW COMPRESSORS

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Claims priority, application Great Britain March 14, 1951

7 Claims. (Cl. 230—114)

This invention relates to multi-stage axial-flow compressors and has for its object to provide means whereby the efficiency of the compressor may be maintained over a wide speed range of operation. It is usual to design such a compressor to run at a particular speed which is normally a high proportion of the maximum operating speed of the compressor. The characteristics of the blades of the compressor, including their incidence, profile and pitch, are therefore chosen to give the optimum efficiency at the speed at which the compressor is designed to operate. At speeds below the design 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 of the compressor due to the design overall density ratio not being achieved. This acceleration appears as a reduction of axial velocity at the entry of the compressor and an increase at the exit.

It has been found that the reduction of axial velocity at the entry to the compressor results in the rotor blades of the initial stages of the compressor, and also in some cases the stator blades of the initial stages, operating at a much higher angle of incidence than in the design condition. When the speed of the compressor is reduced sufficiently this high angle of incidence results in the blades stalling, the efficiency of the compressor then being seriously reduced. It has been proposed that air should be bled off from a later stage of the compressor, whereby the axial velocity of the air passage through the earlier stages of the compressor is increased.

This invention is concerned with multi-stage axial-flow compressors having bleed valve means for controlling passages through which air is bled off from a later stage of the compressor, and has for an object to provide a method of controlling the flow conditions in such a compressor so as to maintain a high efficiency of compression through a wide speed range.

According to this invention in one aspect, a method of controlling the flow conditions in a multi-stage axial-flow compressor which has bleed valve means comprises, over part at least of the range of rotational speeds of the compressor, automatically and progressively varying the opening afforded by the bleed valve means so that, for each speed in the range in which control is effected, the bleed valve means has a corresponding opening to give efficient operation of the compressor. By "opening" is meant the effective area of the aperture afforded by the bleed valve, through which the working fluid is allowed to escape.

According to this invention in another aspect, there is provided the combination with a multi-stage axial-flow compressor having bleed valve means, of means operative over part at least of the range of rotational speeds of the compressor for automatically and progressively varying the opening of the bleed valve means in a manner corresponding to changes in the compressor rotational speed, so that, for each speed, the bleed valve means

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has a corresponding opening appropriate to give efficient operation of the compressor at that speed.

In another aspect, the invention provides in combination a multi-stage axial-flow compressor, bleed valve means arranged to control the flow of fluid bled from the compressor, and speed-sensitive means sensitive to the rotational speed of the compressor and connected to control progressively the opening of the bleed valve means so that, for each rotational speed, the bleed valve means has a corresponding opening appropriate to give efficient operation of the compressor at that speed.

In yet another aspect, the invention provides in combination, a multi-stage axial-flow compressor having a bleed passage from a later stage, a bleed valve in said bleed passage to control the flow therethrough, a speed-sensitive device including a member whose position is dependent on the rotational speed of said compressor in a range of speeds, and a connection between said member and said bleed valve arranged so that, when said member moves on increase of rotational speed within the said range, said bleed valve moves towards its closed position and vice versa, so that, for each rotational speed in the said range, the bleed valve has a corresponding opening appropriate to give efficient operation of the compressor at that rotational speed.

According to another aspect of this invention, a multi-stage axial-flow compressor comprises bleed valve means, pressure-sensitive means arranged to control the opening of said bleed valve means, said pressure-sensitive means being loaded in one sense by a fluid pressure load which is a predetermined function of the rotational speed of the compressor, and being loaded in the opposite sense by a force which is a function of the opening of said bleed valve means, said pressure-sensitive means being connected to control said bleed valve means so that, for each speed, the bleed valve means has a corresponding opening appropriate to give efficient operation of the compressor at that speed.

By "rotational speed" is meant either the actual rotational speed or the corrected rotational speed. The corrected rotational speed is equal, as is well known in the art, to the actual rotational speed multiplied by a constant and divided by the square root of the absolute temperature at inlet to the compressor.

According to a feature of the invention the bleed valve means may comprise a slide valve.

According to another feature of the invention, the bleed valve means may comprise a seating formed round an aperture in the compressor stationary structure, which aperture opens into a chamber in communication with the working fluid passage of the compressor, and a valve member which is arranged to slide relative to the seating to open and close the aperture in the compressor stationary structure.

According to yet another feature of the invention, the multi-stage axial-flow compressor having bleed valve means and means for automatically and progressively varying the opening thereof in accordance with engine rotational speed, may also comprise adjustable-pitch stator blades and means for automatically and progressively varying the pitch of the stator blades in accordance with engine rotational speed.

Conveniently the pressure-sensitive means for varying the opening of the bleed valve means may comprise a hydraulic ram of which the piston is loaded by a pressure drop which is dependent on the rotational speed of the compressor against a resilient load so that the piston occupies a position in its cylinder which is dependent on the rotational speed of the compressor. Thus on increase of the compressor rotational speed the piston will be displaced from one position in the ram cylinder in which the

loads on it were balanced before the change to a second position in which the loads are again balanced after the change. On decrease of the compressor rotational speed the piston will be displaced in the opposite direction between appropriate positions.

One such construction of the means for varying the opening of the bleed valve means, comprises a hydraulic ram having a piston with sides of different effective area which is connected with the bleed valve means so that movement of the piston in the ram cylinder from one end to the other effects progressive variation of the opening of the bleed valve means, a pressure fluid supply connected to each side of the piston from a common source, the supply to the side of the piston of larger effective area being through a flow-restrictor, an outlet valve for controlling the flow of pressure fluid from that side of the piston fed through the flow-restrictor, a pressure-responsive device for operating the outlet valve, spring means applying to the pressure-responsive device in the sense of closure of the outlet valve a load which is dependent on the position of the ram piston in the ram cylinder and which increases with increase in the compressor rotational speed, and a second pressure fluid supply arranged to apply to the pressure-responsive device a load which opposes that due to the spring means and which is a function of the compressor rotational speed.

With this arrangement, on, say, an increase in the compressor rotational speed, the load on the pressure-responsive device due to the second pressure fluid supply increases the opening of the outlet valve causing an increase in flow of fluid from the side of the ram piston having the larger effective area, thus causing a drop in the pressure acting on this side of the piston. The piston therefore moves along the ram cylinder increasing the spring load on the pressure-responsive device and thereby closing the outlet valve and restricting the flow of fluid from the side of the piston having the larger effective area. Movement of the piston continues until the flow of fluid from the side of the piston having the larger area is so restricted by the outlet valve that the loads acting on the piston balance one another. It will be seen that since the fluid pressure load on the pressure-responsive device is a function of the compressor rotational speed, the spring load required to close off the outlet valve to an extent necessary to achieve balance of the loads on the ram piston increases with increase of the compressor rotational speed, so that the greater the increase of compressor rotational speed the greater is the distance the piston has to move along the ram cylinder to restore the balance of loads on it. Thus each position of the piston in the ram cylinder corresponds to a different compressor rotational speed.

In such a construction of the means for varying the opening of the bleed valve means, the pressure-responsive device may be subjected to an additional spring load in the sense of closure of the outlet valve to determine the lower limit of compressor rotational speeds at which the means become operative to effect adjustment of the opening of the bleed valve means.

The invention has an important application in a multi-stage axial-flow compressor for supplying pressure air to the combustion equipment of a gas-turbine engine. Many such engines have the compressor and the turbine interconnected to rotate at the same speed or at speeds proportional to one another and are provided with a fuel system having a variable-delivery pump of the swash-plate type driven from the engine, whereof the pump rotor is arranged to act as a centrifugal pump supplying pressure fluid to a fuel control device acting as a governor to limit the maximum fuel supply and thus as a top speed governor for the engine.

According to a feature of this invention, in such engines the pressure fluid pressurised by the centrifugal action of the rotor of the swash-plate variable-delivery pump may be employed to load the pressure-responsive

device as a function of the compressor rotational speed. With such an arrangement the sides of the ram piston may both be connected to the delivery of the pump, the side of larger area being connected to the fuel delivery of the pump through the flow-restrictor.

Some constructional arrangements of this invention will now be described, by way of example, with reference to the accompanying drawings, of which:

Figure 1 shows a gas-turbine engine which has a compressor embodying the invention,

Figure 2 is a sectional elevation of the fuel pump employed in the engine of Figure 1,

Figure 3 is a diagram showing the control means and bleed valves of the compressor of Figure 1,

Figure 4 is a diagram showing the control means and bleed valves of another embodiment, and

Figure 5 is a diagram showing the bleed valve and its operating means of another embodiment.

The invention is applied in these constructions to a multi-stage axial-flow compressor 10 forming part of a gas-turbine engine comprising also combustion equipment 11 receiving compressed air from the compressor 10 and a turbine 12 receiving combustion products from the combustion equipment and arranged to drive the compressor.

Fuel is supplied to the combustion equipment to be burnt in the compressed air by means of a well-known fuel system comprising an engine-driven swash-plate variable-delivery pump 13 which comprises a rotor 14 having a number of cylinders 15 formed therein containing plungers 16 which, on rotation of the pump rotor, are constrained to reciprocate in the cylinders 15 and thereby to draw in fuel from the suction passage 17 of the pump and to deliver it to the engine through the delivery chamber 18.

The pump rotor 14 is formed with a central bore 19 leading from the suction side of the pump to a series of radial drillings 20 which place the central bore in communication with an annular chamber 21 in the housing of the pump rotor. The pump rotor is thus arranged to act as a centrifugal pump delivering fuel to the chamber 21 and the pressure within the chamber 21 is a function of the engine rotational speed and thus of the compressor rotational speed.

The multi-stage axial-flow compressor is provided with one or more bleed valves 30 at an intermediate compressor stage through which working fluid may escape when the bleed valves are open. It will be appreciated that when the valves are open, the mass flow, and therefore the axial velocity, of the working fluid will be increased in the stages prior to the bleed valves, as compared with when the valves are closed. It will be apparent that although the plural is used for convenience, a single valve may be used.

The stator casing 35 of the axial-flow compressor is formed with a number, say three, circumferentially-extending chambers 31, substantially concentric with the axis of the casing, which are in communication, through ports 33, with the working fluid passage 32 of the compressor at their inner radius. The outer walls 34 of the chambers 31 conveniently are in the form of part of the wall of a cylinder whose axis is the axis of the casing 35, and are each formed with a circumferentially-extending aperture 36. The extent of the chambers and apertures in the peripheral direction is preferably a comparatively small portion of the circumference.

Co-operating with the inner surface of the outer wall of each chamber is a sliding plate valve 37, sliding of which in the axial direction is arranged to vary the area of the respective aperture 36 between the limits of a fully open and a fully closed position. An operating shaft 38 is supported in bearings in the radial walls 39 which bound the chambers at their axially-spaced ends, the shaft 38 being connected to each plate valve 37 and having a portion 40 extending beyond one end of the chambers.

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In order that the compressor may operate efficiently over a wide range of engine speeds, it is desirable that the opening of the bleed valves should be adjusted so that, for each speed, their opening is suitable to give a high efficiency of the compressor. It is thus desirable to arrange that, as the engine speed increases, the bleed valves are progressively closed and for this purpose the following control arrangement for the bleed valves is provided.

The operating shaft 38 of the bleed valves is connected for adjustment, through a suitable linkage 41, to a hydraulic ram 42 and the hydraulic ram comprises a cylinder 43, an operating piston 44 working within the cylinder, and a control mechanism whereby the position of the piston 44 within the cylinder 43 is determined in accordance with the engine rotational speed. Since the position of the piston within the cylinder determines the opening of the bleed valves, the opening will thus be determined in accordance with the engine rotational speed.

The ram cylinder 43 is provided internally with a pair of bushes 45 in which the stem 46 of the piston 44 slides so that the piston stem is guided in the bushes, and the piston head 47 is located intermediate the ends of the stem 46 and between the bushes 45, so that the bushes act as limit stops for the piston. The stem 46 is hollow and in communication with the cylinder on the right hand side of the piston head 47. In this way the effective area of the right hand side of the piston is substantially greater than that of the left hand side.

The cylinder is provided with a pressure fluid supply connection 50, which in this arrangement is connected to the delivery of the engine-driven swash-plate type variable-delivery pump 13, and bores 51, 52 are taken from this connection to each side of the ram piston, the bore 52 to the side of larger effective area comprising a restriction 53 the purpose of which will be clear from the following description.

Mounted on the end of the ram cylinder adjacent the side of the piston having the larger effective area, there is provided the control mechanism for the piston. This control mechanism comprises a chamber divided into two compartments 56, 57 by a flexible diaphragm 58, the compartment 57 which is nearer the ram cylinder being connected by a duct 59 to the suction side of the fuel pump 13 and the other compartment 56 being connected by a duct 60 to the chamber 21 of the fuel pump into which pressure fluid is delivered by the centrifugal action of the pump rotor. The diaphragm 58 is thus loaded in one direction (towards the ram cylinder) by a pressure which is a function of the actual rotational speed of the engine.

The diaphragm 58 is also arranged to be loaded by a main compression spring 62 accommodated within the hollow stem of the ram piston and for this purpose the end wall of the ram cylinder is formed with an axially-directed neck 63 having a bore therein containing a sliding push rod 64, one end of which bears on the diaphragm 58 and the other end of which carries an abutment 65 for the spring. The other abutment for the spring is formed integrally with the piston stem 46. The push rod 64 slides in the bore in the neck 63 and suitable fluid-tight seals are provided to prevent leakage of pressure fluid from the ram cylinder into the chamber 57. It will be clear that as the piston 44 moves to the right, the spring load on the diaphragm will increase and will be dependent upon the position of the piston head 47 within the ram cylinder 43. It will also be clear that the spring load will oppose the fluid pressure load on the diaphragm 58.

The diaphragm 58 is also arranged to be loaded by a secondary spring 66 in the same sense as by the main spring 62. The secondary spring 66 has one abutment on the diaphragm 58 and its second abutment on a shoulder formed within the neck 63 containing the push rod 64.

Movements of the diaphragm 58 under control of the fluid pressure and spring loads are communicated by a second push rod 67 mounted slidably in a bush 68 fitted in the wall of the diaphragm chamber to a half-ball valve

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member 69 which cooperates with a seating to form a half-ball outlet valve controlling the flow of pressure fluid from a passage 70 communicating with the bore 52 which leads to the right-hand end of the ram cylinder. The second push rod 67 is shaped to provide a fluid seal between the diaphragm chamber 56 and a chamber 71 accommodating the outlet valve. This latter chamber 71 is connected with the suction side of the fuel delivery pump. The half-ball carrier and the second push rod are lightly spring-loaded into engagement with the diaphragm.

The operation of the hydraulic ram is as follows.

When the engine is stationary the half-ball valve 69 will be closed and the piston head 47 will be at the left hand end of the ram cylinder 43, where it is held by the main spring 62. If now the engine is started up the pressure on each side of the piston head will increase, but since there is no leak from the right hand end of the cylinder through the outlet valve 69, the pressures will be equal and the piston will remain stationary. At the same time the fluid pressure load acting on the diaphragm 58 to move it to the left will increase due to increase in engine speed.

When the fluid pressure acting on the diaphragm has increased sufficiently to overcome the secondary spring 66 and thereby to permit the half-ball outlet valve 69 to open, pressure fluid is bled off from the right hand end of the ram cylinder and the pressure within the cylinder on this side of the piston will fall due to the presence of the restriction 53 in its feed bore. When the pressure at this end of the cylinder falls, the piston will start to move to the right within the cylinder and will continue to move so long as the engine rotational speed increases, until it reaches the limit of its travel.

It will be seen that the secondary spring 66 acts to afford a lower limit to the range of speeds over which the ram 42 is effective to adjust the opening of the bleed valves 30.

Assume now that the engine speed is steady within the range of speed over which the ram operates to adjust the opening of the bleed valves and the engine speed is to be increased to a new speed in this range. As the speed increases, the pressure load acting on the diaphragm 58 will increase permitting the half-ball valve 69 to open which allows fluid to leak away from the right hand end of the ram cylinder. The pressure on this side of the piston therefore falls (due to the presence of the restriction 53 in its feed bore) and the piston moves within the ram cylinder gradually increasing the spring load afforded by the main spring 62 on the diaphragm until it is equal to the pressure load on the diaphragm. Increase of the main spring load tends to close the half-ball outlet valve 69 and to cut down the leak flow from the ram cylinder and, when the piston head 47 reaches a position in the cylinder appropriate to the new engine speed, the half-ball outlet valve 69 will have been closed off to such an extent that the loads acting on the piston are balanced and the piston will stay in this position. This position is the one in which the spring load on the diaphragm 58 will balance the fluid pressure load derived from the centrifugal pump formed in the fuel pump rotor.

From the foregoing description it will be seen that for each engine actual rotational speed of the engine, and therefore of the compressor, the piston 44 occupies a corresponding position in the ram cylinder 43, so that the opening of the bleed valves 30 controlled by the hydraulic ram can be arranged to be that appropriate to the particular engine speed; moreover, for progressive changes of speed, the opening of the bleed valves will be adjusted progressively.

If it is desired to control the opening of the bleed valves to be a function of corrected engine speed (i. e. actual speed multiplied by a constant and divided by the square root of the engine intake temperature), an arrangement as shown in Figure 4 may be employed in which the diaphragm 58 is not loaded by the pressure

fluid delivered by the centrifugal pump formed in the fuel pump rotor as above described, but is loaded by the pressure drop across a variable-area orifice 100, of which the area is controlled by a capsule 101 contained in a chamber 102 connected through the capillary tube 103 to a bulb 108 in the engine intake. The capsule 101 expands and contracts in response to variations in the engine intake temperature. The orifice 100 is in a conduit 109 fed by an engine-driven feed capacity positive-displacement pump 104 driven at engine speed or at a speed proportional to engine speed, the whole of the pump output passing through the orifice. The inlet of pump 104 is connected to duct 105, which may be the supply duct to the engine fuel pump, and the conduit 109 may discharge back into duct 105 downstream of the orifice 100. A tapping 106 from conduit 109 upstream of the orifice 100 is taken to the compartment 56' of the diaphragm chamber and another tapping 107 from conduit 109 downstream of the orifice 100 is taken to the compartment 57' on the other side of the diaphragm 58'.

The fluid flow through the orifice 100 is proportional to engine speed, and if the orifice area is controlled to be proportional to the square root of the engine inlet temperature, it can be shown that the pressure difference applied across the diaphragm 58' is proportional to the actual speed divided by the square root of the inlet temperature, i. e. to the corrected speed.

The arrangement of the present invention for controlling the adjustment of bleed valves may be used in combination with an arrangement for automatically and progressively varying the pitch of the stator blades in accordance with engine speed. For instance, as shown in Figure 1, the same hydraulic ram 42 may be used to control both the bleed valves and the stator blades, the piston of the ram 42 being connected through a linkage 110 to a crank 111 which adjusts the angular setting of the stator blades at the inlet of the compressor 10.

In another embodiment shown in Figure 5 the bleed valve instead of being a sliding plate valve may be of the form of a piston valve, that is, a piston 120 sliding in a cylinder 121 and cooperating with ports 122 in the cylinder walls, the position of the piston in the cylinder determining the uncovered area of the ports and thus the effective opening of the bleed valve. That part of the cylinder to which the ports open (when the valve is in the position in which the bleed valves are open) will be in communication with the working fluid duct 123 of the compressor, and the cylinder may conveniently be formed as part of the stator casing 124 of the compressor. The part of the cylinder on the other side of the piston is closed, and is connected through a connection 125 to a source of high pressure, for example to the delivery duct 126 of the compressor. The piston may be formed with a skirt 127 extending into this part of the cylinder so that no escape of the compressed air takes place through the ports when the bleed valves are closed. There is a restriction 128 in the connection 125 to the compressor delivery duct, and there is also provided a vent 129 connection which communicates either with the cylinder or with the high-pressure connection downstream of the restriction, and communicates at its other end with atmosphere or any other convenient point at a relatively low pressure. A valve 130 is provided in the vent connection to afford a variable restriction, and this valve is connected to a hydraulic ram such as the ram 42 that is described above, by means of a suitable linkage such as 41. The bleed valve piston may be lightly spring-loaded by a spring 131 in the sense of opening the valve.

In operation, when the valve 130 in the vent connection 129 is closed, the bleed valve 120 is maintained in the closed position since the pressure on the side of the piston tending to close the valve, e. g. compressor delivery pressure, exceeds the pressure on the other side of the piston, which will be the pressure at an intermediate stage in the compressor. However, as the valve 130 in the vent

connection is opened by the action of the hydraulic ram 42, so the pressure tending to close the valve 120 will be progressively reduced, and the effective area of the ports 122 of the bleed valve will be progressively increased. It is arranged that the effective area of the ports of the bleed valve is increased as the speed of the compressor decreases, and vice versa, over the desired range of speeds.

I claim:

1. A multi-stage axial-flow compressor comprising an inlet, an outlet, a stationary casing, a working fluid passage extending through said stationary casing between said inlet and said outlet, bleed valve means including means defining an aperture in said stationary casing communicating with said passage at a stage of said compressor intermediate said inlet and said outlet and including a moveable valve member to co-operate with said aperture, a cylinder, a piston in said cylinder, a connection between said piston and said moveable valve member, and control means to control the position of said piston in said cylinder comprising pressure-sensitive means, means including a pump driven at a speed proportional to the speed of said compressor to produce a fluid pressure load on said pressure-sensitive means which is a predetermined function of the rotational speed of the compressor, and resilient means in abutment with said pressure-sensitive means and with said piston to produce a resilient load in opposition to said fluid pressure load, said resilient load being a function of the position of the piston in the cylinder, and thus of the opening of the bleed valve means, and means operable on movement of said pressure-sensitive means in said one sense to adjust a pressure acting on said piston in the sense to cause closing of said bleed valve means and operable on movement of said pressure-sensitive means in said opposite sense to adjust said pressure in the sense to cause opening of said bleed valve means, so that, for each speed, the bleed valve means has a corresponding opening.

2. A multi-stage axial-flow compressor as claimed in claim 1, wherein said pressure-sensitive means comprises a flexible diaphragm.

3. A multi-stage axial-flow compressor comprising an inlet, an outlet, a working fluid passage extending between said inlet and said outlet, bleed valve means communicating with said passage at a stage of said compressor intermediate said inlet and said outlet, a hydraulic ram having a cylinder, a piston in said cylinder having sides of different effective area and connected with the bleed valve means, so that movement of the piston in the ram cylinder from one end to the other causes progressive variation of the opening of the bleed valve means, a pressure fluid supply, a direct connection from said supply to the smaller-effective-area side of the piston, a restricted connection from said supply to the larger-effective-area side of the piston, an outlet valve in communication with said larger-effective-area side of the piston, a pressure-responsive device connected to said outlet valve to operate it, spring means in abutment with said pressure-responsive device, a part connected to move with said piston and also abutting said spring means, whereby there is applied to said pressure-responsive device in the sense of closure of the outlet valve a resilient load which is dependent on the position of the ram piston in the ram cylinder and which increases as the bleed valve means move toward the closed position, and means including a pump driven at a speed proportional to the speed of said compressor to apply to the pressure-responsive device a fluid pressure load which opposes that due to the spring load and which is a function of the compressor rotational speed and increases as the speed increases, so that, for each speed, the bleed valve means has a corresponding opening.

4. A multi-stage axial-flow compressor as claimed in claim 3, comprising also additional spring means in abutment with said pressure-responsive device, and an abut-

ment for said additional spring means in fixed relation to said cylinder, said additional spring means loading said pressure-responsive device in the sense of closure of the outlet valve, whereby the fluid pressure load which is a function of the compressor rotational speed must overcome the load of said additional spring means before the outlet valve can open, and thus whereby the lower limit of compressor rotational speeds is determined at which the means become operative to effect adjustment of the opening of the bleed valve means.

5. A multi-stage axial-flow compressor as claimed in claim 3 wherein said means to apply to the pressure-responsive device a fluid pressure load which is a function of the compressor rotational speed comprises a pump rotor, means defining a central bore in said rotor, means defining radial drillings in said rotor in communication with said bore, whereby the rotor acts as a centrifugal pump, drive means interconnecting said rotor and said compressor, and means to place said pressure-responsive device in communication with said drillings.

6. A multi-stage axial-flow compressor as claimed in claim 3 wherein said means to apply to the pressure-responsive device a fluid pressure load which is a function of the compressor rotational speed comprises a fixed-capacity positive-displacement pump, drive means interconnecting said pump and said compressor whereby the delivery of said pump is a function of the compressor speed, a discharge conduit from said pump, a variable-area orifice in said discharge conduit, and temperature-sensitive means connected to control the area of said orifice and adapted to be sensitive to the intake temperature of the compressor, and means including a pair of tapings connected to said discharge conduit at points respectively upstream and downstream of said orifice to apply the pressure drop across said orifice to said pressure-responsive device.

7. A multi-stage axial-flow compressor comprising a stator casing, a port in said stator casing between the first and last stages of said compressor, valve means cooperating with said port, a hydraulic ram comprising a piston member and a cylinder member, the piston member dividing the cylinder member into a first space and a second space, and one of said members being connected to the stator casing, a linkage by which the other of said members is connected to said valve means, and means to vary

the relative positions of said piston member and said cylinder member as a function of the rotational speed of the compressor comprising a source of fluid pressure, a first conduit and a second conduit connecting said source to said first and said second cylinder spaces respectively, a restriction in said second conduit, a fixed-capacity positive-displacement pump, drive means interconnecting said pump and said compressor, whereby said pump is driven at a speed proportional to the compressor speed, a source of fluid connected to the inlet of said pump, a third conduit connected to the outlet of said pump, an orifice in said third conduit through which passes the whole delivery of the pump, a chamber, a pressure-sensitive device dividing said chamber into a first part and a second part, a fourth conduit connecting said third conduit upstream of the orifice with said first part and a fifth conduit connecting said third conduit downstream of the orifice with said second part, whereby said pressure-sensitive device is loaded by a pressure difference proportional to the speed of the compressor towards said second part, resilient means between said pressure-sensitive device and said piston member to load it by an amount dependent on the relative positions of the piston member and the cylinder member away from said second part, an outlet from said second cylinder space, and a valve controlling said outlet and connected to said pressure-sensitive device.

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