Aug. 11, 1953 G. L. WILDE ET AL 2,648,195

CENTRIFUGAL COMPRESSOR FOR SUPERCHARGING INTERNAL-COMBUSTION ENGINES

Filed Feb. 6, 1947 3 Sheets-Sheet 1

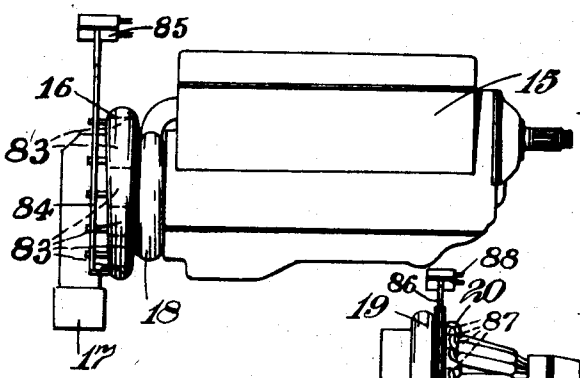


Fig.1.

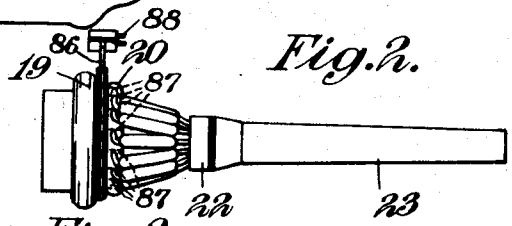


Fig.2.

Fig.3.

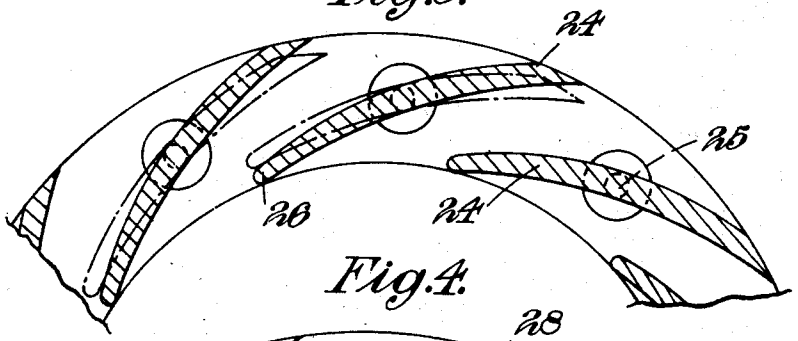


Fig.4.

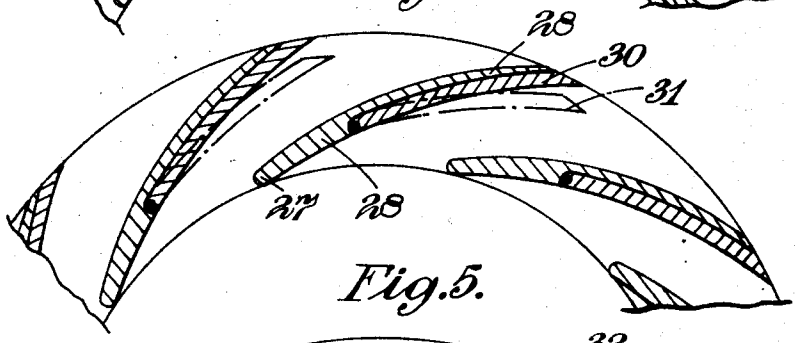
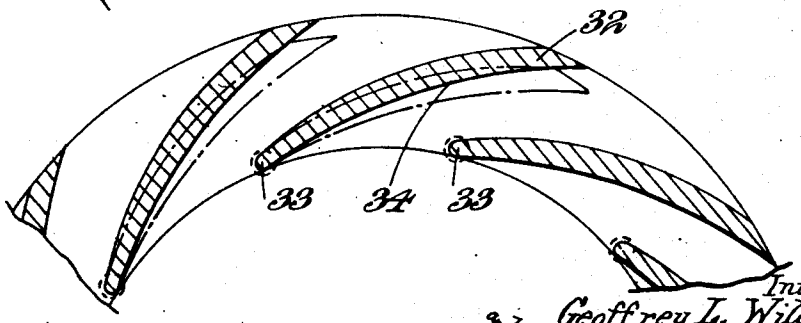


Fig.5.



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Fig.6.

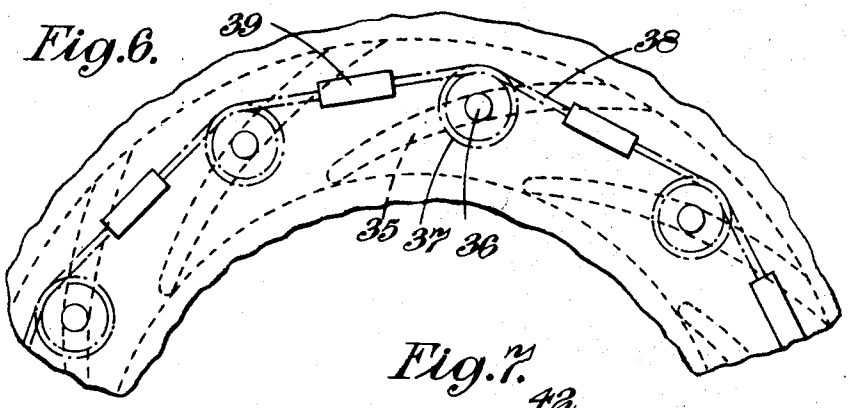


Fig.7.

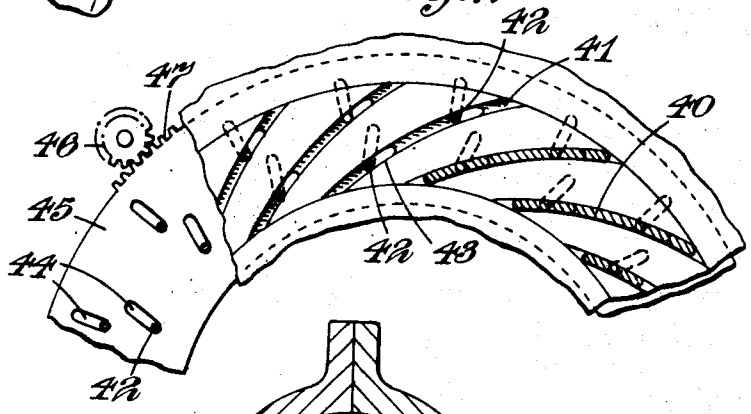


Fig.8.

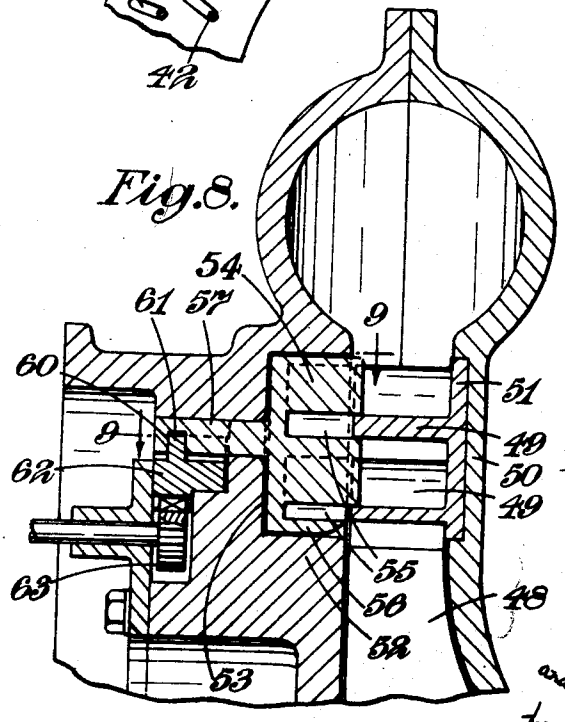
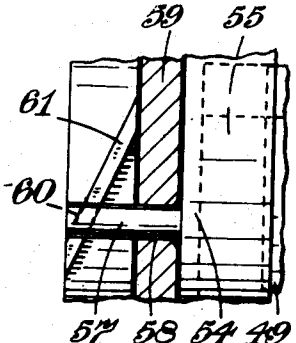


Fig.9.



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Fig.10.

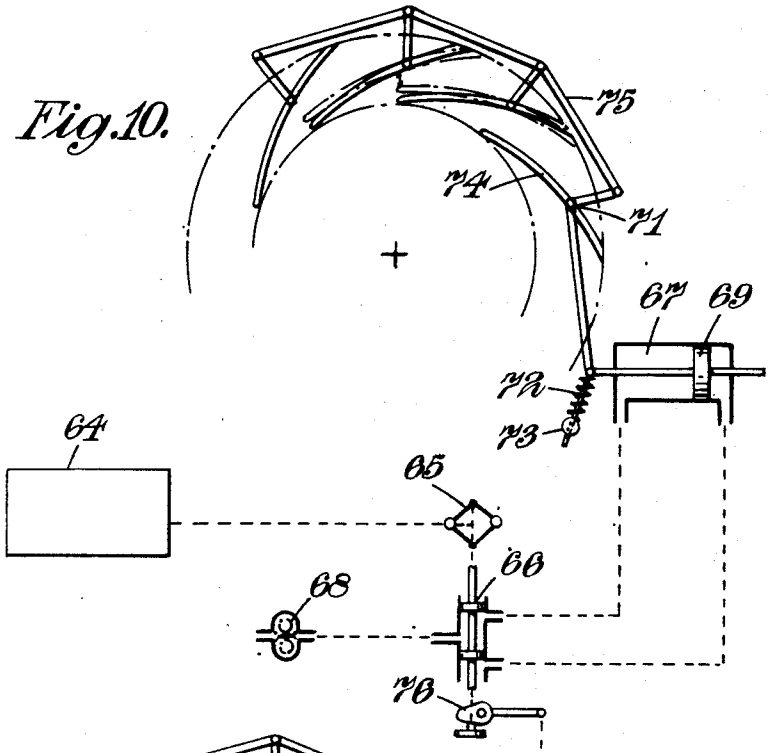
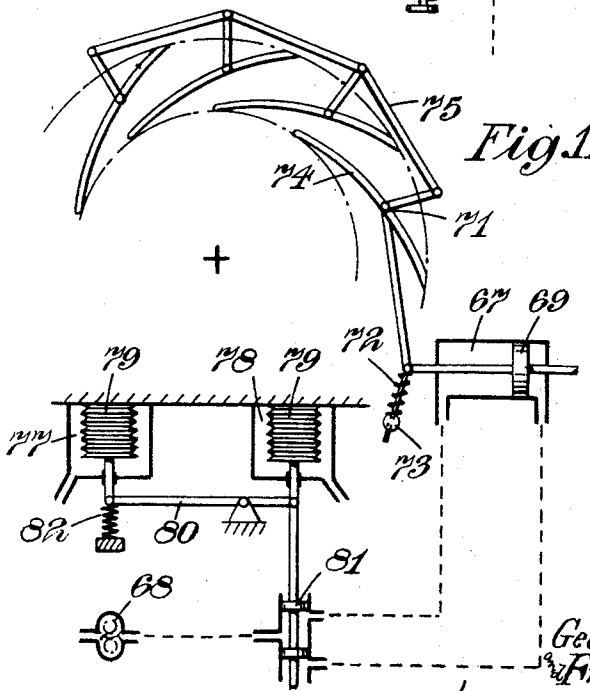


Fig.11.



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UNITED STATES PATENT OFFICE

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CENTRIFUGAL COMPRESSOR FOR SUPERCHARGING INTERNAL-COMBUSTION ENGINES

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9 Claims. (Cl. 60—39.29)

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This invention relates to centrifugal compressors used for supercharging internal-combustion engines such as aero engines which are required to operate over a wide range of altitude and speed. In designing a centrifugal compressor for such an engine it is desirable that its characteristics should be matched with those of the engine to give the optimum benefit. In the case of a piston-engine the maximum benefit of increased power-output of the engine is obtainable at high altitudes, say 20,000 feet or higher, by providing a compressor of very high capacity, but an increase of capacity to a suitable extent leads to the occurrence of surging at low engine-speeds owing to the inherently different charge-flow speed characteristics of a centrifugal supercharger and a piston-engine. In the case however of a gas-turbine, the conditions are reversed in that the compressor tends to surge at high speeds and high altitudes. In either case therefore a variable capacity compressor would be desirable.

It is advantageous for various reasons to use a two-stage compressor, and one of the characteristics of a two-stage compressor is that the first stage controls the surge-flow at low speeds, and also the maximum flow at high speeds, whereas the second stage controls the surge-flow at high speeds and the maximum flow at low speeds. This is due to the varying density-ratio and the changing stage-matching characteristics with increase or decrease of supercharger speed. This invention accordingly comprises a two-stage centrifugal compressor for a supercharged internal-combustion engine wherein automatic means are provided for varying the capacity of one stage whilst that of the other stage is fixed. For a piston-engine, the variation is provided on the first stage of the compressor, whereas for a gas-turbine, it is provided on the second stage.

Preferably the variation in capacity of either stage of the compressor is effected by changing the effective throat-area of the diffuser-vanes.

According to another feature of the invention, the effective throat-area may be changed as aforesaid by pivoting the vanes each about a point in its chord, the pivotal axis of each vane being preferably as near to the centre of pressure as is practicable to reduce the aerodynamic torque on the pivots and hence reduce the loads in the operating linkage. Pivoting at the leading edge of each vane might be desirable for the purpose of maintaining a constant clearance of the vanes from the rotor tip.

The invention also comprises other methods of

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changing the effective throat-area as hereinafter described.

According to another feature of this invention, the adjustment of the capacity of the variable stage of the compressor is made automatic, being controlled for example either by a governor in accordance with the speed of the compressor, or by the change in compression-ratio with varying speeds.

In the accompanying drawings, which are purely diagrammatic,

Figure 1 is a side elevation of a piston engine with a two-stage centrifugal compressor for supplying the cylinders;

Figure 2 illustrates a gas-turbine jet-propulsion unit, fitted with a two-stage centrifugal compressor;

Figures 3, 4 and 5 are part sectional views showing various modes of adjustment of the diffuser guide-vanes of a centrifugal compressor;

Figure 6 shows diagrammatically a method of operating the adjustable guide-vanes, and of providing differential preliminary adjustment;

Figure 7 is a part sectional view illustrating yet another mode of adjusting the guide vanes;

Figure 8 is a part sectional view illustrating yet another construction in which the effective throat-area is varied by changing its axial width;

Figure 9 is a sectional view on the line 9—9 of Figure 8;

Figure 10 is a purely diagrammatic representation of automatic means for controlling adjustable guide-vanes in accordance with the speed of the engine, and

Figure 11 is a similar diagrammatic representation of automatic means for controlling adjustable guide-vanes in accordance with the compression-ratio at which the compressor is operating.

This invention may be applied to a centrifugal compressor for use with a piston engine as diagrammatically illustrated in Figure 1; the engine is indicated by the reference 15 and the compressor, driven by the engine, is of the centrifugal type having two stages whereof the first stage 16 takes in air through the intake 17 and delivers it to the second stage compressor 18 which in turn delivers the compressed air to the induction system of the engine. The compressor may be driven through a change-speed gear by the engine, such gearing providing for say three different speeds, and the selection of these speeds may be effected manually by the pilot of the aircraft in which the engine is fitted or the selection may be made automatically in accordance

with the altitude and other conditions in which the engine is operating.

As mentioned above, in the case of a piston engine, the capacity of the first stage of the compressor is made variable for instance by adjusting the effective throat area between the pivoted diffuser vanes 83 in accordance with the setting of the servo-motor 85 which is connected to pivot the diffuser vanes by means of the chain 84, as is more fully described hereinafter. In the case of an internal combustion turbine however such as is diagrammatically illustrated in Figure 2, the first stage 19 of the compressor feeds the second stage 20, and it is the capacity of this second stage which is made variable by means of the adjustable diffuser vanes 87 adjusted by the servo-motor 88 through the chain 86. The compressed air is delivered from the second stage of the compressor to the combustion system 21, turbine 22 and in the case of the jet propulsion unit, the gases are discharged from the turbine through the jet-tube 23.

The variation in the capacity of a compressor, whether it be the first stage as in Figure 1 or the second stage as in Figure 2 may be effected as shown in Figure 3. The diffuser guide vanes 24 in this construction are each pivoted on an axis 25 at about the middle of its length, so that when the vanes are rocked from the position shown in full lines to the position shown in chain lines, the leading edge 26 of each vane approaches or recedes from the next adjacent blade and by thus changing the space between them it varies the effective throat-area.

An alternative construction of adjustable vane is illustrated in Figure 4. In this case each vane is made in two parts whereof one constitutes the leading edge 27, the forward part 28 of the vane, and a portion 29 of the thickness of the trailing part of the vane. There is thereby provided in the trailing part, a recess in which there is pivotally mounted at its forward end the second part 30 of the vane. This part 30 is so shaped that when lying snugly in the recess it provides a diffuser vane of normal section, but when it is swung out towards the next adjacent vane, to the position 31, it reduces the effective throat-area.

In yet another construction of adjustable guide-vanes as illustrated in Figure 5, each vane 32 is pivoted at its leading edge 33 so that it can be swung inwards to diminish the distance between its concave face 34 and the leading edge 33 of the next adjacent vane.

In the three constructions of adjustable vane above described the adjustment is effected by a pivotal movement of each vane or a part thereof, and this pivotal movement may be effected as diagrammatically illustrated in Figure 6.

Each vane 35 is provided with or mounted on a pivot pin 36 which extends through the side wall of the diffuser chamber and carries a sprocket-wheel 37. A chain 38 extends around the complete set of sprockets so as to couple them together for simultaneous movement. In order to facilitate the assemblage and the correct and similar setting of all the vanes, a tensioning device 39 is provided between each two adjacent sprockets; the master-control may be applied to the chain 38 in any convenient manner, as for example through one of the sprockets which is engaged by it.

Figure 7 illustrates an alternative construction of the adjustable diffuser vanes, in which the vanes 40 are of circular arc formation. Each

vane 40 is mounted to slide in grooves 41 in the side walls of the diffuser chamber so that the leading edge can be advanced to or withdrawn from the periphery of the rotor chamber. For the purpose of effecting this movement each blade is provided with one or more pins 42 extending through openings 43 in its groove 41, and through the side wall of the diffuser chamber to engage a slot 44 in a ring 45 which is capable of rotary movement with respect to the diffuser chamber; this movement may be effected by a spur gear 46 engaging the rack 47 formed on the ring 45. The slots 44 are arranged approximately radially in the ring 45, and this construction provides that rotational movement of the ring 45 causes the pins 42 to be traversed along the openings 43 thereby adjusting the vanes in their grooves 41.

Figures 8 and 9 illustrate yet another method of varying the effective throat-area of the diffuser-vanes, and in this case the change is made by a variation in the axial width of the throat. Figure 8 is a radial section of a part of the compressor showing a rotor blade at 48 and diffuser-vanes at 49. One side wall 50 of the diffuser chamber receives a ring-like member 51 which carries the diffuser vanes either integrally or secured thereon, but the other side wall 52 of the diffuser chamber is formed with a recess 53 in which there is located a ring 54 that is slotted at 55 to receive the edges of the vanes 49, and is movable axially of the compressor shaft from the position indicated, in which it lies almost entirely within the recess 53 outwards therefrom towards the other wall 50 of the diffuser chamber. The radially inner corner of the ring 54 is rounded at 56 to provide a suitable inflow from the rotor to the diffuser-vanes in any setting of the ring 54.

The axial movement of the ring 54 is effected by providing on it a series of spaced projections 57 which extend through openings 58 in the base 59 of the recess 52, and are formed near their outer end with a recess 60 which is engaged by a helically disposed rib or cam 61 carried on a cam-ring 62. The cam-ring is rotatable by means of a spur gear 63 or in any other convenient manner through a small angular range to traverse the helical rib 61 through the slot 60 in the projection 57 and thereby adjust the ring 54 in an axial direction.

In the control of the adjustable guide vanes, it is usually sufficient to arrange that they are set to one end or other of a definite range of movement, that is to say to a maximum or minimum throat-area, but it will be appreciated that it is also possible to provide for intermediate adjustments. Another feature of this invention relates to the provision of an automatic control and one form of such mechanism is diagrammatically illustrated in Figure 10. In this figure the engine indicated in 64 drives a centrifugal governor device which operates the valve 66 of a hydraulic servo-motor 67. The servo-motor is supplied by a pump 68 driven by the engine and its piston 69 is connected in this particular construction to a toggle linkage comprising a link 70 pivoted at 71, and a spring link 72 pivoted at 73. The use of the spring link 72 ensures that the toggle is moved to the limit of its range of movement whenever the piston 69 moves it past the dead-centre. As illustrated the link 70 is secured on the pivot pin 71 of a diffuser guide vane 74 so as to rock it, as for example in the manner described with reference to Figure 3;

it will be appreciated, however, that it may be applied to any of the constructions calling for a pivotal movement of the guide vanes, or by any convenient mechanical connection from the piston **69**, it may be applied to operate the gear-wheel **46** of Figure 7 or **63** of Figure 8. As shown in Figure 10, the angular movement of the link **70** rocks the diffuser guide-vane to which it is connected, and a similar movement is transmitted to all the other vanes by a simple linkage **75**.

When the compressor is driven through a change-speed gear, it is desirable to avoid making any adjustments of the diffuser vanes on the low-speed and medium-speed ratios since these would normally be used only in conditions in which the maximum capacity of the compressor is not required. For this purpose there may be provided an overriding cam **76**, as shown in Figure 10 which is operative on the valve **66**; the cam **76** is interconnected with the change-gear mechanism so that it holds the valve **66** inoperative when either the low-speed or medium-speed gears is in operation.

An alternative construction of automatic control mechanism is illustrated in Figure 11 in which the adjustment of the diffuser-vanes is controlled by the compression-ratio across the compressor. For this purpose there are provided two chambers one of which, **77**, is subject to the intake-pressure of the compressor and the other, **78**, to the boost-pressure as delivered by the compressor. Any suitable device, such as an evacuated capsule **79**, or a piston, is provided in each chamber so as to be responsive to the pressure therein, and these two devices are connected to opposite ends of a lever **80** which is also connected to the control-valve of a servo-motor. The two arms of the lever are unequal in length, the ratio of their lengths being made equal to the compression ratio at which it is desired that the hydraulic control-valve should be operated. The shorter arm of the lever is connected to the device which is subjected to the delivery pressure of the compressor. If for example it is desired to operate the control when a compression-ratio of 6 : 1 is attained by the compressor, then two arms of the lever are made also in the ratio of 6 : 1. So long as the compression ratio of the blower is less than 6 : 1, the intake-pressure capsule **79** rocks the lever in the direction of movement of its capsule owing to its greater leverage. When the compression-ratio reaches 6 : 1, the two capsules are balanced in their effect on the lever, by virtue of their respective leverages, and when the compression-ratio exceeds 6 : 1, the lever is rocked in the opposite direction. The lever is connected to the control valve **81** of a hydraulic servo-motor as in Figure 10 and the remainder of the mechanism is similar to that already described. A light spring **82** may be provided to operate on the lever to bias it slightly in the direction in which it is moved by the low-pressure capsule in the chamber **77**.

We claim:

1. The combination with an engine of a two-stage centrifugal compressor having a compressor shaft, two rotors connected with said shaft to be driven thereby at a constant ratio of speeds, and diffuser vanes for each stage whereof the diffuser vanes of one stage only are adjustable to vary the effective throat area of said vanes of said one stage and the diffuser vanes of the other stage are fixed, and speed-sensitive automatic means to adjust said adjustable diffuser vanes.

2. The combination with an internal combustion engine of the piston type, of a two stage centrifugal compressor having a compressor shaft, two rotors connected with said shaft to be driven thereby at a constant ratio of speeds and diffuser vanes for each stage whereof the diffuser-vanes of one stage only are adjustable to vary the effective throat area of said vanes of said one stage and the diffuser-vanes of the other stage are fixed, and speed-sensitive automatic means to adjust said adjustable diffuser-vanes.

3. The combination with an internal combustion turbine of a two-stage centrifugal compressor having a compressor shaft, two rotors connected with said shaft to be driven thereby at a constant ratio of speeds and diffuser-vanes for each stage whereof the diffuser-vanes of the second stage only are adjustable to vary the effective throat area of said vanes of said second stage, and the diffuser-vanes of the first stage are fixed, and speed-sensitive automatic means to adjust said adjustable diffuser-vanes.

4. A two-stage centrifugal compressor of the kind comprising a first-stage compressor rotor, a first-stage diffuser including a first ring of diffuser vanes, a second stage compressor rotor and a second-stage diffuser including a second ring of diffuser vanes, through which rotors and diffusers the working fluid passes consecutively, a compressor shaft to which both said rotors are connected to be driven at a constant ratio of speeds, speed-sensitive means responsive to the speed of said shaft, and a piston-and-cylinder mechanism connected to said speed-sensitive means to be moved thereby in accordance with the speed sensed by said speed-sensitive means; in which compressor part at least of each diffuser vane of one only of said rings is pivoted about an axis transverse to the flow of working fluid through this ring and the diffuser-vanes of the other of said rings are fixed, said compressor further comprising connecting means between said piston-and-cylinder mechanism and each of said parts, whereby the throat areas between adjacent vanes are adjusted in accordance with the speed of the compressor shaft.

5. A two-stage centrifugal compressor of the kind comprising a first-stage compressor rotor, a first-stage diffuser including a first ring of diffuser vanes, a second stage compressor rotor, and a second-stage diffuser including a second ring of diffuser vanes, through which rotors and diffusers the working fluid passes consecutively, a compressor shaft to which both said rotors are connected to be driven at a constant ratio of speeds, speed-sensitive means responsive to the speed of said shaft, and a piston-and-cylinder mechanism connected to said speed-sensitive means to be moved thereby in accordance with the speed sensed by said speed-sensitive means, in which compressor the whole of each diffuser vane of one only of said rings is pivoted about an axis transverse to the flow of working fluid through this ring and the diffuser-vanes of the other of said rings are fixed, said compressor further comprising, connecting means between said piston-and-cylinder mechanism and said diffuser vanes whereby the throat areas between adjacent vanes are adjusted in accordance with the speed of the compressor shaft.

6. In or for a reciprocating engine having a

plurality of cylinders and a crank-shaft, a two-stage centrifugal compressor comprising a first-stage compressor rotor, a first-stage diffuser including a first ring of diffuser vanes each of which has a part at least pivoted about an axis transverse to the flow of working fluid through said first-stage diffuser, a second-stage compressor rotor and a second-stage diffuser including a second ring of fixed diffuser vanes of which the effective throat area is fixed, through which rotors and diffusers the working fluid passes consecutively from atmosphere to the cylinders of said reciprocating engine, a compressor shaft to which both said rotors are connected to be driven at a constant ratio of speeds and which compressor shaft is also connected to said crank shaft to be driven thereby, a speed-sensitive means responsive to the speed of said compressor shaft, a piston-and-cylinder mechanism connected to said speed-sensitive means to be moved thereby in accordance with the speed sensed by said speed-sensitive means, and connecting means between said piston-and-cylinder mechanism and said parts of said vanes in said first-stage diffuser, whereby the throat areas between adjacent vanes in said first-stage diffuser are adjusted in accordance with the speed of the compressor shaft.

7. In or for a reciprocating engine having a plurality of cylinders and a crankshaft, a two-stage centrifugal compressor comprising a first-stage compressor rotor, a first-stage diffuser including a first ring of diffuser vanes, each of which is pivoted about an axis transverse to the flow of working fluid through said first-stage diffuser, a second-stage compressor rotor and a second-stage diffuser including a second ring of fixed diffuser vanes of which the effective throat area is fixed, through which rotors and diffusers the working fluid passes consecutively from atmosphere to the cylinders of said reciprocating engine, a compressor shaft to which both said rotors are connected to be driven at a constant ratio of speeds and which compressor shaft is also connected to said crankshaft to be driven thereby, speed-sensitive means responsive to the speed of said compressor shaft, a piston-and-cylinder mechanism connected to said speed-sensitive means to be moved thereby in accordance with the speed sensed by said speed-sensitive means, and connecting means between said piston-and-cylinder mechanism and said diffuser-vanes of said first-stage diffuser whereby the throat areas between adjacent vanes of said first-stage diffuser are adjusted in accordance with the speed of the compressor shaft.

8. In or for a gas turbine engine comprising combustion equipment and a turbine, a two-stage centrifugal compressor comprising a first-stage compressor rotor, a first-stage diffuser including a first ring of fixed diffuser vanes of which the effective throat area is fixed, a second-stage compressor rotor and a second-stage diffuser including a second ring of diffuser vanes, each of which has a part at least pivoted about an axis transverse to the flow of working fluid through said second-stage diffuser, through which rotors and diffusers the working fluids passes consecutively, the working fluid being delivered at outlet from the compressor to the combustion equipment where fuel is burnt with it, the products of combustion passing to the turbine to drive it, a compressor shaft to which both said rotors are connected to be driven at a constant ratio of speeds, which compressor shaft is also connected to the turbine to be driven thereby, speed sensitive means responsive to the speed of said compressor shaft, a piston-and-cylinder mechanism connected to said speed-sensitive means to be moved thereby in accordance with the speed sensed by said speed-sensitive means, and connecting means between said piston-and-cylinder mechanism and said parts of said vanes in said second-stage diffuser whereby the throat areas between adjacent vanes in said second-stage diffuser are adjusted in accordance with the speed of the compressor shaft.

9. In or for a gas turbine engine comprising combustion equipment and a turbine, a two-stage centrifugal compressor comprising a first-stage compressor rotor, a first-stage diffuser including a first ring of fixed diffuser vanes of which the effective throat area is fixed, a second-stage compressor rotor and a second-stage diffuser including a second ring of diffuser vanes, each of which is pivoted about an axis transverse to the flow of working fluid through said second-stage diffuser through which rotors and diffusers the working fluid passes consecutively, the working fluid being delivered at outlet from the compressor to the combustion equipment where fuel is burnt with it, the products of combustion passing to the turbine to drive, a compressor shaft to which both said rotors are connected to be driven at a constant ratio of speeds, which compressor shaft is also connected to the turbine to be driven thereby, speed-sensitive means responsive to the speed of said compressor shaft, a piston-and-cylinder mechanism connected to said speed-sensitive means to be moved thereby in accordance with the speed sensed by said speed-sensitive means, and connecting means between said piston-and-cylinder mechanism and said diffuser vanes in said second-stage diffuser whereby the throat areas between adjacent vanes in said second-stage diffuser are adjusted in accordance with the speed of the compressor shaft.

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