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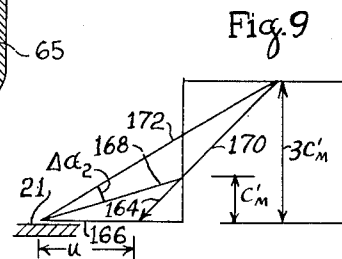
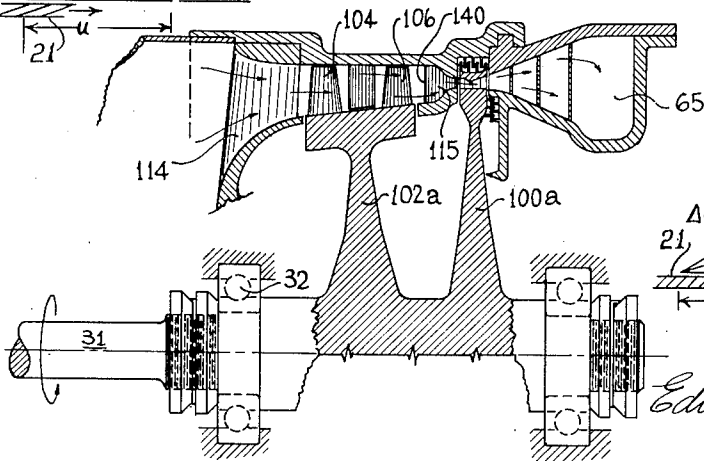
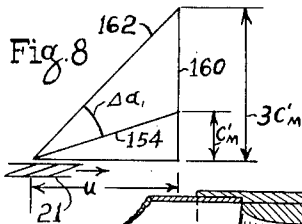
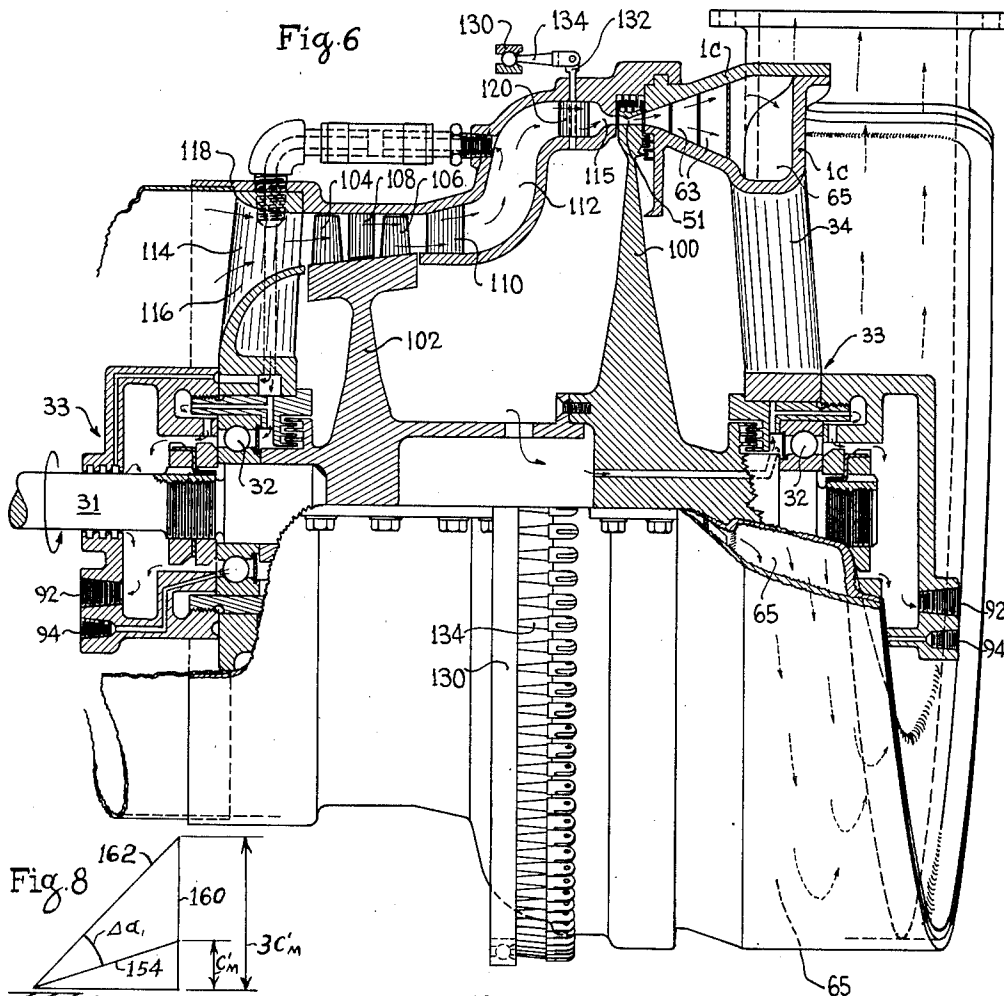
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2,648,493

COMPRESSOR

Filed Oct. 23, 1945

2 Sheets-Sheet 2



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2,648,493

COMPRESSOR

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Application October 23, 1945, Serial No. 624,013

15 Claims. (Cl. 230-119)

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This invention relates to compressors, in particular to a new type compressor uniquely utilizing a principle herein called supersonic ram diffusion which will be discussed in the following description and explanation of the accompanying drawings.

It is an object of this invention to provide a compact and efficient compressor of light weight, small dimensions and low cost.

Another object is to provide an efficient means of reducing windage losses.

Another object is to provide an efficient supersonic compressor.

Other objects will appear from the following description, the accompanying drawings, and the appended claims.

I accomplish the above objects by the means illustrated in the accompanying drawings in which—

Figure 1 is a sectional view of the compressor taken normal to a vertical plane through the rotor axis.

Figure 1a is a cross section of a typical streamlined hub support vane at the entrance to the compressor taken along line 1a-1a of Figure 1.

Fig. 1b is a partial sectional view on the same plane as Fig. 1 showing an alternative slot arrangement.

Figure 2 is an enlarged fragmentary developed view of the compressor vanes looking inboard normal to a plane represented by line 2-2 of Figure 1.

Figure 3 is a section of the supersonic ram diffusers taken along line 3-3 of Figure 2.

Figure 3a is a section of an alternate form of the supersonic ram diffuser taken along line 3-3 in Figure 2.

Figure 4 is a radial section of the stator diffusers which follow the supersonic ram diffusers and is taken along line 4-4 of Figure 2.

Figure 5 is a quarter segment front view of the centrifugal impeller with its shroud removed.

Figure 6 is a fragmentary side view partly in section of another form of the invention.

Figure 7 is a fragmentary axial section of still another form of the invention.

Figures 8 and 9 are vector diagrams showing respectively the conditions which exist when the flow of fluid is directed axially toward the rotor, and when it is directed at an angle thereto by means of the nozzle structure ahead of the rotor.

Cross reference is made to Prime Movers in Serial Number 593,631, filed May 14, 1945.

This application differs from the application Serial No. 593,631 in that it deals with rotor passages having throats and with supersonic relative fluid velocities of the passage inlets. It is also concerned with counterrotating impellers and specific types of impellers which discharge fluid into the supersonic rotor.

Although this compressor could be designed to pump any compressible fluid, for simplicity of

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explanation, it is assumed in the following discussion that the compressor is handling air.

The compressing of the air is accomplished by a centrifugal impeller which discharges air substantially axially with respect to the impeller and into a counterrotating rotor having passages near its perimeter. The relative air velocity at the inlet of said passages is supersonic and the passages first converge to reduce the velocity to sonic and then diverge, thereby converting a large portion of the dynamic pressure to static pressure. The air leaving these supersonic ram diffuser passages discharges into stationary diverging passages where a large portion of the remaining velocity pressure is converted to static pressure. This high pressure air is then discharged into a suitable collector for final delivery to the reservoir or machine for which the compressor is employed.

The compressor unit as shown in Figure 1 is housed in an outer case made up of three coaxial sections 1a, 1b and 1c, housing the internal rotating and static elements.

The hub element 3, attached to housing 1a (see Figures 1 and 1a) by means of the radial streamlined vanes 5, rigidly supports the stationary shaft 7 by means of key 9 and nut 11, which shaft in turn mounts ball-bearings 13 and 15 of centrifugal impeller 17; ball-bearing 19 of the supersonic ram diffuser rotor 21; and planet gears 23 by means of mounting bolts 25, hardened steel sleeve spacers 27, and oil slinger reservoir 29, the purpose of which will be discussed in the subsequent description of the oil system.

The compressor power input shaft 31, which is supported by means of bearing 32, housing assembly 33 and support spokes 34, from case 1c, is brazed integral to rotor 21 to which is attached internal gear 35 of the impeller planetary gear system by means of screws 37. The action of internal gear 35 on planet gears 23 causes the sun gear 39, which is attached to the centrifugal impeller 17 by means of screws 41, to rotate impeller 17 in a counter direction to rotor 21.

Figure 5 shows a quarter segment front view of impeller 17 which is comprised of a plurality of radial walls or vanes 43 disposed uniformly about the axis of rotation. Air enters the centrifugal impeller rotor 17 making an angle of approximately 30° relative to the entrance plane at the outside and approximately 40° relative to the entrance plane at the inside. In order to reduce entrance losses to a minimum, the longer centrifugal impeller vanes 43a should accommodate the above angles relative to the entrance plane and spiral rearward, as shown in Figure 5, toward radial axial planes at the exit such that when the air makes the accelerating turn 45 at the exit as shown in Figure 1, it will leave substantially axially with respect to the centrifugal impeller 17, as shown in Figure 2. These vanes 43 could be routed from a solid rotor

blank by means of a router pivoted at radius R, Figure 1, said router actuating a cam-follower mechanism which automatically rotates the impeller blank to the correct azimuth of cut as the router progresses through its router arc R.

It will be noted in Figure 5 that three different vane lengths are indicated in the grouped relationship 43a, 43b and 43c, such that any particular blade is identical to the 3rd, 6th, 9th, etc. blades from itself. Blades 43a are full length, blades 43b are medium length, and blades 43c are short. For ease in fabrication, the shorter blades 43b and 43c are identical to like geometrical portions of full length blades 43a. The medium length blade 43b should be the next blade adjacent to the inside radius of the helical turn formed by the full length blades 43a, and the short blade 43c should be the next blade adjacent to the outside radius of this turn. Such a disposition of blades can be made to give the air a very even axial velocity distribution about the exit circumference of impeller 17, and insures better compressor efficiency.

It will be noted in Figure 1 that a thin bell-shaped shroud 47, which rotates with impeller 17, encloses impeller vanes 43 so as to form air-flow passages 49. These passages are radially designed so as to gently diffuse the high velocity entering air to a low relative duct velocity before making the turn 45. The acceleration of the air in turn 45 insures a constant axial velocity along a radial line at the impeller exit, which is another factor giving improved compressor efficiency.

For an efficient compressor pumping air against a head of 80 pounds per square inch gauge, the velocity of efflux of the jet from the impeller exit would be of the order of 800 feet per second, and when combined vectorially with the peripheral velocity of 1200 feet per second at the impeller exit, it would give an absolute leaving velocity of some 1450 feet per second. Under these conditions there would be a static pressure ratio of 1.4 at the exit from impeller 17.

With the periphery of rotor 21 turning at a velocity of 900 feet per second in the opposite direction to impeller 17, the relative entering velocity of the air to the passages 51 formed by the supersonic ram diffuser vanes 53 on this periphery, is some 2250 feet per second found as the vector sum of 900 and 1450 feet per second. Figure 3 is a radial section of the supersonic ram diffusers taken along line 3-3 of Figure 2. Because the air velocity relative to the inlet at A is well above the velocity of sound, the rotor passages are convergent from A to B to bring the air to the velocity of sound at throat B of the passage 51 and then divergent to C in a normal diffusion passage. Due to centrifugal effects in the rotor passages 51 and also for easier fabrication, the inside surface 55 of the passage 51, which is the outer surface of rotor 21, can be a cylindrically turned surface into which oblique slots have been cut at regular intervals for insertion of vanes 53. These vanes and outer labyrinth ring 53 can be a brazed assembly with the rotor 21 and drive shaft 31.

It will be noted in Figure 3 that boundary layer bleed-off ports 59 have been provided downstream from throat B of passage 51. These insure proper diffusion following the throat at design conditions and help to reduce the ill effects of shock burble at off design conditions.

It is important to control the boundary layer

in the diffuser as will appear from the following discussion.

When air is flowing at a velocity greater than the velocity of sound it cannot be brought to a subsonic velocity by a simple expansion as in a diverging tube since at or above sonic speed, expansion of the tubes of flow leads to an increase of velocity. Only if a shock wave occurs which lower the velocity below sonic by an increase in entropy can an expansion cause a reduction in velocity and an increase in pressure.

In the compressor described, at design conditions, the supersonic velocity is brought to a sonic value by the converging portion of the nozzle. A mild shock occurs near the beginning of the expansion lowering the velocity below the velocity of sound in the local fluid. The further expansion then gives a static pressure rise and a decrease of velocity. Since the shock occurs when the velocity is very close to the sonic value, little available energy is lost and the diffusion is accomplished efficiently provided the flow does not separate from the walls.

It is desirable to precipitate the shock wave near the throat, that is near sonic value of the velocity and the slot action will do this but it should only be done if separation from the wall can be prevented. Hence as pointed out above the diffusion downstream from the throat must be carried out in a "normal diffusion passage," that is in a passage which has the walls extending downstream from the throat substantial distances before being greatly curved or being abruptly expanded in passage cross sectional area. The passage walls should lap for a substantial distance upstream beyond any rapid change in direction of a portion of a blade. Abrupt change in direction of the walls will cause separation of the flow from the diverging walls. Shock waves may also cause separation. Preferably the aft portion of a blade should lie substantially along the direction of the fore portion or at least the aft portion should lie more along the direction of the fore portion than along a line perpendicular to a plane tangent to the leading edges of the adjacent blades forming a rotor passage.

Separation of the boundary layer from the walls is caused by the steep adverse pressure gradient through the shock wave. The boundary layer flow is unable to proceed against the sharply rising pressure and actually flows forward close to the wall, causing the main flow to separate from the wall.

In the present invention, the two devices are used to prevent separation. It will be noted in Figures 1 and 3 that the inner wall of the passage 51 is straight, all the curvature occurring along the outer wall. It is where the wall is curving from the flow that the separation will be apt to occur. It will not be as likely to occur at the inner wall which is straight. Separation at the curved wall will be prevented by the centrifugal pressure which tends to force the air against the outer wall.

It will also be noted that the outer or curved wall of the passage 51 or shroud ring 57 has the holes 59 which bleed off the boundary layer air and prevent separation. There are a number of these holes spaced peripherally about the shroud and for a short distance along the axis.

In Fig. 1b and in Fig. 3a is shown the alternate diffuser which has the discharge slot 60 served with compressed air through a plurality of tubes 62 leading to the annular cavity 64 from the

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compressed air collector 65. Air reaches the slots 69 via the holes 66 drilled in the shroud ring 57a. The jets from the slots 60 serve to prevent separation of the diffuser flow from the wall. The form of construction shown in Fig. 1b and in Fig. 3a is an alternative form to that shown in Figs. 1 and 3. Only one form, either that of Fig. 3 or Fig. 3a, is used at one time to the exclusion of the other form.

The air leaves the passages 51 of rotor 21 with an absolute velocity of appreciable magnitude. A goodly portion of this velocity energy is converted to static pressure energy as the air is further diffused in the stator passages 61 of Figure 2 formed by stator vanes 63 located in the diverging annular portion of case 1c. Figure 4 shows a radial section of the stator diffuser passages 61 taken along line 4—4 of Figure 2.

The final high pressure air leaves passages 61, Figure 1, to be collected in scroll passage 65 of case 1c for continuous delivery to a reservoir or machine for which the compressor is employed.

Windage loss in any centrifugal compressor is nearly always one of the main causes for the low adiabatic efficiency of this type compressor. It is already a well-known fact that impellers having an outer shroud, such as shroud 47 of Figure 1, are more efficient than those having no shroud and using a closely fitting housing. To obtain even better efficiency for impeller 17 in Figure 1, the annular labyrinth partitions 70, which are machined directly into the case 1a, are incorporated for two reasons. First, to form a set of labyrinth seals to cut down on air blow-by from the compressor; and second, to reduce the windage circulation pockets as shown at 72.

Incorporated throughout the unit shown in Figure 1 is a special type low-friction oil seal wherever there might be a change for oil to pass unwanted. To show the principle of this seal the forward impeller bearing 13 is considered. The principle is to provide an air annulus 80 intermediate to the shielded ball-bearing 13 and the labyrinth 82 such that when high pressure air is introduced in the air annulus 80 by means of tube 84 connected to the high-pressure annulus pocket 66, there will be enough air flow toward the bearing 13, regardless of the air leaking out the labyrinth seal 82, to satisfactorily prohibit oil particles from migrating toward and through the labyrinth. This same air that is flowing toward the bearing 13, besides keeping the oil from passing the bearing, accomplishes the job of scavenging oil slinger reservoir 29 after by-passing bearing 13 by means of passages 88 to the reservoir 29. The high pressure caused thereby in reservoir 29 relative to atmospheric pressure pushes any oil and excess air out through the oil scavenger tube 90 to be delivered by means of a return oil line from exit port 92 to a vented oil tank that would be part of the oil system installation.

Lubrication of bearings 13, 15, 19 and planetary gears 23, 35 and 39 is accomplished by the normal practice of supplying oil under high pressure to inlet port 94 from which it is distributed by means of suitable holes drilled in the elements of the machine including shaft 7, planet gear mounting bolts 25, sleeve spacer 27, and ball-bearing spacer sleeve 96.

A similar sealing, scavenging and oil system is employed for bearing 32 as shown on Figure 1.

A rotor having a nozzle passage for converting supersonic velocity to static pressure I will call a supersonic rotor.

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In another form of the invention shown in Figure 6 compressed elastic fluid is directed to the supersonic rotor 100 by the axial-flow rotor 102. This carries about its periphery two stages of blading, namely, the first stage composed of blades 104 and the second stage composed of blades 106. Stator blades 108 and 110 cooperate with the rotor blades to direct compressed fluid through the annular passage 112. The fluid enters through the inlet 114 across which streamline struts 116 extend to support the outer case 118.

At the downstream end of passage 112 there is a stage of adjustable guide vanes 120 which direct the fluid peripherally so that it has a large peripheral velocity upon approaching the supersonic nozzle 51. This velocity is also magnified by the contraction in passage 112 forming the exit nozzle 115 which can raise the issuing absolute velocity to sonic velocity or higher. The fluid leaving the nozzle 115 is directed counter to the direction of rotation of the rotor 100. Hence the velocity of the fluid approaching the supersonic nozzle 51 is supersonic of large magnitude. The action through the nozzle 51 is similar to that already described with respect to Figure 1.

The guide vanes 120 are placed in the large cross section of passage 112 where the fluid velocity is subsonic. This makes it possible for vanes 120 to deflect the flow without producing compressibility turbulence.

The vanes are adjusted by rotating ring 130 about the case. Each vane is pivotally mounted by its shaft 132 and an articulated arm 134 connects each shaft to the ring 130.

It is a feature of this invention that the supersonic nozzle 51 is placed at a greater radius than the axial flow rotor blades 104 and 106. The latter must be operated well below the velocity of sound while the supersonic nozzle should be operated at as high a speed as the material will permit. This difference in diameter permits both rotors (100 and 102) to be mounted upon the same shaft. This greatly simplifies the drive since the high speed gears like 23 are eliminated.

The passage 112 expands in cross section in the downstream direction, chiefly because the mean diameter of the annulus increases. The greater area reduces the velocity which in turn reduces the losses in the flow.

The design of Figure 6 can be made to produce as great a pressure rise as that of Figure 1 as well as produce the structural advantage described, and also provides for a greater range of efficient delivery of volume. This is so because the vanes 120 can be adjusted to direct the fluid at the proper angle into the supersonic nozzle 51 as the rate of rotation of the rotors changes. This is very important for machines such as turbines which must operate efficiently over a large variation in rotative speed.

Any of the passage structures conducting fluid are essentially nozzle structures. The rotator and stator nozzles or passages can be regarded as subpassages of the main flow passage.

In another form of the invention where size and cost are to be reduced, the stages of the axial compressor are placed close to the supersonic rotor. The rotors 100a and 102a are the same as described for Figure 6 with respect to the blades and nozzles. The guide vane 140 is different being shown fixed in the nozzle 115.

It may be observed particularly in Figure 1 that the exit area of the passage 51 is substan-

tially greater than the inlet area. This is an important feature since it enables the rotor 21 to pump even at low speeds for a flow directed along the axis 4-4 of the passages 51.

According to Euler's formula the pressure rise is

$$E = \rho U u$$

where ρ is the mass density of the fluid in slugs per cu. ft., U is the peripheral velocity at the average radius of the flow and u is the component of peripheral velocity added to the air by the rotor.

If the velocity in the direction of the axis of passage 51 were the same for inlet and exit (as they would be for a subsonic flow and equal inlet and exit areas) there would be no change in peripheral velocity, that is u would be zero since it is only the difference in peripheral components of the velocity at inlet and exit along the axis of 51. When the inlet and exit areas are different the velocity vectors and hence their peripheral components are different.

It is also a feature of this invention that the passages 51 diffuse the flow radially instead of peripherally as in the conventional axial-flow compressor where the curving of the blades or their mean camber line provides a larger area at exit from the passages than at the inlet of the passages between the blades.

The straight vanes 53 also present structural and cost advantages.

Tapering the passages in the radial direction has the added advantage that the opposite walls are substantially alike and disposed alike with respect to the resultant flow vector at the entrance to the passages.

The advantage of having the flow directed toward the supersonic rotor against its direction of rotation may be observed from Figures 8 and 9.

Figure 8 shows the vector diagram for a case where the structure ahead of the supersonic rotor directs the flow axially toward the rotor along vector 150. When combined with the rotor peripheral vector 152 this gives the resultant vector 154 relative to the rotor 21.

If the back pressure is reduced the axial flow through the compressor will increase for the same rate of rotation. This is the vector 150 may be multiplied by 3 for instance giving the new axial velocity vector 160 equal to 3 C'm. The new relative resultant vector is 162. The change in angle of approach of the air relative to rotor 21 is $\Delta\alpha_1$ and is about 30 degrees which is a greater range of angles than the blades of the rotor can accommodate. They can accommodate only about 16 degrees.

In Figure 9 the nozzle structure ahead of the rotor 21 directs a flow of fluid toward this rotor along the vector 164 whose axial component is still C'm. This vector combined with the peripheral vector 166 gives the relative vector 168. If the back pressure is decreased so that the new axial component is 3C'm the vector 164 becomes 170. This combined with 166 which remains constant gives the new relative velocity 172. The change in direction of the air approaching the rotor is then $\Delta\alpha_2$ which is about 7 degrees.

It is thus clear that by giving the flow from the structure ahead of the rotor a flat angle with respect to the rotor with the velocity directed against the direction of rotation of the rotor 21 the range of angles which the rotor must accommodate is made very small, in the instance cited 7° which is well within the capabilities of even straight or flat blades. This is important for

subsonic flows and is very important for supersonic flows which are very sensitive to a flow oblique to the blades of the rotor.

The larger the angle B can be made the smaller is the range of angles $\Delta\alpha$.

Where the flow in the rotor 21 is diffused radially the rotor may also be called a radial diffusion rotor.

In a conventional axial flow rotor the amount of diffusion is the difference in the width between two streamlines approaching the nose of two adjacent blades and the width between two streamlines leaving the trailing edges of the same blades. Since the pressure rise is dependent on the diffusion, the pressure rise varies with the angle of approach of the fluid to the blades. On the other hand the amount of diffusion in the radial diffusion rotor is built into the rotor by way of the ratio of exit to inlet area. Hence the radial diffusion rotor has a far more constant pressure rise for a wider range of fluid delivered per revolution. This is very important for an axial flow machine which has the disadvantage of a sharp drop in pressure with increasing mass flow per revolution.

A radial diffusion rotor gives its best efficiency when the passage inlet has a radial width which is small in comparison to the distance of the inlet from the axis of rotation. In other words if the blades are considered as defining the passages, the ratio of the radius to the blade root to the radius at the blade tip should be large, of the order of 0.90. With such a ratio there is not a great difference in the head added to the air at the root and tip. With a small ratio there would be a large difference which would lead to losses in the diffusion following the rotor. Consequently it is important that a radial diffusion rotor be used following a number of stages which have compressed the air into an annulus of small radial width or large ratio of its two radii. For this reason the last stage of an axial flow compressor is the best place for a radial diffusion rotor.

To recapitulate, I employ supersonic nozzles distributed about the peripheral part of a compressor rotor to compress elastic fluids. The nozzle is adapted to convert a supersonic relative velocity of the fluid to static pressure. Since structurally there is a limit to the speed of rotation I arrange for oppositely rotating rotors, one delivering fluid to the other. Because of the counterrotation the relative flow of velocity relative to the one with supersonic nozzles can be well above the velocity of sound without danger of structural failure.

As already remarked, in this invention, the throat to precipitate the shock wave is provided by the curvature in the outer wall of the flow passage of the rotor. The shock wave will extend inward from the outer wall transversely across the passage with the shock intensity a maximum at the outer wall. The pressure rise across the shock wave tends to cause the flow to separate from the diverging wall but this tendency is suppressed by the high centrifugal pressure arising from the rotation. (If even larger angles of diffusion are desired the boundary layer is controlled by the openings 59 and 60.) Since static pressures operate in all directions the flow is also restrained from separating from the hub peripheral surface by the rise in static pressure from rotation at this locality. With the walls diverging radially the pressure rise from the shock wave is increased by the diffu-

sion occurring after the shock. This is not feasible if the diffusion is in the peripheral direction since to provide the diffusion the blades must be curved and the convex surface of the blade will introduce an adverse pressure gradient readily causing separation from the convex wall. Because of this tendency to separate from the blade wall, supersonic compressors of the peripheral diffusion type employ a minimum of diffusion and rely for the pressure rise chiefly on the change in pressure across the shock wave and on little or no diffusion downstream therefrom. A radial diffusion rotor provides a far higher pressure rise for the same efficiency by suppressing the tendency to flow separation and by providing for large diffusion after the shock wave.

In one form of the invention, the first rotor or impeller compresses by centrifugal force.

In another form of the invention, to eliminate the gearing which may be troublesome in small diameter compressors, I rotate all rotors in the same direction. To get a counterrotation of the flow entering the supersonic compressor, I employ stator vanes which deflect the air peripherally in a direction counter to the supersonic rotor.

To maintain efficiency over a wide range of relative speeds I employ adjustable vanes just ahead of the supersonic rotor. I place these vanes preferably in a flow of subsonic velocity. By adjusting the vanes the proper direction of approach can be given the flow about to enter the supersonic rotor.

Downstream from the adjustable vane I construct the passage conducting the flow so as to give a high velocity relative to the supersonic rotor.

It will now be clear that I have disclosed a novel and efficient compressor of small dimensions, light weight, and low cost, embodying the several unique features originally specified as objects. It is to be understood however that the invention is not limited to the particular construction illustrated and described and that I intend to claim it broadly as indicated by the scope of the appended claims.

I claim:

1. In combination in a compressor, a supersonic rotor mounted for rotation about an axis, said rotor having a plurality of diverging passages spaced from said axis and directed with a component of length along said axis, each said passage having an exit portion of increasing cross sectional rear in the downstream direction, a casing ahead of said rotor adapted to lead a flow of fluid up to the inlets of said passages, an axial-flow rotor having blades mounted therein, means mounting said axial flow rotor with its blades in said casing ahead of said supersonic rotor for rotation to compress the said flow of fluid therein, a plurality of adjustable stator blades peripherally mounted in said casing between said rotors, means to adjust said stator blades to direct the flow into said supersonic rotor counter thereto, each said passage having an exit of greater radial depth and cross sectional area than the inlet thereof adapting each said passage to convert supersonic velocity to static pressure, and means to rotate said rotors to compress fluid, the portion of said casing between rotors having an annular cross section of expanding area in the downstream direction.

2. In combination in a compressor, a supersonic rotor mounted for rotation about an axis,

said rotor having a plurality of diverging passages spaced from said axis and directed with a component of length along said axis, each said passage having an exit portion of increasing cross sectional area in the downstream direction, a casing ahead of said rotor adapted to lead a flow of fluid up to the inlets of said passages, an axial-flow rotor having blades mounted thereon, means mounting said axial flow rotor with its blades in said casing ahead of said supersonic rotor for rotation to compress the said flow of fluid therein, a plurality of adjustable stator blades peripherally mounted in said casing between said rotors, means to adjust said stator blades to direct the flow into said supersonic rotor, and means to rotate said rotors to compress fluid, each said passage having an exit of greater radial depth and cross sectional area than the inlet thereof adapting each said passage to convert supersonic velocity to static pressure, the portion of said casing between rotors having an annular cross section of expanding area in the downstream direction, the first said rotor having a diameter substantially greater than the tip diameter of the second said rotor to provide for supersonic action of the first said rotor.

3. In combination in a compressor, a rotor, a counter-rotation supersonic axial flow rotor, means mounting said rotors for rotation about an axis, peripherally adjacent radial walls in said supersonic rotor defining passages there-through, the first said rotor being adapted to discharge fluid into the inlet of said passages at a relative supersonic speed and with a component of velocity directed against the direction of rotation of said supersonic rotor, each said passage being rotatable with said supersonic rotor and having an increasing cross sectional area and increasing radial depth in the downstream direction to convert the supersonic velocity to static pressure compressing said fluid, each said passage having an exit facing rearward to discharge fluid in the general direction of said axis, and means to apply power to said supersonic rotor to rotate the inlet of said passages at said relative supersonic speed.

4. In combination in a compressor adapted to deliver fluid against a substantial back pressure, a nozzle structure mounted therein having a plurality of peripherally adjacent passages there-through each comprising a converging inlet portion succeeded by a throat and a diverging exit portion of increasing cross sectional area and radial depth in the downstream direction, an impeller mounted ahead of said structure for rotation about an axis and adapted to discharge a flow of fluid into each said passage inlet portion with supersonic velocity relative to said inlet, each said passage being peripherally spaced in the same plane transverse to said axis, means to rotate said impeller to provide said flow, each said passage having a slot in its wall nearer said throat than the exit of said passage, and means to induce a flow through said slot to localize near said throat a shock wave precipitated by said increasing passage area and said back pressure.

5. In combination in a compressor having a main flow passage therein, an axial flow rotor mounted for rotation about an axis with a plurality of blades in said main passage, said blades being spaced peripherally about said rotor and dividing said main passage into a plurality of sub-passages having inlets and exits spaced from said axis, each said exit facing rearward

to direct said flow rearward therefrom in the general direction of said axis, a fluid impeller mounted ahead of said rotor for rotation about said axis adapted to discharge elastic fluid into the inlets of said sub-passages, and means to rotate said rotor and impeller in opposite directions to provide a supersonic flow of elastic fluid relative to said inlets of said rotor, said main passage increasing in cross sectional area and radial depth between the inlets and exits of said sub-passages adapting said rotor to convert the fluid supersonic velocity to static pressure.

6. In combination in a compressor, a supersonic rotor mounted for rotation about an axis, said rotor having a plurality of axially directed passages therethrough spaced from said axis and rotatable with said rotor, said rotor passages being peripherally adjacent, and each of said passages having a downstream portion thereof of increasing cross sectional area and radial depth in the downstream direction, a source of fluid under pressure, a duct adapted to conduct fluid to the inlets of said passages from said source of fluid, said duct having a converging nozzle at its exit to convert the fluid pressure to high fluid velocity, said nozzle including vanes set obliquely to said axis for directing said fluid into the inlets of said passages against their direction of rotation, and means to rotate said rotor at supersonic speed relative to fluid adjacent said inlets to compress and impel fluid through said passages.

7. In combination in a compressor adapted to impel fluid against a substantial back pressure, an axial flow rotor having a plurality of passages therethrough rotatable with said rotor and having inlets and exits spaced from the rotor axis, each said exit facing rearward to discharge fluid rearward in the general direction of the axis of said rotor, means to rotate said rotor about said axis with a fluid supersonic velocity relative to the inlets of said passages to induce flows through said passages, said passages each having peripheral walls diverging radially in the downstream direction so a fluid adjacent thereto flowing against said back pressure gives rise to a shock wave in each said passage tending to cause separation of said flow from said walls and tending to prevent conversion of dynamic pressure to static pressure, and means to induce a flow through a said wall to induce conversion of dynamic pressure of a supersonic fluid flow to static pressure within said passages, each said exit of a said passage being greater than the inlet thereof in radial depth and cross sectional area.

8. In combination in an axial flow compressor adapted to pump a fluid against a substantial back pressure, a nozzle structure supported therein, said structure having a plurality of radial blades defining a plurality of passages therebetween each having an inlet and an exit, an impeller mounted ahead of said structure for rotation about an axis, said impeller having its discharge exits in communication with the inlets of said passages to direct a flow of fluid thereinto, means to rotate said impeller to provide a flow of elastic fluid through said impeller exits with supersonic velocity relative to said passage inlets, said blades being substantially straight along a substantial distance in the direction of the passage flow, said passages being bounded by opposed peripheral walls diverging in the downstream direction of the passage flow to provide a diverging portion of cross sectional areas increasing in the downstream direction, each said passage having an entrance portion of decreasing cross sec-

tional area and a throat portion preceding said diverging portion to reduce said supersonic velocity to sonic velocity, each said diverging portion serving in cooperation with said back pressure to precipitate a shock wave in the fluid flowing therein so that said diverging portion can convert the sonic velocity in said throat to static pressure, a wall of said passage having a slot therein near said throat, and means to induce a flow through said slot to precipitate said shock wave near said throat.

9. In combination in an axial flow compressor adapted to pump a fluid against a substantial back pressure, a nozzle structure supported therein, said structure having a plurality of radial blades defining a plurality of passages therebetween each having an inlet and an exit, an impeller mounted ahead of said structure for rotation about an axis, said impeller having its discharge exits in communication with the inlets of said passages to direct a flow of fluid thereinto, means to rotate said impeller to provide a flow of elastic fluid through said impeller exits with supersonic velocity relative to said passage inlets, said blades being substantially straight along a substantial distance in the direction of the passage flow, said passages being bounded by opposed peripheral walls diverging in the downstream direction of the passage flow to provide a diverging portion of cross sectional areas increasing in the downstream direction, each said passage having an entrance portion of decreasing cross sectional area and a throat portion preceding said diverging portion to reduce said supersonic velocity to sonic velocity, each said diverging portion serving in cooperation with said back pressure to precipitate a shock wave in the fluid flowing therein so that said diverging portion can convert the sonic velocity in said throat to static pressure, a wall of said passage having a slot therein upstream from the passage exit, and means to induce a flow through said slot to precipitate said shock wave a substantial distance upstream from said exit, opposed walls of said passage being substantially straight downstream beyond said slot for a substantial distance.

10. In combination to form a supersonic compressor, a case having an inlet and an exit, an impeller mounted in said case for rotation in one direction about a rotor axis to impel a flow of fluid through said case, a supersonic rotor mounted in said case aft of said impeller for rotation about said axis in counter direction to said impeller, said supersonic rotor having a plurality of blades spaced peripherally thereabout in the same plane transverse to said axis defining a plurality of passages extending through from the front to the back of said rotor, said supersonic rotor blades making a substantial angle with respect to said axis of rotation, said impeller having a plurality of passages therethrough adapted to direct a fluid flow into the inlets of said supersonic rotor passages, each said supersonic rotor passage having an inlet portion of decreasing cross sectional area succeeded by an exit portion of radially increasing cross sectional area, the inlet portion of each said supersonic rotor blade having a substantially straight length and the rear portion of each said blade being more nearly in line with the direction of said length than in line with the direction of said rotor axis to provide a form for each said supersonic rotor passage adapted to convert supersonic velocity to static pressure, and means to rotate said impeller in one direction and said supersonic rotor in the

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other direction at such speeds that the supersonic rotor has a supersonic speed relative to the fluid flow directed toward its passage inlets.

11. In combination to pump a fluid against a substantial back pressure, a case, a nozzle structure mounted within said case, said structure having a plurality of blades serving as walls spaced apart peripherally along the wall of said case defining a plurality of passages extensive between the leading and trailing edges of said blades, each said passage comprising an inlet portion of decreasing cross sectional area and a throat and an exit portion of radially increasing cross sectional area in the downstream direction, an impeller mounted in said case ahead of said structure for rotation about an impeller axis and adapted to discharge a flow of fluid in the general axial direction into the inlet of each said passage with supersonic velocity relative to said inlet, the inlet portion of each said blade being substantially straight, means to rotate said impeller to provide said flow, said blade portion defining a said passage exit portion extending downstream substantially in line with the direction of said inlet portion of said blades for a substantial distance beyond said throat to provide a passage form suitable to convert said supersonic velocity to static pressure, each said passage exit portion serving in cooperation with said back pressure to precipitate a shock wave in the fluid flowing therein, a said wall of said passage having a slot therein substantially upstream from the trailing edges of said blades defining said passage exit, and means to induce a flow through said slot to control the location of said shock wave.

12. In combination in a compressor having a main flow passage with a portion thereof of decreasing cross sectional area in the downstream direction of a flow within, a plurality of stages of axial flow rotor blades mounted in tandem in said main passage for rotation about an axis to impel a flow of fluid through said stages in succession, said stages compressing said fluid through successively smaller annular cross sections of said main passage and a radial diffusion rotor mounted downstream from said stages for rotation about an axis, said diffusion rotor having a plurality of peripherally adjacent rotor passages in said main passage adapted to receive said fluid from said axial flow stages by way of said main annular passage portion of reduced cross sectional area, said diffusion rotor passage lying in the same peripheral plane transverse to said axis, each said diffusion rotor passage having radially diverging walls and an exit cross sectional area and radial depth greater than its inlet cross sectional area and radial depth, said inlets and exits being spaced by similar distances from said axis, said exits being directed rearward to direct a fluid flow rearward in the general direction of said axis.

13. In combination in a compressor, a supersonic rotor mounted for rotation about an axis, said rotor having a plurality of radially diverging passages spaced from said axis, each said passage having an exit of greater area and radial depth than the inlet thereof, each said passage extending through from front to rear of said rotor to said exit facing rearward to direct fluid rearward in the general direction of said axis, a casing ahead of said rotor adapted to lead a flow of fluid up to the inlets of said passages, an axial-flow rotor having blades mounted therein, means mounting said rotor with its blades in said casing ahead of said supersonic rotor for

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rotation to compress the said flow of fluid therein, a plurality of adjustable stator blades peripherally mounted in said casing between said rotors, means to adjust said stator blades to direct the flow from said axial flow rotor into said passages of said supersonic rotor counter thereto, and means to rotate said rotors to compress fluid, said means being adapted to give said supersonic rotor a supersonic speed at the inlet of said passages relative to the air approaching said supersonic rotor.

14. In combination in a compressor, an axial flow rotor having a plurality of peripherally adjacent rotor passages therethrough from front to rear of said rotor and spaced outward from the rotor axis, each said passage having its exit and inlet rotatable with said rotor and having said exit facing rearward to discharge a fluid flow in the general axial direction, means to rotate said rotor about said axis to induce a flow through said passages, each said rotor passage having a peripheral wall diverging radially with respect to said axis to increase the cross sectional areas in the downstream direction to provide an exit area of each said passage greater than the inlet area thereof, and means to induce a flow through said peripheral wall between said inlet and exit of each said passage to suppress separation of the fluid from said wall.

15. In combination in a compressor, a first rotor, a counter-rotating supersonic rotor, means mounting said rotors in tandem for rotation about an axis, said supersonic rotor having an axially directed passage extending therethrough from front to back thereof and rotatable therewith, said first rotor being adapted to supply fluid to the inlet of said passage with a supersonic velocity relative to said inlet, said passage being rotatable with said rotor and having an increasing cross sectional area and increasing radial depth in the downstream direction to convert the supersonic velocity to static pressure, and means to apply power to said supersonic rotor to rotate the inlet of said passage at said relative supersonic speed.

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