June 22, 1954 W. G. LUNDQUIST 2,681,760

CENTRIFUGAL COMPRESSOR

Filed Feb. 26, 1949

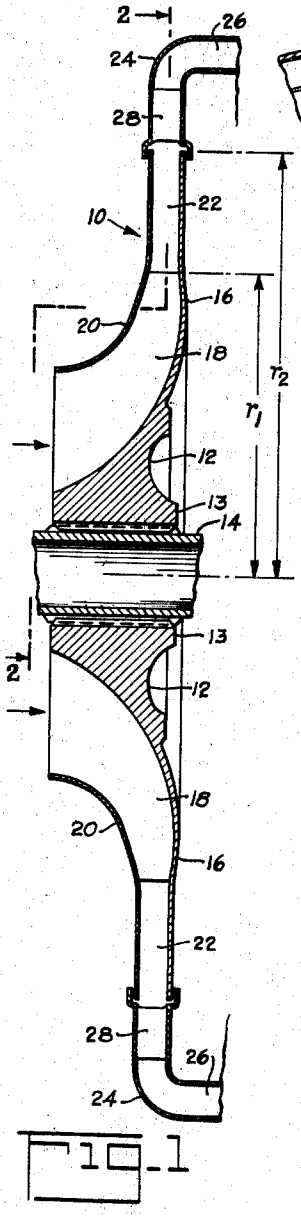

FIG. 1

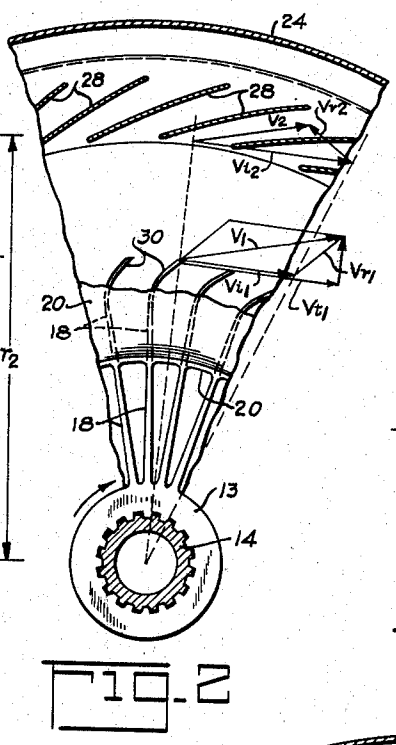

FIG. 2

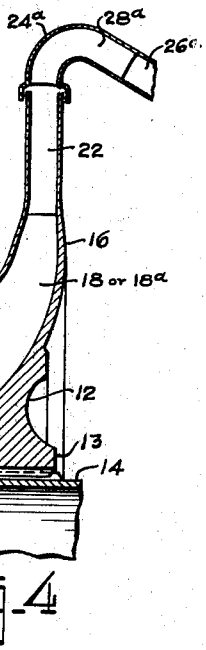

FIG. 4

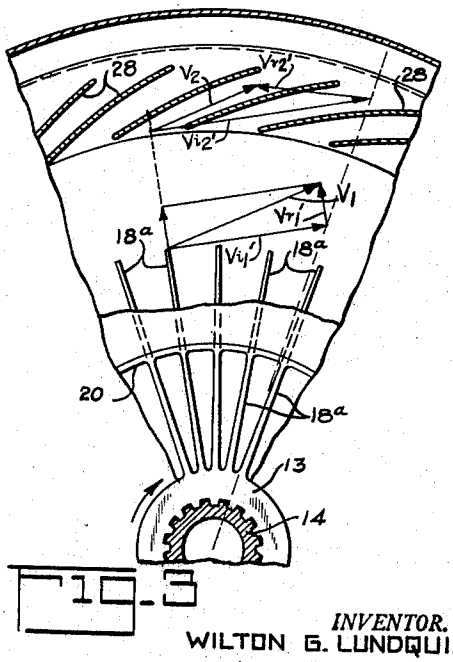

FIG. 3

INVENTOR.
WILTON G. LUNDQUIST.
BY Victor D. Behn
ATTORNEY

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CENTRIFUGAL COMPRESSOR

Wilton G. Lundquist, Hohokus, N. J., assignor to Curtiss-Wright Corporation, a corporation of Delaware

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1 Claim. (Cl. 230—127)

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This invention relates to centrifugal compressors and is particularly directed to a diffuser construction for such compressors and to a novel method of compressing a fluid.

The conventional centrifugal compressor comprises an impeller having a plurality of blades which, upon rotation, impart kinetic energy to the air or other fluid being compressed. At the discharge or peripheral end of the impeller blades the compressor is provided with a diffuser construction for converting the kinetic energy of the compressor fluid into pressure head. Thus the pressure rise produced by a given centrifugal compressor increases with increase in the kinetic energy imparted to the compressor fluid, that is with increase in the rotational speed of the impeller. The conventional diffuser construction of a centrifugal compressor comprises a plurality of fixed guide vanes disposed about and adjacent to the periphery of the impeller blades, the compressor fluid discharging between said guide vanes as it leaves the impeller blades. Because of the turbulence created by the impact and contact of the compressor fluid with the diffuser vanes and with the walls of the diffuser and because of the friction between said compressor fluid and the surfaces of the diffuser over which said fluid flows, there necessarily is some loss of energy in the diffuser. This loss of energy obviously increases with increase in the velocity of the compressor fluid relative to the parts over which said fluid flows and if said relative velocity exceeds the velocity of sound this loss of energy becomes excessive.

An object of this invention comprises the provision of a diffuser construction for a centrifugal compressor in which the aforementioned loss of energy in the diffuser is minimized. A further object of the invention comprises a diffuser construction in which the compressor fluid has a high absolute velocity as it leaves the impeller blades but the velocity of said fluid relative to any portion of the compressor over which said fluid flows is substantially less than said high velocity. With such a diffuser construction, the velocity of the compressor fluid over any part of the compressor can be kept below the velocity of sound even though the impeller is rotated at a speed sufficiently high to impart a super-sonic velocity to the compressor fluid as said fluid leaves the impeller blades.

Specifically the invention comprises a vaneless diffuser rotatable with the impeller of a centrifugal compressor. In accordance with the present invention the compressor impeller comprises a pair of annular walls across which the impeller blades are disposed and said annular walls both extend a substantial distance radially beyond the outer periphery of the impeller blades to form a vaneless diffuser chamber for the compressor fluid. The compressor stator structure and its diffuser guide vanes are disposed at and about the outer periphery of the vaneless diffuser chamber whereby the absolute velocity of the compressor fluid decreases, from its velocity at the discharge end of the impeller blades, before said fluid enters between and contacts the diffuser vanes or any other portion of the stator structure.

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Other objects of the invention will become apparent upon reading the annexed detailed description in connection with the drawing in which:

Figure 1 is an axial sectional view of a compressor embodying the invention;

Figure 2 is a view taken along line 2—2 of Figure 1;

Figure 3 is a view similar to Figure 2 but illustrating a modified construction; and

Figure 4 is a view similar to Figure 1 but illustrating a further modification.

Referring first to Figures 1 and 2 of the drawing, a centrifugal compressor 10 comprises a rotor or impeller 12 having a hub 13 splined to a shaft 14 for driving said impeller. The impeller has a back wall 16 extending radially from its hub 13 and a plurality of circumferentially spaced blades 18 are formed integral with and extend from said back wall and hub. An annular shroud or forward wall 20 is secured to and disposed across the forward or tip ends of the impeller blades. This shroud or forward wall 20 may be formed integral with the impeller blades or it may be suitably secured to said blades, as for example by welding. The shroud or forward wall 20 is axially spaced from the back wall 16 and is radially spaced from the impeller hub 13 to form an annular passage for the compressor fluid, the impeller blades 18 extending across said passage.

The structure of the centrifugal compressor so far described is conventional. The conventional centrifugal compressor also generally includes a stator having a plurality of diffuser vanes circumferentially spaced about and disposed adjacent to the periphery of the impeller blades. In accordance with the present invention, however, the forward and back walls 16 and 20 of the impeller both extend radially beyond the discharge ends of the impeller blades

18 to form an annular circumferentially continuous or vaneless diffuser chamber 22 about said blades and into which the compressor fluid discharges from said blades. A stator structure 24 is disposed about the outer periphery of the impeller walls 16 and 20 and their chamber 22 to form an annular passage 26 into which the compressor fluid discharges from the radially outer periphery of the annular chamber 22. A plurality of diffuser vanes 28 extend across the stator passages 26, said vanes being circumferentially spaced about the outer periphery of the annular vaneless diffuser chamber 22.

With this construction, the absolute velocity of the compressor fluid at the entrance to the stator passage 26 is substantially less than the absolute velocity of the compressor fluid at the periphery of the impeller blades 18. In fact the ratio of the absolute velocity of the compressor fluid at the periphery of the diffuser chamber 22 to its absolute velocity at the radially inner or entrance end of said chamber is approximately equal to the ratio of the radius of the periphery of said chamber to the radius at its inner or entrance end. This relationship can be established as follows: Consider a small mass m of compressor fluid within the diffuser chamber 22. From the principle of the conservation of angular momentum, as this mass of fluid moves through the chamber 22 its angular momentum is constant. Therefore, if Vt is the tangential component of the absolute velocity of this mass of fluid and r is its radius at any point along its path as said mass moves through the chamber 22, then the expression $mrVt$ is a constant. From this it follows that the absolute tangential velocity Vt of the compressor fluid varies inversely as its radius r as said fluid moves through the chamber 22. Neglecting velocity changes resulting from changes in the density of the compressor fluid, if the walls of the chamber 22 are parallel the radial component of the absolute velocity of the compressor fluid will also very inversely as the radius. Since both the radial and tangential components of the absolute velocity of the compressor fluid will vary inversely as its radius, as said fluid travels through the diffuser chamber 22, the absolute velocity of said fluid will also vary inversely as its radius. Therefore, if V_1 and r_1 are respectively the absolute velocity and radius of the compressor fluid at the inner end of the annular diffuser chamber 22 as said fluid leaves the impeller blades and V_2 and r_2 are respectively the absolute velocity and radius of the compressor fluid at the outer end of said chamber then

$$V_2 = V_1 \frac{r_1}{r_2}$$

From the above relation it follows that since the walls 16 and 20 extend a substantial distance radially outwardly beyond the periphery of the impeller blades, there is a substantial reduction in the absolute velocity of the compressor fluid, from its value at the periphery at the impeller blades, before said fluid enters the stator 24 and its vanes 28. Therefore, although the absolute velocity of the compressor fluid as it leaves the impeller blades is quite high, this absolute velocity is reduced before any portion of said fluid contacts the stator. With the proportions illustrated in the drawing, the radius r_2 to the outer end of the diffuser chamber is approximately 40% greater than the radius r_1 to the inner end of said chamber whereby the absolute velocity V_1 of the compressor fluid as it leaves the impeller blades and enters the chamber 22 is approximately 40% greater than its absolute velocity V_2 at the discharge end or outer periphery of said chamber.

One of the prime advantages of the above described centrifugal compressor construction is that this construction makes it possible to keep the velocity of the compressor fluid over any portion of the compressor below the velocity of sound even though sufficient kinetic energy is imparted to the compressor fluid to raise its absolute velocity above the velocity of sound. In this way, a high degree of compression can be obtained with a centrifugal compressor without the high energy loss which would result if the velocity of the compressor fluid over, for example, the diffuser vanes exceeded the velocity of sound. In the case where the centrifugal impeller is operated at a speed sufficiently high to raise the velocity of the compressor fluid above the velocity of sound, the annular walls 16 and 20 of the vaneless diffuser chamber are extended a sufficient distance radially beyond the periphery of the impeller blades so that the absolute velocity of the compressor fluid is reduced below the velocity of sound before said fluid enters the stator 24 and its diffuser vanes 28. With the proportions illustrated in the drawing, the absolute velocity V_1 of the air at the periphery of the impeller blades may correspond to a "Mach" number equal to 1.52 whereas the absolute velocity V_2 at the outer periphery of the vaneless diffuser chamber 22 may correspond to "Mach" number equal to 0.96. It should be clear therefore that the extent to which r_2 is greater than r_1 is in no way limited to the specific magnitudes or ratio of r_1 and r_2 illustrated in the drawing.

In the modifications of Figures 1 and 2, the radially outer periphery of the discharge ends of the impeller blades are curved forwardly in the direction of rotation of the impeller as indicated at 30. With this construction the tangential component of the absolute velocity of the compressor fluid as it leaves the impeller blades is increased above the peripheral velocity of said blades. Therefore this forward curvature of the impeller blades makes it possible to obtain a desired absolute velocity of the compressor fluid with a smaller rotative speed of the impeller. This feature is particularly important in a compressor in which super-sonic velocities are imparted to the compressor fluid since it is a simple way of obtaining such high velocities without having the speed of rotation of the impeller become excessive. As illustrated, the forwardly curved portion 30 of the blades is limited to the discharge ends of said blades. Obviously, however, all or at least a major portion of the blades may be so curved.

If higher rotative speeds of the impeller are possible or feasible, the impeller blades 18 of Figures 1 and 2 may be replaced by flat impeller blades 18a as illustrated in Figure 3. The remaining portion of the compressor of Figure 3 is identical to that of Figures 1 and 2 so that like parts have been indicated by like reference numerals. In Figure 3 the compressor fluid is indicated as having an absolute velocity V_1 of the same magnitude as the absolute velocity V_1 in Figure 2. It is evident however that, in obtaining this same magnitude of absolute velocity of the compressor fluid at the periphery of the impeller blades 18 and 18a, the peripheral velocity Vi of the impeller blades 18 of Figures 1 and 2 is substantially

less than the peripheral velocity Vi' of the impeller blades **18***a* of Figure 3. Thus in Figures 1 and 2, the peripheral velocity Vi of the impeller blades is less than the absolute tangential velocity Vt_1 of the compressor fluid at the periphery of said blades by an amount equal to the tangential component of the velocity of the compressor fluid at and relative to the periphery of said blades. In Figure 3, however, the absolute tangential velocity Vt_1' of the compressor fluid at the periphery of the impeller and the peripheral velocity Vi' of the impeller blades are equal.

The tangential speed of any point on the impeller is proportional to the radius of said point from the impeller axis so that the tangential velocity Vi_2 of the impeller at the outer periphery of the impeller walls **16** and **20** is greater than the tangential velocity Vi_1 of the impeller at the periphery of the impeller blades in the ratio of r_2 to r_1. Nevertheless, as illustrated in the drawing, the velocity of the compressor fluid at and relative to the outer periphery of the impeller walls **16** and **20** is not excessive. This relative velocity is represented by Vr_2 on Figure 2 and by Vr_2' on Figure 3.

The provision of the vaneless diffuser chamber **22** increases the overall diameter of the compressor above that of a conventional compressor in which there is no such chamber and in which the diffuser vanes are disposed adjacent to the periphery of the impeller blades. If desired, however, the overall diameter of the compressor may be reduced from that of the compressors illustrated in Figures 1 to 3 by eliminating the radially extending portion of the stator. Such a construction is illustrated in Figure 4.

In Figure 4 a stator **24***a* has an annular discharge passage **26***a* with a plurality of stator vanes **28***a* disposed across and adjacent to the periphery of the vaneless diffuser chamber **22**. Instead of being disposed in a radial portion of the passage **26***a* as in Figures 1 to 3, the diffuser vanes **28***a* are disposed in a bend in said passage thereby reducing the overall diameter of the compressor from that illustrated in Figures 1 to 3. The compressor of Figure 4 is otherwise similar to that of Figures 1 and 2 or to that of Figure 3 and like parts have been indicated by like reference numerals.

While I have described my invention in detail in its present preferred embodiment, it will be obvious to those skilled in the art, after understanding my invention, that various changes and modifications may be made therein without departing from the spirit or scope thereof. I aim in the appended claim to cover all such modifications.

I claim as my invention:

A centrifugal compressor comprising a rotatable impeller and a stator structure, said impeller having a pair of spaced annular walls forming an annular open-ended space therebetween for the fluid to be compressed, one end of said annular space comprising an inlet for the compressor fluid and both said annular walls extending radially outwardly in axially spaced relation from their inlet ends, said impeller also having a plurality of circumferentially spaced impeller blades extending between and being secured to both said annular walls to partition said space into a plurality of passageways for the compressor fluid, the discharge end of each impeller blade being curved about the impeller axis such that when viewed in the direction of fluid flow between the impeller blades said discharge end bends in the direction of rotation of the impeller, said annular impeller walls extending a substantial distance radially outwardly beyond the discharge ends of said impeller blades to form an annular chamber about said discharge ends into which said compressor fluid discharges as it leaves said impeller passages, the radial dimension of said chamber being sufficiently large that there is a substantial reduction in the absolute velocity of compressor fluid as said fluid flows through said chamber from its radially inner to its radially outer end, said stator structure having a pair of spaced walls forming a continuation of said impeller walls beyond said chamber, said stator structure also including a plurality of circumferentially-spaced stationary diffuser vanes extending between said stator walls about the radially outer periphery of said chamber so that the compressor fluid discharges between said vanes from the radially outer periphery of said chamber, each said diffuser vane having one end disposed adjacent to the outer periphery of said annular chamber and extending from said one end in a direction inclined to the radial direction through said one end so that the other end of said vane is spaced both radially outwardly and circumferentially in the direction of impeller rotation from its said one end.

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