April 9, 1957 E. A. STALKER 2,788,172

BLADED STRUCTURES FOR AXIAL FLOW COMPRESSORS

Filed Dec. 6, 1951

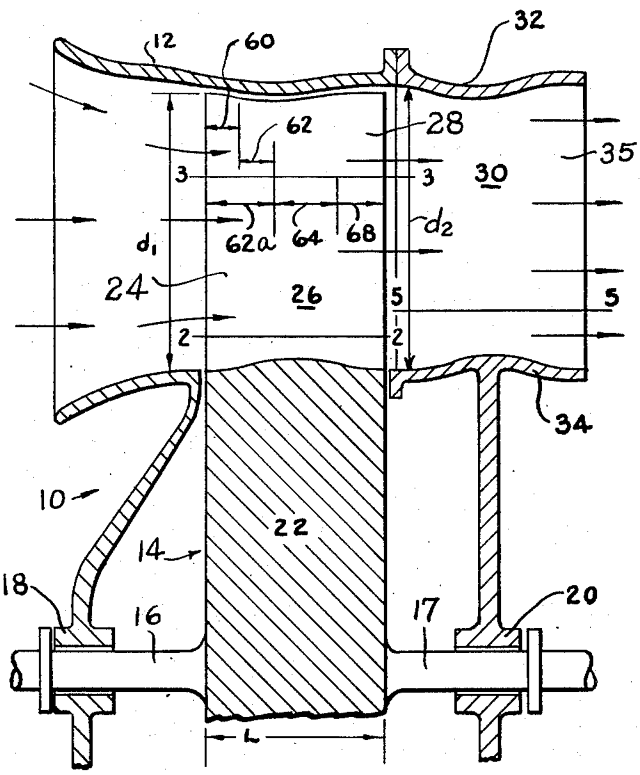


Fig. 1

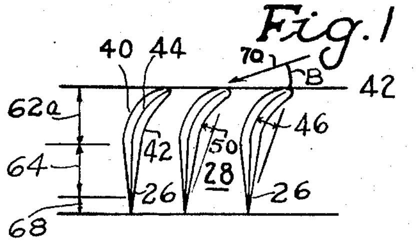


Fig. 2

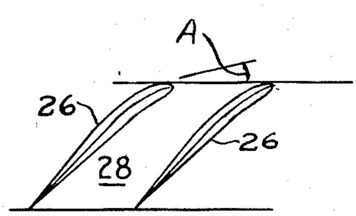


Fig. 3

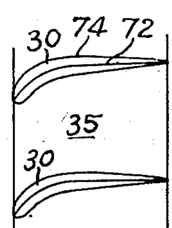


Fig. 5

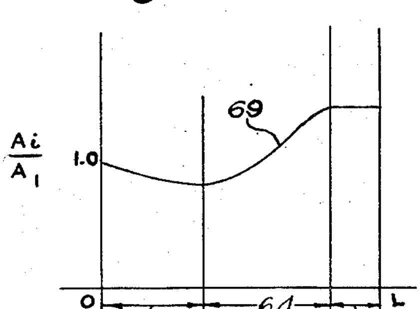


Fig. 4

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## BLADED STRUCTURES FOR AXIAL FLOW COMPRESSORS

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4 Claims. (Cl. 230—120)

This invention relates to compressors of the axial flow type and particularly to the blades for the rotors and stators.

This application differs from application Serial No. 81,104, filed March 12, 1949, entitled Axial Flow Fluid Transmissions Including Slotted Surfaces, now Patent No. 2,678,537, in that it is directed to blades and flow passages which are adapted to turn the fluid flow chiefly at the forward portions thereof under accelerating conditions of flow. It is also directed to blade sections of airfoil shape as defined later herein.

An object of the invention is to provide blades of a special shape, preferably airfoil shape, which cooperate with the boundary walls at the ends of the passages defined by the blades to provide turning of the fluid flow at the forward portions thereof under conditions of acceleration of the fluid.

Another object is to provide the blades of this invention with such shape that the flow of fluid in the passages defined by the blades is not substantially diffused along a substantial distance forward from the trailing edges of the blades.

Other objects will appear from the description and claims.

The above objects are accomplished by the means illustrated in the accompanying drawings in which:

Fig. 1 is a fragmentary axial section through a compressor according to this invention;

Fig. 2 is a fragmentary development of the blading taken along line 2—2 in Fig. 1;

Fig. 3 is a fragmentary development of the blading taken along line 3—3 in Fig. 1;

Fig. 4 is a graph of the cross section areas along the axial length of a passage between blades; and

Fig. 5 is a fragmentary development of the stator blading at line 5—5 in Fig. 1.

Referring now to the drawings, the compressor is indicated generally as 10. The case is 12 enclosing the rotor 14 mounted by shafts 16 and 17 in bearings 18 and 20.

The case and the rotor hub 22 define the annular channel 24 for conducting the flow through the compressor.

The rotor carries the blades 26 spaced peripherally about the hub and extending spanwise and radially across the channel defining the rotor flow passages 28 between the blades.

The stator blades are 30 supported between the radially spaced walls 32 and 34 defining the stator passages 35. The wall 34 has a surface at the radially inner ends of blades 35 converging toward the surface of wall 32.

The rotor blades have upper and lower camber lines 40 and 42 respectively defining the mean camber line 44 whose maximum ordinate above its subtending chord line is 46 positioned in the forward half thereof. The maximum ordinate of the lower camber is 50 and it is also positioned at the forward portion of the blade ahead of its mid-chord point. The mean camber line is substantially straight along the aft portion of each blade.



Preferably the maximum thickness is located at or rearward of the junction of the curved portion of the mean camber line with the substantially straight portion.

By confining the curvature of the mean camber line to the forward portion 52 of each blade the entering flow is turned while the flow is being accelerated. The acceleration is in part obtained from the thickening of the blades which reduces the width of the passage between blades and also from changing the radial depths of the passages. Thus in Fig. 1 the case and rotor hubs are adapted to vary the depths of the passages. Along the portion 60 the case is substantially parallel to the hub surface. Along the portion 62 forward of the mid-chord point of the blade the case and hub surfaces converge, one relative to the other, to reduce the passage depth. Along the portion 64 the case and hub surfaces diverge one relative to the other, to increase the radial depth of the passage. Along the portion 68 the depth remains substantially constant. Thus the distribution of cross sectional areas along the flow passages may conform to the graph 69 in Fig. 4.

To assure a converging portion of each passage ahead of about the mid-chord point of a blade, the blades are spaced closely together with the normal projection of the leading edge of each following blade on an adjacent leading blade forward of the mid-chord point of the leading blade.

Near the entrance to the rotor passages the case and hub need not converge substantially since the rapid increase in the thickness of the blades reduces the passage cross section sufficiently rearward along the passage.

Further along the case and hub surfaces converge relatively to continue the passage length of decreasing cross sectional areas rearward preferably beyond the locality of the mean camber maximum ordinate 46, the locality of maximum thickness, or the end of the curvature of the curved nose portion of the blade as shown by the graph 69 in Fig. 4. Thus the flow is accelerated until it enters the substantially straight portions 64 and 68 of the passage 28 as seen in Figs. 2 and 3.

It is only with subsonic flows that a fluid flow is accelerated by a converging passage. Thus the compressors of this invention are for operation at subsonic flow velocities relative to the blades.

The fluid enters the rotor with the direction 70 and is turned by the forward portions 62*a* of the blades while the flow is being accelerated. The flow next enters the passage rearward portion 64 where the cross sectional areas are increasing rearward. It is diffused to a lowered velocity and increased static pressure. It then enters the portion 68 of substantially constant cross section where the static pressure equalizes across the passage so that when the trailing edges of the blades are reached there is no substantial difference in pressure between opposite faces of the blades. If diffusion continued up to the trailing edges of the blades the fluid would be subjected to different pressures on the front and back sides of the blades.

The variation in radial depth can be accomplished on either the case or the hub or preferably both.

The depth $d_2$ may be equal to $d_1$ or have any other ratio thereto. In compressors designed according to the vortex theory or approximations thereof, $d_2$ may be somewhat smaller than $d_1$.

In order to confine the turning of the flow chiefly to the forward halves or portions of the passages, the forward portions of the blades are preferably given a concave under camber with the maximum ordinate 50 thereof positioned close to the nose of each blade, as remarked earlier.

By confining the turning of the flow to the forward portion where it is accelerated, it can be turned through large angles. Fig. 2, for instance, shows the flow turned through about 45° whereas conventional axial flow machines, in practice, turn the flow only about 20° or sometimes less.

The blades are shown twisted so that the pitch angle A at the tips is substantially less than the similar angle B at the roots but other distributions of the pitch angles along the radius may be used.

The stator blades **30** as shown in Figs. 1 and 5 are similar to the rotor blades **26** in having the curvature at the nose of the blades and the case is adapted to cooperate with the blades in a similar manner. The mean camber line is **72** and the upper camber line is 74.

The blades may have sections of varying thickness along their chords or they may have substantially constant thickness as when made from sheet material. Blade sections which have a forward portion of increasing thickness defined by fair curves extending rearward a substantial distance from the nose and an aft portion joined thereto defined by fair curves tapering to a thin trailing edge are herein called airfoil sections. Such blade sections have the virtue of accelerating the flow along their forward portions.

An axial flow machine is characterized by a main flow channel directed in the general direction of the axis. The blades of an axial flow rotor divide this channel into rotor flow passages extending lengthwise from an inlet at the front side of the rotor to an exit at the rear side to discharge fluid rearward with a component of axial velocity relative to the rotor directed more along the axis of rotation than normal thereto.

While I have illustrated a specific form of this invention it is to be understood that I do not intend to limit myself to this exact form but intend to claim my invention broadly as indicated by the appended claims.

I claim:

1. An axial flow subsonic compressor for operation with relative fluid velocities less than sonic relative to the blades thereof comprising in combination a case, a rotor hub mounted in said case for rotation about an axis defining an annular axial flow channel therewith and a plurality of axial flow blades carried on said hub spaced peripherally thereabout and extending spanwise radially across said channel, said blades defining a plurality of axial flow passages therebetween each having an inlet and an exit respectively at the front and rear sides of said rotor, said case and said hub bounding said passages and defining the general lengthwise direction thereof, each said blade having a curved mean camber line presenting the concave side thereof toward the direction of rotation with the maximum curvature thereof in the forward half thereof positioning the mean camber line maximum ordinate above its subtending chord substantially forward of the mid point of said chord to turn the flow in each said passage chiefly in the forward half thereof toward the direction of rotation, said case and said hub cooperating to define portions of the surfaces thereof at radially opposite ends of each said blade converging rearward radially one relative to the other along a forward portion of the chord of each said blade establishing for each said passage cross-sectional areas and radial depths thereof decreasing in magnitude rearward therealong from each said inlet to a locality substantially as far rearward as said ordinate providing continuously decreasing cross-sectional areas of said passage to accelerate the flow in each said passage while said flow is being turned by the forward portions of said blades.

2. An axial flow subsonic compressor for operation with relative fluid velocities less than sonic relative to the blades thereof comprising in combination a case, a rotor hub mounted in said case for rotation about an axis defining an annular axial flow channel therewith and a plurality of axial flow blades carried on said hub spaced peripherally thereabout and extending spanwise radially across said channel, said blades defining a plurality of axial flow passages therebetween each having an inlet and an exit respectively at the front and rear sides of said rotor, said case and said hub bounding said passages and defining the general lengthwise direction thereof, each said blade having a curved mean camber line presenting the concave side thereof toward the direction of rotation with the maximum curvature thereof in the forward half thereof positioning the mean camber line maximum ordinate above its subtending chord substantially forward of the mid point of said chord to turn the flow in each said passage chiefly in the forward half thereof toward the direction of rotation, each said blade having a maximum thickness rearward of said ordinate, said case and said hub cooperating to define portions of the surfaces thereof at radially opposite ends of each said blade converging rearward radially one relative to the other along a portion of the chord of each said blade establishing for each said passage rearward decreasing cross-sectional areas and radial depths thereof, said cross-sectional area continuously decreasing in magnitude rearward therealong from each said inlet to a locality substantially as far rearward as said ordinate to accelerate the flow in the forward portion of each said passage while said flow is being turned by the forward portion of said blades toward the direction of rotation, said hub and case cooperating to define other portions of the surfaces thereof at radially opposite ends of each said blade diverging radially one relative to the other rearward of said converging portions establishing cross-sectional areas and radial depths of each said passage increasing rearward therealong rearward of said locality with the radial depth of each said exit greater than the radial depth at said locality.

3. An axial flow subsonic compressor for operation with relative fluid velocities less than sonic relative to the blades thereof comprising in combination a case, a rotor mounted in said case for rotation about an axis defining an annular flow channel therewith and a plurality of axial flow blades carried on said hub spaced peripherally thereabout and extending spanwise radially across said channel, said blades defining a plurality of axial flow passages therebetween each having an inlet and an exit respectively at the front and rear sides of said rotor, said case and said hub bounding said passages and defining the general lengthwise direction thereof, each said blade having a curved mean camber line presenting the concave side thereof toward the direction of rotation with the maximum curvature thereof in the forward half thereof positioning the mean camber line maximum ordinate above its subtending chord substantialy forward of the mid point of said chord to turn the flow in each said passage chiefly in the forward half thereof toward the direction of rotation, one of said walls defining a portion of its surface at the radially inner end of said blades converging relative to the other said wall establishing for each said passage rearward decreasing cross-sectional areas and radial depths thereof, said cross-sectional areas continuously decreasing in magnitude rearward therealong from each said inlet to a locality substantially as far rearward as said ordinate to accelerate the flow in each said passage while said flow is being turned by said blades toward the direction of rotation.

4. An axial flow subsonic compressor for operation with relative fluid velocities less than sonic relative to the blades thereof comprising in combination a case, a rotor mounted in said case for rotation about an axis defining an annular flow channel therewith and a plurality of axial flow blades carried on said hub spaced peripherally thereabout and extending spanwise radially across said channel, said blades defining a plurality of axial flow passages therebetween each having an inlet and an exit respectively at the front and rear sides of said rotor, said case and said hub bounding said passages and defining the general lengthwise direction thereof, each said blade having a curved mean camber line presenting the concave side thereof toward the direction of rotation with

the maximum curvature thereof in the forward half thereof positioning the mean camber line maximum ordinate above its subtending chord substantially forward of the mid point of said chord to turn the flow in each said passage chiefly in the forward half thereof toward the direction of rotation, one of said walls defining a portion of its surface at the radially inner end of said blades converging relative to the other said wall establishing for each said passage rearwardly decreasing cross-sectional areas and radial depths thereof, said cross-sectional areas continuously decreasing in magnitude rearward therealong from each said inlet to a locality substantially as far rearward as said ordinate to accelerate the flow in the forward portion of each said passage while said flow is being turned by the forward portions of said blades toward the direction of rotation, said blades being closely spaced with the normal projection of the leading edge of each following blade on an adjacent leading said blade being forward of the mid-chord point of said leading blade so that said passages have converging portions forward of said mid-chord point.

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