

Jan. 9, 1934.

F. LJUNGSTRÖM

1,942,608

TURBINE

Filed Sept. 8, 1931

6 Sheets-Sheet 1

Fig. 1.

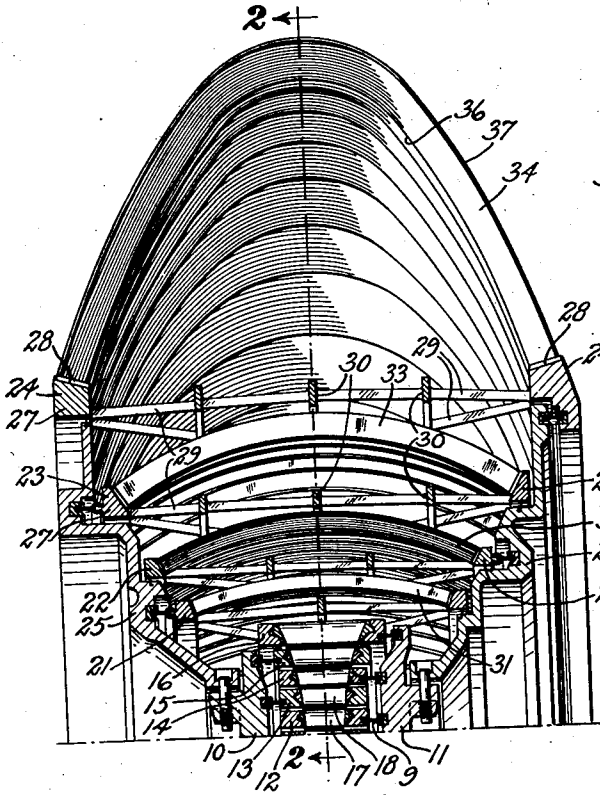


Fig. 2.

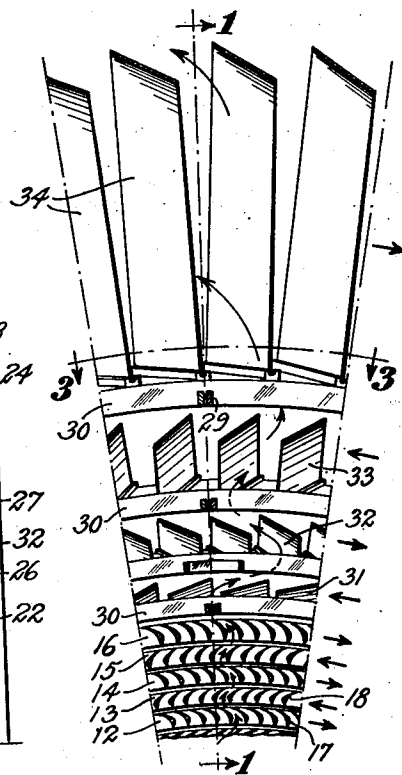


Fig. 3.

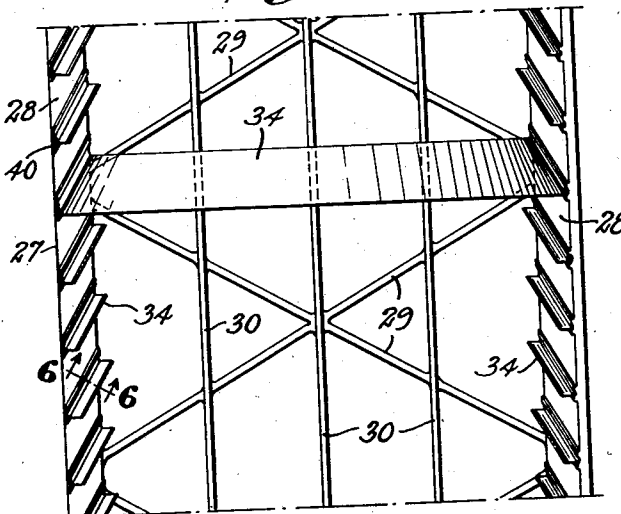
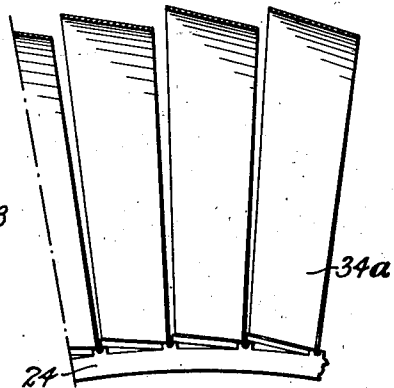


Fig. 4.



INVENTOR
Fredrik Ljungström
BY
J. J. Hedlund
his ATTORNEY

Jan. 9, 1934.

F. LJUNGSTRÖM

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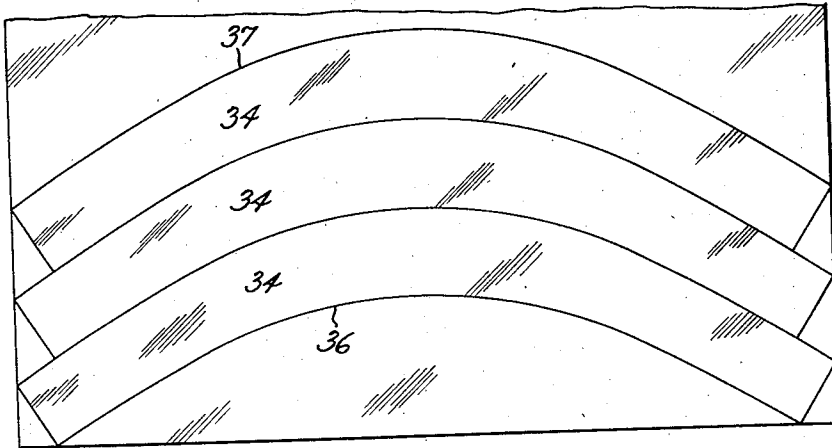


Fig. 5.

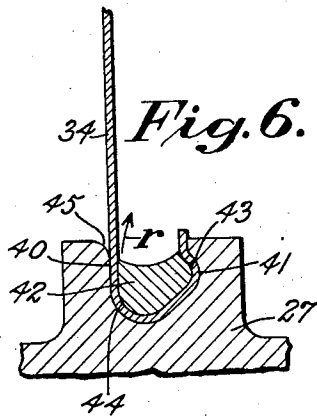


Fig. 6.

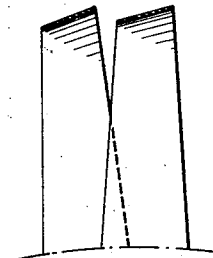


Fig. 7a.

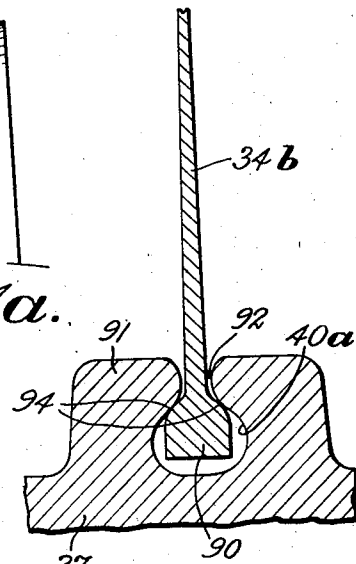


Fig. 7.

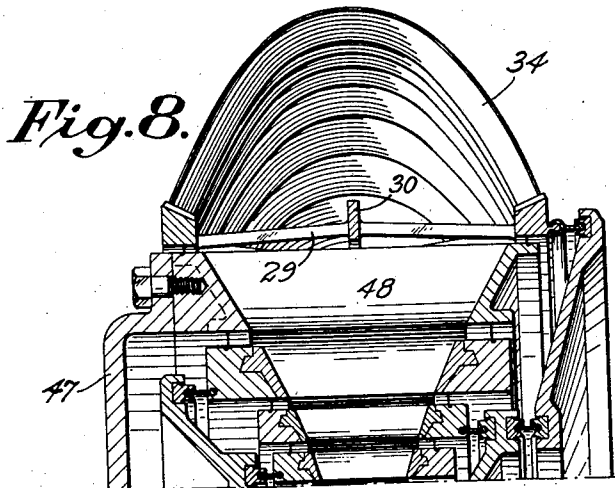


Fig. 8.

INVENTOR
Fredrik Ljungström
BY *H. J. Hedlund*
his ATTORNEY

Jan. 9, 1934.

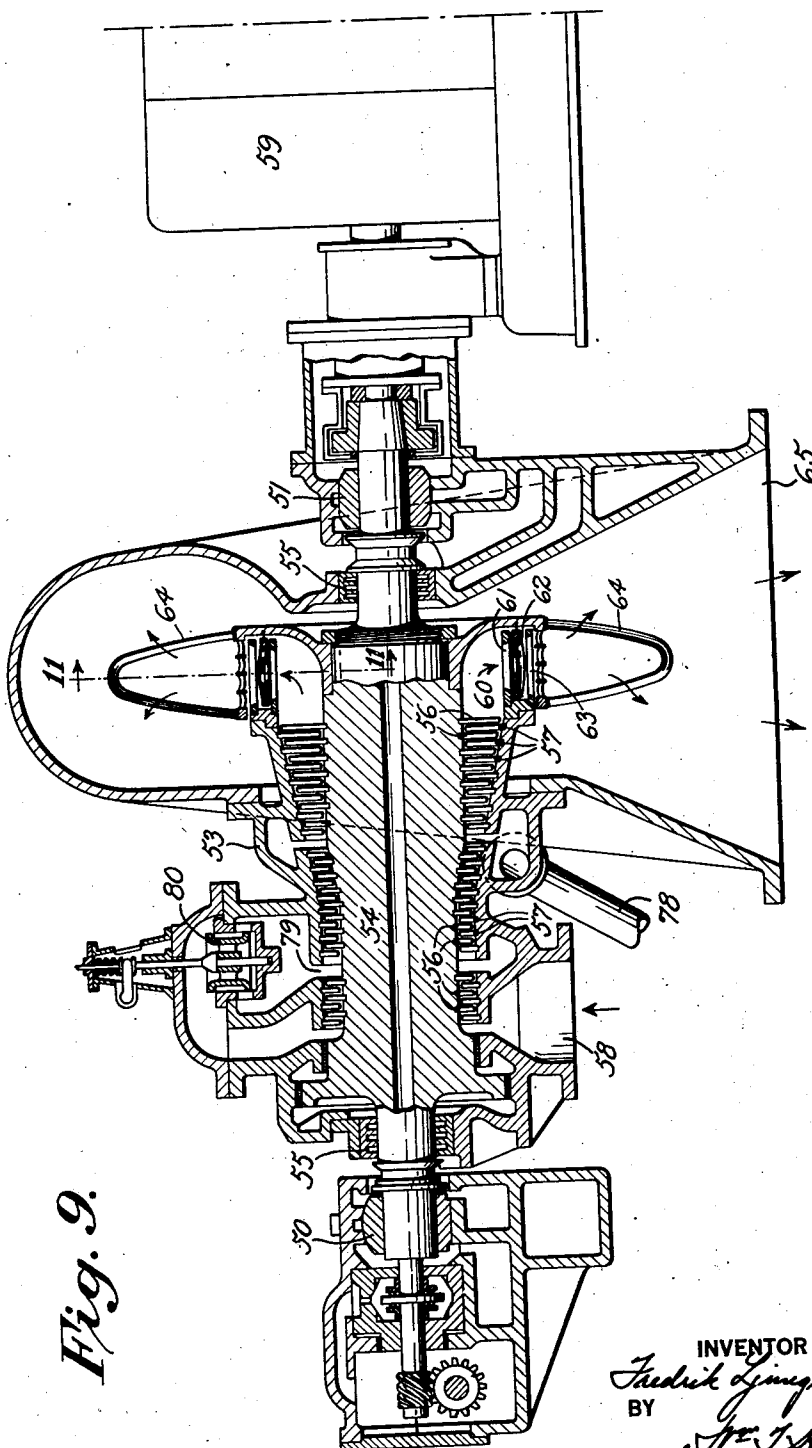
F. LJUNGSTRÖM

1,942,608

TURBINE

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INVENTOR
Fredrik Ljungström
BY
W. F. Halland
ATTORNEY

Jan. 9, 1934.

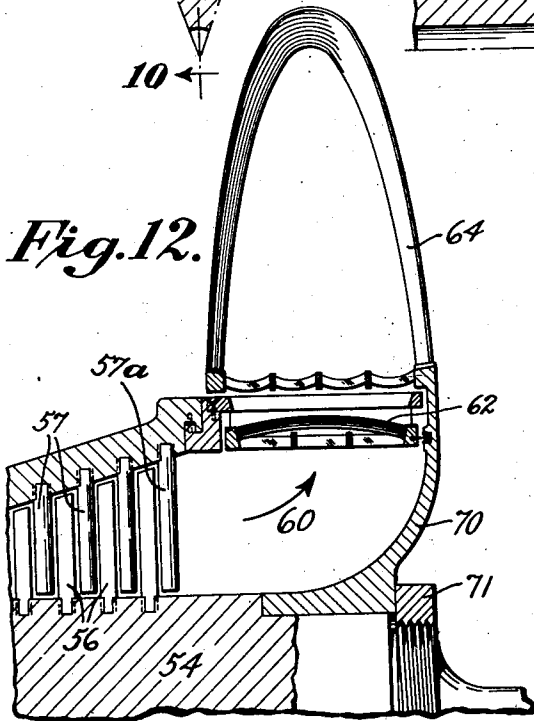
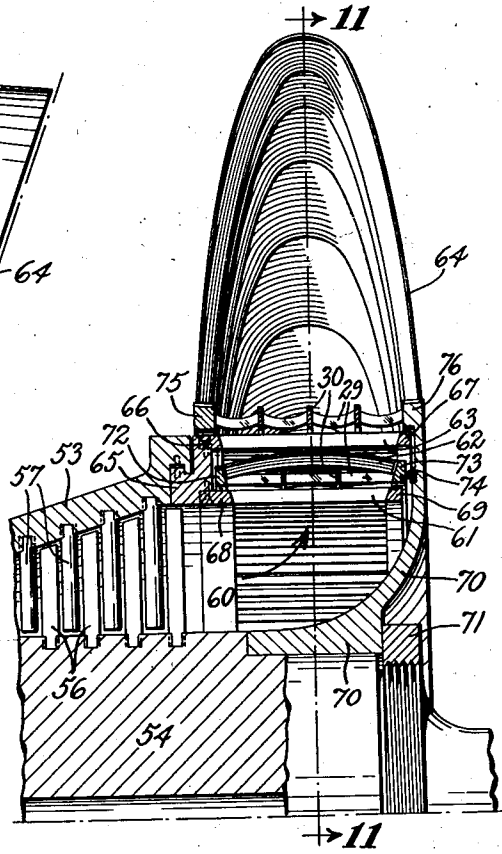
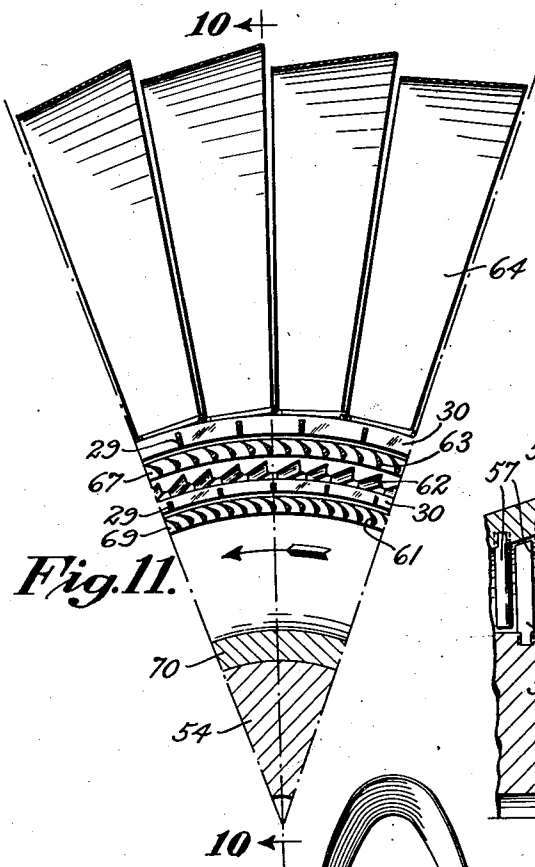
F. LJUNGSTRÖM

1,942,608

TURBINE

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6 Sheets-Sheet 4



INVENTOR
Fredrik Ljungström
BY
John J. Westlund
his ATTORNEY

Jan. 9, 1934.

F. LJUNGSTRÖM

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TURBINE

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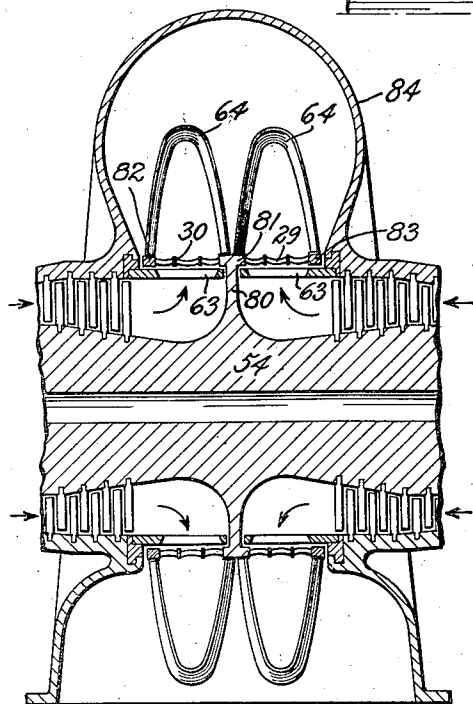
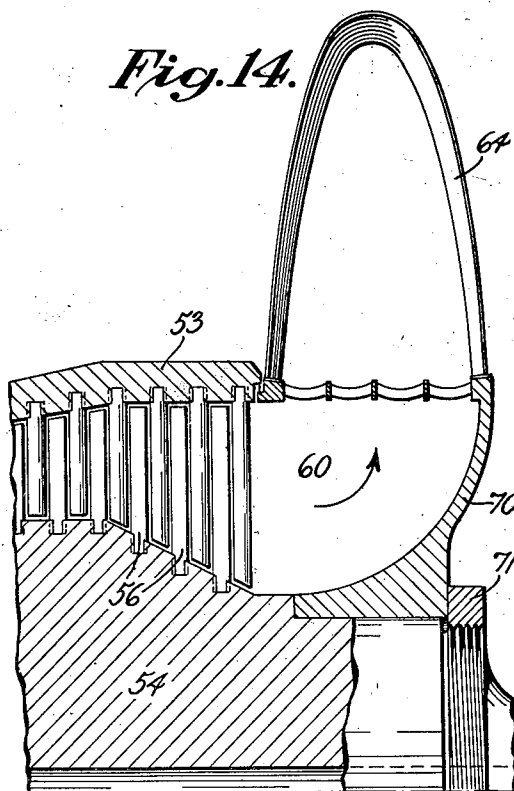
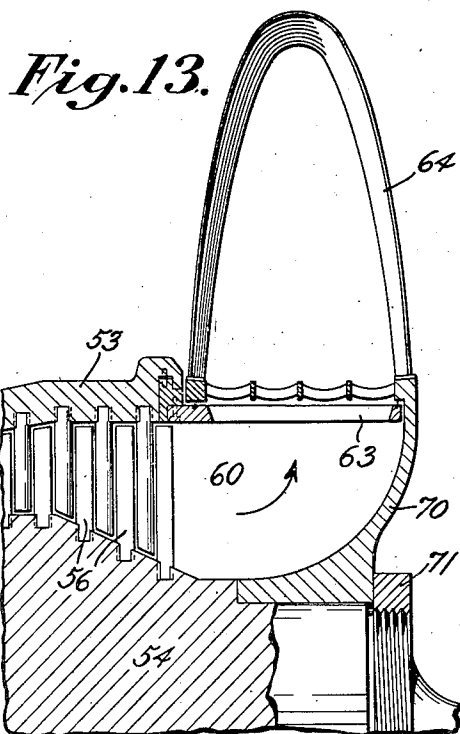


Fig. 15.

INVENTOR
Fredrik Ljungström
BY
H. J. Skellern
ATTORNEY

Jan. 9, 1934.

F. LJUNGSTRÖM

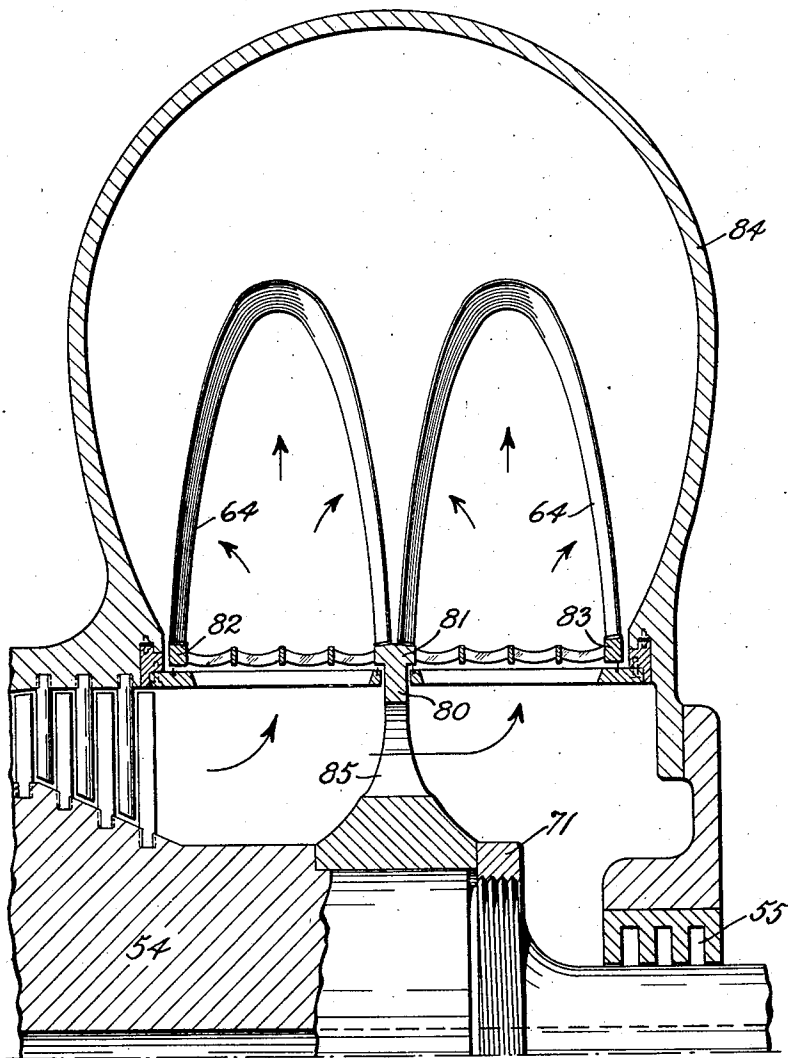
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TURBINE

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Fig. 16.



INVENTOR
Fredrik Ljungström
BY
H. J. Hedlund
his ATTORNEY

UNITED STATES PATENT OFFICE

1,942,608

TURBINE

Fredrik Ljungström, Brevik, Lindingo, Sweden,
 assignor to Aktiebolaget Spontan, Stockholm,
 Sweden, a corporation of Sweden

Application September 8, 1931, Serial No. 561,565,
 and in Germany September 15, 1930

46 Claims. (Cl. 253—16.5)

In the design of turbines, the designer has, as given predetermined factors, certain conditions of the steam or other expansible motive fluid. Such factors are, for example, the initial pressure and temperature of the steam and the final pressure, which may be a vacuum, and the power output. These factors taken together, will, in general, determine the quantity of steam. Steam will theoretically expand according to inherent characteristics or laws of thermodynamics. Having selected the general thermodynamic conditions under which the steam is to act (adiabatic expansion, impulse, reaction, etc.), the designer's task is to adapt the design to the most efficient utilization of the steam. But he has not been entirely free in this respect because of limitations of structural nature, principally in limits of stress and strain of materials. Generally speaking, these limitations have prohibited the best utilization of steam expansion, and a compromise has resulted between the most efficient expansion path for the steam and structural requirements. This situation is usually expressed by the statement that due to structural limitations it is impossible to construct the last or later stages of a turbine to most efficiently utilize the steam, a statement which is obviously based on a predetermined selection of size and other characteristics.

The limiting factors involve centrifugal stresses and stresses due to vibration both in later stage wheels or bond rings and blades attached thereto. These factors have been considered as necessary evils and various mechanical expedients have been devised to offset them. My invention aims to utilize these structural factors as assisting factors, rather than opposing factors, in adapting the path of steam flow to steam conditions. In the preferred form of my invention, I utilize centrifugal force to determine the shape and contour of some of the blades.

In my Patent No. 1,897,172, granted Feb. 14, 1933 on my copending application filed August 16, 1929, I have disclosed a turbine having outwardly curved low pressure blades designed to permit increased flow area with relatively small stresses in the blades and in the blade carrying parts. In the structure therein disclosed, blades of substantially uniform cross-section are used which are curved between the points of attachment in such manner that, when the blades are rotated in operation, only or substantially only tension (or compression) stresses exist in the blades. The blades therein are of a cross-section of the general character used in turbines; that is,

the blades are thicker in the middle than at the inlet or outlet edges. In designing blading in accordance with the disclosure of my aforesaid copending application, the proper curvature is first calculated, which can be readily done from knowledge of the various factors, and then the blades are formed to conform to such curvature so that when the turbine is rotated at the intended speed, the blades will be stressed only longitudinally, as in a freely suspended rope, forming what is known as a catenary curve. In my aforesaid application, however, the blades are designed as rigid blades.

The present invention constitutes an improvement over what is shown in my aforesaid application, the major feature of the present invention consisting in the provision of light blades of flexible material such that of themselves they do not have the requisite rigidity for reacting against the steam. The blades are supported at axially spaced points and are longer than the distance between the points of attachment. In operation they are given their shape due to centrifugal force. Thus, I employ the basic principle of the aforesaid application whereby a long blade is obtained while stresses in the retaining members are kept at a minimum, the retaining members being at a considerable distance radially inward of the outward portions of the blades, and I provide blades which are of very light construction and which are preferably made of thin sheet metal, which blades, although of themselves flexible and bendable in natural state, form rigidly acting blades when rotated in the turbine.

As a subsidiary feature of the invention, I provide novel means for securing blades in retaining members, wheels or bond rings.

Another feature of my invention is a combined axial flow and radial flow turbine of very high efficiency and very small weight per unit power output.

My invention will be further explained by reference to the accompanying drawings forming a part of this specification, with respect to which:

Fig. 1 is an axial sectional view of a turbine of the radial flow type embodying the invention, and is taken on the line 1—1 of Fig. 2;

Fig. 2 is a transverse view normal to the axis of rotation of the same turbine, and is taken on the line 2—2 of Fig. 1;

Fig. 3 is a developed peripheral view taken on the line 3—3 of Fig. 2 showing one blade in full.

Fig. 4 is a view similar to Fig. 2 of a modified form of blade;

Fig. 5 shows how blades in accordance with the invention can be cut from a sheet of material;

Fig. 6 shows one novel means in accordance with the invention for securing the flexible blade ends in a retaining member, and is a cross-sectional view taken on the line 6—6 of Fig. 3;

Fig. 7 shows a blade of variable thickness and another means for securing the ends of the blades;

Fig. 7a shows, diagrammatically, overlapping blading converging in width away from the axis of rotation;

Fig. 8 shows a turbine of the radial flow type having but one row of flexible blades and a row of fixed guides;

Fig. 9 is an axial cross-sectional view, somewhat diagrammatic, of a combined axial flow and radial flow turbine embodying the invention;

Fig. 10 is an enlarged view of the lower pressure stages of the turbine shown in Fig. 9;

Fig. 11 is a transverse sectional view taken on the line 11—11 of Fig. 9;

Figs. 12, 13 and 14 are views similar to Fig. 10, but more diagrammatic, of modified constructions;

Fig. 15 shows, more or less diagrammatically, a combined axial flow and radial flow turbine embodying the invention and having paths of flow directed toward each other from separate inlets to a common outlet; and

Fig. 16 shows, more or less diagrammatically, a combined axial flow and radial flow turbine embodying the invention having two rows of last stage blades through which steam passes in parallel.

Referring more particularly to the embodiment shown in Figs. 1, 2, 3, 5 and 6, reference characters 10 and 11 designate oppositely rotating coaxially mounted wheels or discs of a radial flow turbine. Annular rotors 12, 13, 14, 15 and 16 are alternately supported by and rotate with discs 10 and 11 by means of expansion rings 9. Rotors 12 to 16 each comprise two blade retaining rings between which the blades extend and into which the blades are secured. The blades 17 carried by member 12 are disposed as shown in Fig. 2 so that member 12 rotates as indicated by the arrow at the right of Fig. 2. The blades 18 of the next radially outward rotor are oppositely curved so that rotation is in the opposite direction as indicated by the arrow at the right of Fig. 2. Thus, alternate rotors rotate together in one direction and the intermediate alternate rotors rotate in the opposite direction. The blades carried by members 12 to 16 are straight, rigid blades as shown in Fig. 1, having cross-sections as shown in Fig. 2. This represents known turbine construction and may be used for the earlier stages of a turbine embodying my invention.

Rotors 21, 22, 23 and 24 include blades embodying the present invention. Rotors 21 and 23 are connected by expansion rings to a member 25 connected to disc 10 to rotate therewith. Rotors 22 and 24 are connected by expansion rings to a member 26 connected to disc 11 to rotate therewith. Thus rotors 22 and 24 rotate in opposite direction to rotors 21 and 23. Each of these rotors 21, 22, 23 and 24 comprises two substantially similar blade retaining members or rings 27 having outer surfaces 28 oblique to the axis of rotation. Stays 29 extend obliquely between the blade retaining rings 27 and are secured thereto as by welding. (See Fig. 3.) Stays 29 are preferably

welded to or integrally formed with peripheral reinforcing strips or bands 30, thereby forming an axially extending stiffening web structure between the blade retaining rings of each rotor carrying the curved blades, that is, the blades bent outwardly in accordance with the invention, and maintaining the retaining rings a fixed distance apart. The blades of rotor 21 are numbered 31; the blades of rotor 22 are numbered 32; the blades of rotor 23 are numbered 33; and the blades of rotor 24 are numbered 34. I will describe the blades 34 in detail and it will be understood that the blades 31, 32 and 33 are similar to blades 34 but of less outward curvature, the lengths of the blades being selected to give the correct width of path of flow of steam for the respective stages.

The blades 34 are made of thin strips of sheet material, preferably stainless steel. Fig. 5 shows how these blades may be cut from a sheet of steel. The theory underlying the form of these blades is that of the catenary. The catenary curve is that curve assumed by a flexible rope or the like freely suspended between to points of attachment and of longer length than the straight line distance between the points of attachment. This curve is such that the suspended member is subjected only to longitudinal stresses; that is, no bending stresses. When the blades 34 assume their shape in the turbine, they are under the influence of centrifugal force and therefore I term the curve assumed by these blades a centrifugal catenary. The developed shape of the sheet material to give a suitable curve as shown in Fig. 1 when the blades are in the turbine, can be readily computed for any desired structure and set of operating conditions. It will be seen that both the inlet edges 36 and the outlet edges 37 are curved outwardly between the points of attachment. The blades are preferably so cut from the sheet material and so held in the retaining members that each inlet and outlet edge lies in a single plane. These planes may be parallel as shown in Fig. 2; or they may diverge from the axis of rotation as a center, as shown at 34a in Fig. 4; or they may converge away from the axis of rotation, in which last case they may overlap at the points of attachment as shown in Fig. 7a. When formed and mounted, all the surface lines of the blades in axial planes are curved and all the surface lines in radial planes are substantially straight. Blades according to the invention, if removed from the turbine should return to or toward or be readily bent to their original flat shape.

With the present invention the blades can be designed to give any desired cross-sectional area of flow therebetween with the best selected angles to suit the steam expansion. At the same time, the retaining members are relatively near the center of rotation and the stresses in these members are kept at a minimum. The stresses in the blades themselves are best suited to the structure, and blading of minimum thickness can be utilized.

Fig. 3 shows the oblique grooves 40 in the blade retaining members into which the ends of the blades are fitted. It will be seen that the grooves are of opposite angular relationship with respect to the axis of rotation. Fig. 6 shows one method of retaining the blades in the grooves. The grooves 40 are undercut to form a fulcrum or pivot recess at 41. The ends of the blades are bent over or curved to fit the grooves. After the end of the blade is placed in the groove, a key or wedge 42

discs. The turbine is shown as coupled to and driving an electric generator 59, though it will be understood that it may drive any type of rotatable power consumer.

After the steam passes through the axial blade system, it enters a space 60 and thence flows radially through guides 61, blades 62, guides 63 and blades 64. After leaving blades 64, the steam passes out at 65 to the condenser. The guides 61 and 63 and the blades 62 and 64 constitute what I term a radial blade system. These parts are shown more in detail in Figs. 10 and 11.

Secured to the main part of the casing 53 is an annular member 65 which carries two axially spaced rings 66 and 67 into which are set the guides 63. The cross-sectional character of these guides is shown in Fig. 11. Rings 68 and 69 and guides 61 set therein are also fixed to ring 65. It will be seen that rings 67 and 69 are supported only through guides 63 and 61 respectively.

Mounted on the rotor 54 is a member 70 which is secured thereto by a clamping ring 71 screwed onto the rotor and which may be keyed onto the rotor. Member 70 may be termed a rotor flange and extends radially outward beyond ring 67. Blades 62 are secured in retaining rings 72 and 73 and ring 73 is secured to flange member 70 by an expansion ring 74. Blades 64 are secured in rings 75 and 76 of which ring 76 may be integral with flange member 70. Stay members 29—30 connect rings 72 and 73. Similar stay members connect rings 75 and 76.

After the steam has passed through the axial blade system in known manner, it passes radially through the stationary guide member composed of the rings 68 and 69 and the guides 61 connecting the same. The steam then passes through the radial flow rotor comprising the retaining rings 72 and 73, the outwardly curved flexible blades 62 connected thereto and the stay members 29—30 connecting the rings 72 and 73. The steam then passes through another stationary guide member comprising rings 66 and 67 and the connected guides 63. The steam then passes through the last radial flow rotor made up of the rings 75 and 76, the intermediate connected structure 29—30, and the blades 64 connected thereto. The blades 63 and 64 are in all essential respects similar to the blades 33 and 34 respectively of Fig. 1. The blades may be secured to the retaining members in the manner shown in Fig. 6 or Fig. 7.

Fig. 9 clearly shows how the invention provides a large blade area at an outward radial point while the same is supported by carrying members which are radially much nearer the axis of rotation. In effect, the steam, before it passes to the condenser, passes between a series of bands thrown or held outwardly a considerable distance, much as a child's jump rope, the bands being made of flat strips of steel and having shorter front edges than rear edges.

It will also be evident from Fig. 9 that an axial turbine of known construction can be converted to embody the invention and thereby increase its capacity to a very great extent. With many axial turbines it would be a simple expedient to remove some of the later axial flow stages and add a flange member 70 and provide radial blading in accordance with the invention. The possibilities of the invention in providing extremely long blades without intermediate support are clearly shown in Fig. 9.

The turbine may be equipped with various aux-

iliaries such as a bleed line 78 for extracting steam between stages. The extraction of steam is much more adaptable to an axial flow turbine than a radial flow turbine, and the adaptability of the invention to an axial flow turbine facilitates bleeding. The turbine may also be equipped as shown in Fig. 9 with intermediate stage admission, for example, through a passage 79 controlled by a valve 80.

The arrangement shown in Fig. 12 differs from that shown in Fig. 10 only in that instead of using axially extending guides 61, the axial flow system is provided with a last row of radial guides 57a. Thus the steam enters chamber 60 from between stationary guides and passes directly to blades 62. It will be obvious that the guides 57a may be placed at various positions between the last movable blades of the axial blade system and the first movable blades of the radial blade system.

In Fig. 13 the radial flow system includes one row of blades 64. Ahead of this row is an axially disposed set of guides 63. In this case, as in Fig. 10, the last steam directing members of the axial system are rotatable blades. Fig. 14 differs from Fig. 13 only in that the guides ahead of the single row of blades 64 are in the axial flow system, extending radially inwardly from the casing 53.

Comparison of Figs. 9 to 14 will show that a standard turbine rotor and casing can be designed and by relatively simple changes in structure and relation of parts of the axial flow system to the radial flow system, a great variation in capacities can be obtained. Thus the invention aids in the standardization of manufacture and cheapening of manufacture of turbines in general. Steam may be bled from chamber 60 and it will be understood that the pressure in this chamber will vary depending on the selection of arrangements shown in Figs. 9 to 14.

Fig. 15 shows an embodiment of the invention in which there are two axial blade systems and two radial blade systems in parallel. The rotor has an intermediate flange 80 which carries two sets of blades 64. The outer portion 81 is an intermediate member of a cylindrical rotary web structure including also rings 82 and 83 and the intermediate stay structure 29—30. One group of blades is secured to ring 82 and flange 80 and the other group is secured to ring 83 and flange 80. Steam flows from separate inlets through the axial blade systems and in parallel through radial blade systems, the paths joining at the exits of the blades 64 in the casing 84.

Fig. 16 shows a single axial blade system with two radial blade systems in parallel. In this form, holes 85 are provided in flange 80 and the flow is in the direction indicated by the arrows.

While I have shown and described a variety of forms of embodiment of my invention, it will be understood that many other embodiments are possible within the spirit and scope of the invention.

What I claim is:

1. In a turbine, axially spaced rotatable blade retaining members, a blade consisting of a relatively thin flexible strip of material secured to said members, and means providing a radial flow of fluid to said blade.

2. In a turbine, axially spaced rotatable blade retaining members, a blade of structurally flexible formation secured to said members and adapted to change its form under the influence of centrifugal force, and means providing a radial flow of fluid to said blade.

is inserted to fill the inner space of the bent over portion to such an extent as to bend the blade into the undercut recess 41. Centrifugal force tends to pull the blade 34 out of the groove. This tends to rotate the key 42 as indicated by the arrow r about the pivot point 43 in the recess 41. This causes the key 42 to wedge the blade since the distance from the pivot point 43 to the opposite side of the groove decreases from the point 44 upwardly. Centrifugal force therefore acts to wedge the key and the blade into the groove 40. The greater the centrifugal force, the greater is the wedging action. Preferably the material from which the key 42 is made is of softer metal than the blade itself in order to prevent the key from scoring or otherwise injuring the blade. It is also preferable to somewhat round the edge of the groove 40 at 45 adjacent the main portion of the blade which is under stress due to centrifugal force to allow the blade to freely assume its natural contour given to it by centrifugal force due to rotation.

Fig. 7 shows another mode of securing the blade ends. In this form, the ends of the blades are enlarged at 90 and the grooves 40a are spread inwardly of the groove ridges 91. The upset or enlarged ends 90 are wider than the groove entrance spaces 92 so that the wide ends 90 contact the retaining rings 27 under the facing ledges forming the narrow spaces 92. The enlarged ends 90 of the blades may be introduced into the grooves 40a lengthwise of the grooves or in any other suitable way, and when originally made, the parts are preferably such that there is only line contact at 94. When centrifugal force comes into play, the material of the blades or the retaining members or both will yield at the lines of contact 94 and deformation will take place resulting in surface contact. This deformation continues until the contact surfaces have become enlarged to such an extent that they are able to sustain the tension in the blades. In this deformation, the contacting material is, of course, stretched beyond the yield point. By this means the contact can adjust itself to best suit the structure and the material will give so that there is an advantageous distribution of force transmission.

The blade 34b shown in Fig. 7 is thick at the point of attachment and tapers to a minimum thickness at the most radially outward point. This gives a minimum amount of material for the blade since the stress can, in such case, be uniformly distributed. The sheet metal can be rolled to give this variation of thickness. An equivalent effect to the tapering may be obtained by the converging blades as shown in Fig. 7a. It will be understood that both the thickness and the width may be varied. It will also be understood that any of various fastening means may be used with any of various kinds of blading.

It is even conceivable that the blades may be of such soft material as to be entirely limp when the turbine is not operating. Blades of this nature might, for example, be made of fabric or leather or other material depending upon the kind of expansible fluid, the size of the turbine, the speed, etc. For steam turbines of any appreciable size, however, I prefer to use blades made of stainless steel or other hard material which will not be cut, rusted or otherwise affected by the fluid. The less the specific weight of the blade material, the less is the stress on the retaining members. A very light material which might

be used is a reinforced phenol condensation product.

By means of the present invention, blades of such light weight can be used that the retaining rings may be made of such large diameter relative to the number of revolutions per minute that the retaining rings can be allowed to have internal stress due to their own weight approaching the maximum allowable internal stress. Consequently, very high peripheral speed is possible permitting the most favorable relation between peripheral velocity of blade rings and the velocity of steam flowing between the blades. The velocity of the steam between the blades need therefore be only slightly in excess of the peripheral speed of one rotor relative to the next rotor.

The shape acquired by a blade, embodying the present invention, when it is rotating, is determined, at any point along the length of the blade, by the centrifugal force and the distribution of weight longitudinally of the blade. The centrifugal force is so great that there is substantially no deviation of blade form from the natural centrifugal catenary curve due to steam pressure. Furthermore, blades constructed in accordance with the invention are less liable to excessive vibrations than radial blades supported at one end, and the retaining members are correspondingly relieved of the adverse influence of blade vibrations, a factor which is of great importance in turbines of large capacity. The width and edges can be so selected as to give the desired blade angles.

As an analogy, it may be said that the present invention applies the principle of suspension bridge suspension to turbine construction whereby the blades span over considerably longer distances between carrying rings than has hitherto been possible. It is well recognized in the design of suspension bridges that it is of utmost importance that the suspended cables be of light and strong material to allow for suspension over long distances and that the end supports for the suspended cables and the whole structure increase rapidly in weight and space if heavier cables are used. Consequently the blades according to this invention should be made of as small cross-sectional area as possible.

The embodiment shown in Fig. 8 does not differ from the previously described embodiments so far as concerns the last stage. In this case, however, only the last stage includes flexible blades. This turbine has an annulus of stationary guides 48 carried by a stationary web 47 ahead of the rotatable curved blades 34.

Fig. 9 and related figures show the invention applied to a turbine having initial axial flow stages and terminal radial flow stages. The turbine rotor 54 is mounted in bearings 50 and 51. A stationary casing 53 surrounds the rotor 54. The usual packing 55 is provided where the rotor passes through the casing. The rotor 54 carries rows of radially projecting blades 56 of known form between which are rows of stationary guides 57 fixed in and projecting inwardly from the casing 53. Steam is admitted at 58 and passes between the blades and guides causing rotation of the rotor. The flow of steam past the blades 56 and guides 57 is in a generally axial direction and in well known axial flow manner. The blades 56 and guides 57 may be termed an axial flow blade system. One or more stages may be of the impulse type. Various forms of structure may be used. For instance, the blades and guides may be set into separate blade wheels and guide

3. In a turbine, axially spaced rotatable blade retaining members, a blade composed of a relatively thin flexible strip of steel having its ends secured to said members and adapted to modify its form under the influence of centrifugal force, and means providing a radial flow of fluid to said blade.
4. In a turbine, axially spaced rotatable blade retaining members, a structurally flexible blade which is designed to be flexed by a centrifugal force and which is secured to said members, all surface lines on said blade extending between said retaining members being curved, and means providing a radial flow of fluid to said blade.
5. In a turbine, axially spaced rotatable blade retaining members, a structurally flexible blade which is designed to be flexed by centrifugal force and which is secured to said members, all surface lines on said blade in radial planes being substantially straight, and means providing a radial flow of fluid to said blade.
6. In a turbine, axially spaced rotatable blade retaining members, a blade which is designed to be flexed by centrifugal force and which is secured to said members, all surface lines on said blade extending between said retaining means being curved and all surface lines in radial planes being substantially straight, and means providing a radial flow of fluid to said blade.
7. In a turbine, axially spaced blade retaining members, a blade consisting of a flexible strip of material secured at its ends to said members, said strip between said ends being longer than the axial distance between the retaining members and assuming its operating shape due to centrifugal force, and means providing a radial flow of fluid to said blade.
8. In a turbine, axially spaced blade retaining members, a blade consisting of a flexible strip of material secured to said members and shaped by centrifugal force, said strip having inlet and outlet edges both longer than the axial distance between the retaining members, the inlet edge being shorter than the outlet edge, and means providing a radial flow of fluid to said blade.
9. In a turbine, axially disposed blade retaining members, a flexible strip-like blade attached at its ends to said retaining members and flexing to act as a rigid blade in operation due to centrifugal force, and means providing a radial flow of fluid to said blade.
10. In a turbine, axially disposed blade retaining members, a flexible strip-like blade attached at its ends to said retaining members curved and flexed to the form of a centrifugal catenary on rotation, and means providing a radial flow of fluid to said blade.
11. A turbine comprising a pair of rotatable members having grooves therein, a longitudinally curved blade comprising a flexible strip having its ends in the grooves of said members, and flexed by centrifugal force, means to retain said blade ends in said grooves, and means providing a radial flow of fluid to said blade.
12. A turbine comprising axially spaced rotatable members having grooves therein, a longitudinally curved blade comprising a flexible strip having its ends in the grooves of said members flexed by centrifugal force, means for wedging said blade ends in said grooves under the influence of centrifugal force, and means providing a radial flow of fluid to said blade.
13. A turbine comprising a rotatable member having grooves therein, a blade of flexible strip-like material having each end bent out of the plane of said strip and disposed in said grooves, and means within each bend of the blade for retaining the blade in the groove.
14. A turbine comprising a rotatable member having grooves therein, a blade of flexible strip-like material having each end bent out of the plane of said strip and disposed in said grooves, and a key in each bend for wedging the blade in the groove, said key causing an increased wedging action on increase of centrifugal force.
15. A turbine comprising a rotor, axially disposed retaining rings carried by said rotor, each ring having a series of transverse grooves therein oblique to both its periphery and its axis of rotation and the grooves in one ring being of opposite angular relationship to the grooves of the other ring, and structurally flexible blades having one end fastened in a groove of one ring and the other end fastened in a groove of the other ring, and means providing a radial flow of fluid to said blades.
16. A turbine comprising a rotor, axially disposed retaining rings carried by said rotor, each ring having a series of transverse grooves therein oblique to both its periphery and its axis of rotation and the grooves in one ring being of opposite angular relationship to the grooves of the other ring, structurally flexible, longitudinally curved blades adapted to change their form under the influence of centrifugal force spanning the rings and having their ends fastened in said grooves, and means providing a radial flow of fluid to said blades.
17. A turbine comprising a rotor, axially disposed retaining rings carried by said rotor, each ring having a series of transverse grooves therein oblique to both its periphery and its axis of rotation and the grooves in one ring being of opposite angular relationship to the grooves of the other ring, longitudinally curved blades comprising relatively thin flexible strips of sheet steel spanning the rings and having their ends fastened in said grooves, and means providing a radial flow of fluid to said blades.
18. A turbine comprising a rotor, axially disposed retaining rings carried by said rotor, said rings having grooves therein oblique to both its periphery and its axis of rotation and the grooves in one ring being of opposite angular relationship to the grooves of the other ring, longitudinally curved blades comprising relatively thin flexible strips spanning said rings, retaining means for wedging the ends of the blades in the grooves under the influence of centrifugal force, and means providing a radial flow of fluid to said blades.
19. In a turbine, axially spaced rotatable blade retaining members, stay members connecting said members for maintaining said retaining members a fixed distance apart, structurally flexible blades comprising flexible strips of greater length than said fixed distance attached at one end to one of said retaining members and at the other end to another of said retaining members, and means providing a radial flow of fluid to said blades.
20. In a turbine, axially spaced rotatable blade retaining members, stay members connecting said members for maintaining said retaining members a fixed distance apart, structurally flexible blades comprising flexible strips of thin sheet steel and of greater length than said fixed distance connected at the ends to and spanning said retaining members, and means providing a radial flow of fluid to said blades.
21. In a turbine, axially spaced rotatable blade

retaining members, stay members connecting said members for maintaining said retaining members a fixed distance apart, structurally flexible blades comprising flexible strips of greater length than said fixed distance connected to and spanning

- 5 said retaining members and obtaining their operating shape due to centrifugal force, and means providing a radial flow of fluid to said blades.
- 10 22. In a turbine, axially spaced rotatable blade retaining members, stay members connecting said members for maintaining said retaining members a fixed distance apart, structurally flexible blades of sheet steel of greater length than said fixed distance connected to and spanning
- 15 said retaining members and obtaining their operating shape due to centrifugal force, the ends of the blades being connected to the retaining members obliquely to the axis of rotation and at
- 20 opposite angularity with respect to the axis of rotation, and means providing a radial flow of fluid to said blades.

23. In a turbine, axially spaced rotatable blade retaining members, stay members connecting said
- 25 members for maintaining said retaining members a fixed distance apart, structurally flexible blades comprising flexible strips of sheet steel of greater length than said fixed distance spanning said retaining members and obtaining their operative shape by centrifugal force, grooves of opposite obliquity in said retaining members for receiving the ends of the blades, and retaining keys for wedging the ends of the blades in said grooves.
- 30 24. A turbine blade comprising a flexible strip of metal, said blade being structurally flexible to respond to and assume its operative shape due to centrifugal force, and means providing a radial flow of fluid to said blade.

- 35 25. A turbine blade comprising a flexible strip of metal having substantially parallel side edges, said blade being structurally flexible to respond to and assume its operative shape due to centrifugal force, and means providing a radial flow of fluid to said blade.
- 40 26. A turbine blade comprising a flexible strip of steel, said blade being structurally flexible to respond to and assume its operative shape due to centrifugal force, and means providing a radial flow of fluid to said blade.

- 45 27. A turbine comprising a rotor, a casing, a plurality of axial flow blades and guides secured to said rotor and said casing respectively, a plurality of axially spaced rings connected to said rotor, and a plurality of longitudinally curved
- 50 radial flow blades connected to said rings and constituting low pressure stages of said turbine.
- 55 28. A turbine comprising a rotor, a casing, a plurality of axial flow blades and guides secured to said rotor and said casing respectively, a plurality of axially spaced rings connected to said rotor, and a plurality of structurally flexible and longitudinally curved radial flow blades secured to and spanning said rings at the low pressure end of the turbine.

- 60 29. A turbine comprising a rotor, a casing, a plurality of axial flow blades and guides secured to said rotor and said casing respectively, a plurality of axially spaced rings connected to said rotor, and a plurality of radial flow blades of longitudinally curved and flexible strips secured to and spanning said rings.
- 65 30. A turbine comprising a rotor, a casing, a plurality of axial flow blades and guides secured to said rotor and said casing respectively, and a plurality of radial flow rotors secured to the first-
- 70

mentioned rotor, each of said radial flow rotors comprising axially spaced rings, stays between said rings and curved blades connected to said rings.

31. A turbine comprising a rotor, a casing, a plurality of axial flow blades and guides secured to said rotor and said casing respectively, and a plurality of radial flow rotors secured to the first-mentioned rotor, each of said radial flow rotors comprising axially spaced rings, stays between said rings and flexible curved blades connected to said rings.
- 80 85

32. A turbine comprising a rotor, a casing, a plurality of axial flow blades and guides secured to said rotor and said casing respectively, and a plurality of radial flow rotors secured to the first-mentioned rotor, each of said radial flow rotors comprising axially spaced rings, stays between said rings and curved blades of sheet steel connected to said rings.
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33. A turbine comprising a rotor, a casing, a plurality of axial flow blades and guides secured to said rotor and said casing respectively, and a plurality of radial flow rotors secured to the first-mentioned rotor, each of said radial flow rotors comprising axially spaced rings, stays between said rings, curved blades connected to said rings and axially extending guides between said radial flow rotors secured to said casing.
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34. A turbine comprising a rotor, a casing, a plurality of axial flow blades and guides secured to said rotor and said casing respectively, and a plurality of radial flow rotors secured to the first-mentioned rotor, each of said radial flow rotors comprising axially spaced rings, stays between said rings, curved flexible blades connected to said rings and axially extending guides between said radial flow rotors secured to said casing.
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35. In a turbine, in combination with means providing a radial flow of fluid, a rotatable blade retaining member and a blade adapted to be flexed by centrifugal force loosely secured at each end in said retaining member.
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36. In a turbine, in combination with means providing a radial flow of fluid, axially spaced rotatable blade retaining members and a blade consisting of a flexible strip of metal loosely secured at its opposite ends to said members.
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37. In a turbine, axially spaced rotatable blade retaining members having transverse grooves therein with narrow entrance spaces, and flexible strip-like blades having enlarged heads at their opposite ends, said blades adapted to be flexed by centrifugal force and having said heads located in said grooves and contacting the sides of the grooves on surfaces determined by deformation of material due to centrifugal force.
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38. A turbine blade comprising a flexible arcuate strip of material flexed to an arcuate form and readily deformable under the action of centrifugal force, in combination with means providing a radial flow of fluid to said blade.
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39. A turbine comprising a rotor, a casing, a plurality of axial flow blades and guides secured to said rotor and said casing respectively, a plurality of radial flow rotors secured to the first mentioned rotor, each of said radial flow rotors comprising axially spaced rings, stays between said rings, and curved flexible blades connected to said rings.
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40. In a turbine, axially spaced rotatable blade retaining members, a flexible blade designed to be flexed by centrifugal action and secured to said members, and means providing a radial flow of fluid to said blades.
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41. In a turbine, axially disposed blade retaining members, and a plurality of flexible strip-like blades attached at their ends to said retaining members, said blades overlapping for a portion of their length adjacent their ends. 5
42. In a turbine, axially disposed blade retaining members, and a plurality of flexible strip-like blades attached at their ends to said retaining members, each blade overlying an adjacent blade for only that portion of its length which is near a retaining member. 10
43. In a turbine, axially disposed blade retaining members, and a plurality of flexible strip-like blades attached at their ends to said retaining members, said blades being of increasing width near said retaining members whereby said blades overlap at that portion of their length which is adjacent their attachments to said members. 15
44. In a turbine, axially disposed blade retaining members provided with transverse grooves having narrow openings and a flexible strip-like blade secured at its ends in said grooves, said blade having enlarged ends adapted to make a line contact with each opposite wall of a groove when installed and to make a surface contact with each opposite wall of a groove under the action of centrifugal force. 20
45. In a turbine, axially disposed blade retaining members provided with transverse grooves having narrow openings and a flexible strip-like blade secured at its ends in said grooves, the contacting surfaces of said blade ends and grooves being so shaped as to initially form line contacts and to deform into surface contacts under the action of the centrifugal forces acting on said blades. 25
46. In a turbine, axially disposed blade retaining members provided with transverse grooves having narrow openings and a flexible strip-like blade secured at its ends in said grooves, the contacting surfaces of each blade and the wall of its groove including at least one curved surface which makes a line contact with its opposed surface when the blade is installed but which increases its area of contact under the action of centrifugal force on the blade. 30
- FREDRIK LJUNGSTRÖM. 35
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