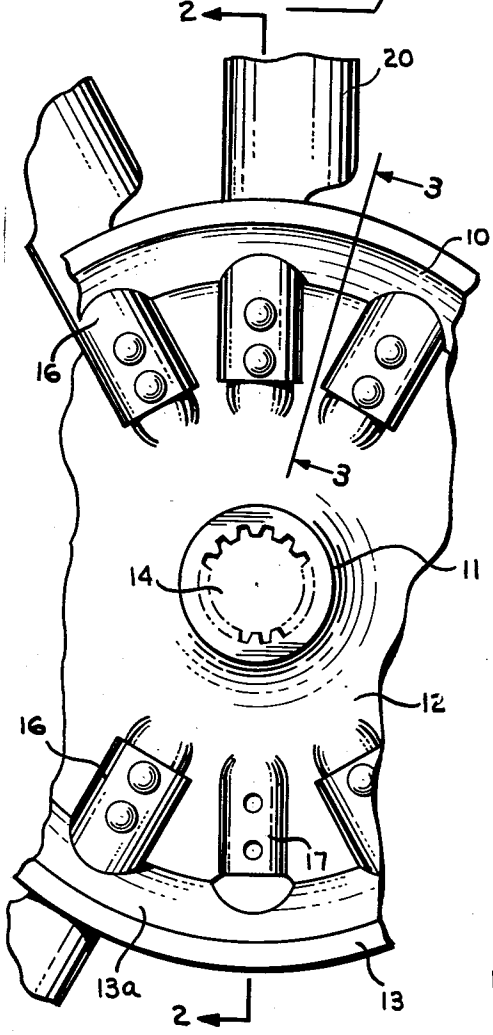
Nov. 13, 1962 C. E. MIDDLEBROOKS, JR 3,063,674

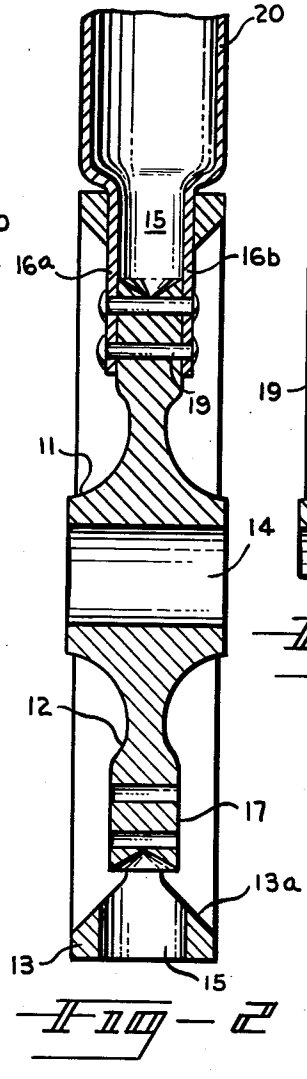
ROTOR CONSTRUCTION AND METHOD

Filed Feb. 8, 1961

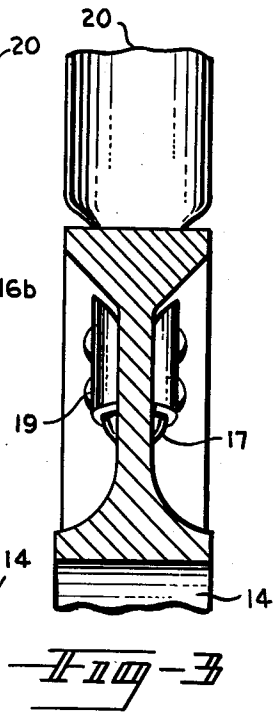
3 Sheets-Sheet 1

Fig—1

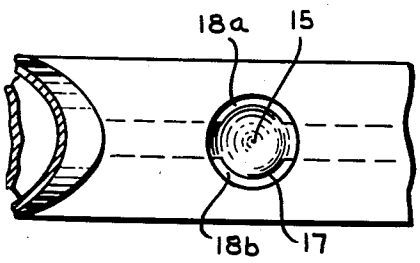




Fig—2



Fig—3



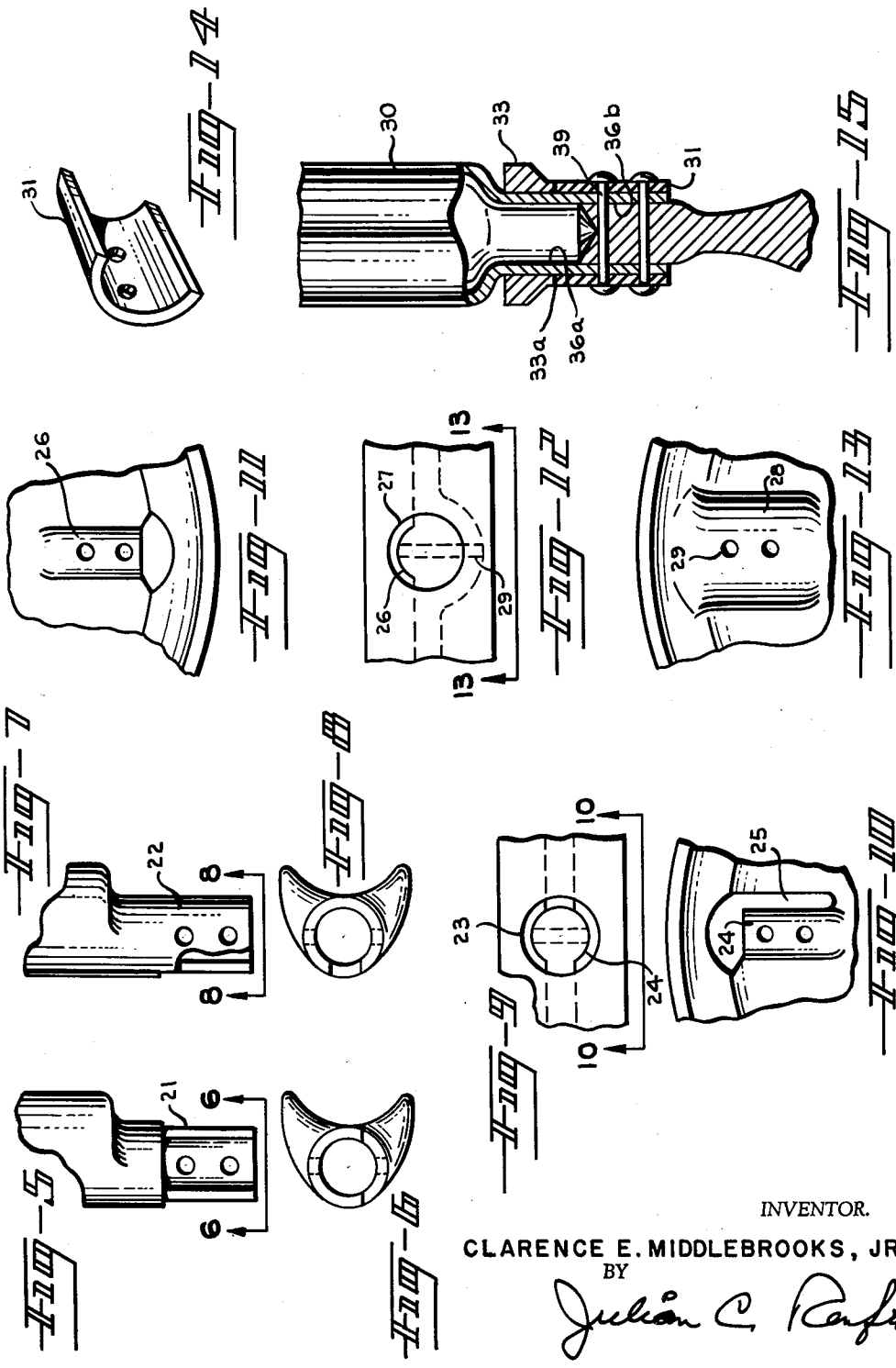
Fig—4

INVENTOR.
CLARENCE E. MIDDLEBROOKS, JR.
BY
Julian C. Renfro

Nov. 13, 1962 C. E. MIDDLEBROOKS, JR 3,063,674

ROTOR CONSTRUCTION AND METHOD

Filed Feb. 8, 1961 3 Sheets-Sheet 2



INVENTOR.

CLARENCE E. MIDDLEBROOKS, JR.

BY

Julian C. Renfro

Nov. 13, 1962 C. E. MIDDLEBROOKS, JR 3,063,674

ROTOR CONSTRUCTION AND METHOD

Filed Feb. 8, 1961

3 Sheets-Sheet 3

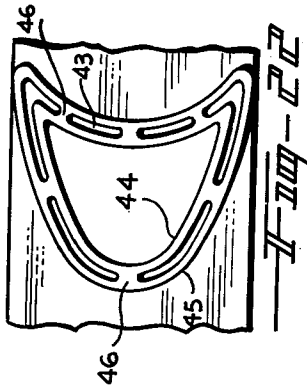


Fig-22

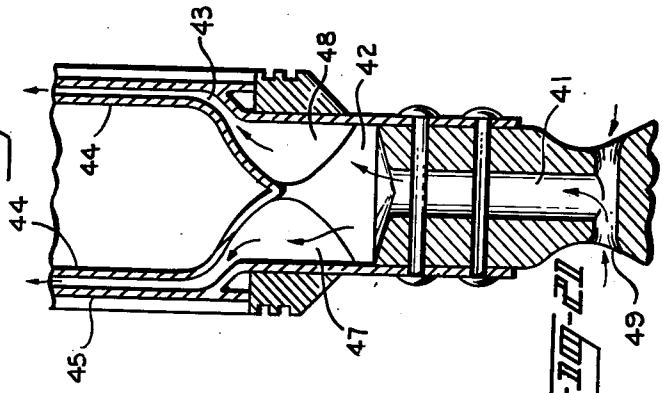


Fig-21

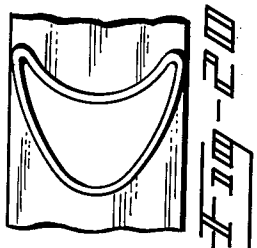


Fig-20

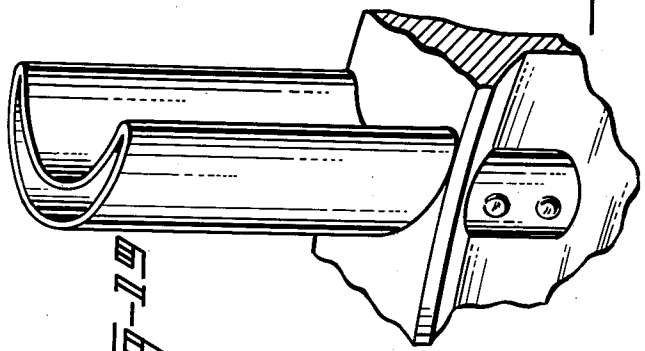


Fig-19

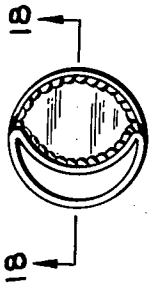


Fig-17

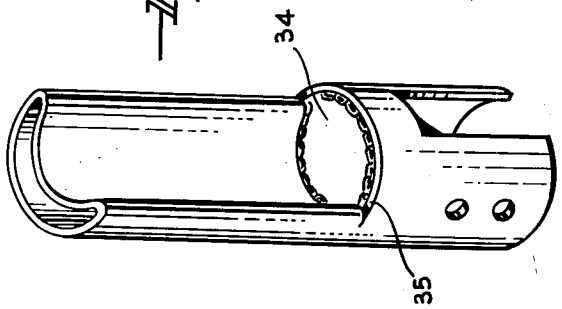


Fig-16

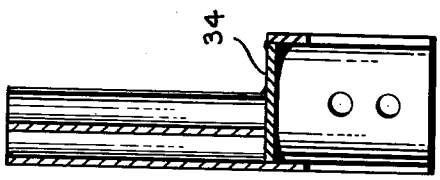


Fig-18

INVENTOR.
CLARENCE E. MIDDLEBROOKS, JR.
BY
Julian C. Renfro

United States Patent Office

3,063,674
Patented Nov. 13, 1962

3,063,674

ROTOR CONSTRUCTION AND METHOD

Clarence E. Middlebrooks, Jr., 3807 Venice Drive, Orlando, Fla.

Filed Feb. 8, 1961, Ser. No. 87,950
10 Claims. (Cl. 253—77)

This invention relates to rotors and blade structures for use in rotating machines such as turbines, compressors, torque converters and the like wherein there is an interchange of energy between fluid and blades, and more particularly to a rotor method and construction utilizing a basic one piece wheel member which can be configured by a minimum of machinery to receive a number of hollow buckets that are readily and inexpensively secured at the desired blade angle directly to the disc portion of the wheel.

In the past, turbine wheels have typically been quite expensive and have been a major deterrent to the widespread use of gas turbines in industry. A principal reason for the expense of turbine wheels is associated with the fact that the turbine buckets have presented a substantial metallurgical problem because of the high temperatures and the high centrifugal forces to which they are typically subjected in normal use. Other problems have involved the necessity of expensive forming means for the forming of buckets, and complicated heavy keyway arrangements used to secure the buckets to the rim of the wheel.

According to the present invention, I utilize lightweight buckets of tubular construction offering minimum stress levels, the tubing being formed into appropriate aerodynamic sections through use of simple and inexpensive stamping or coining techniques. These buckets may be formed with reduced diameter shanks or tangs arranged to be received in spaced holes disposed around the periphery of rim of turbine wheel and attached directly to the disc portion of the wheel with conventional fasteners. This arrangement makes removal and replacement of blades a simple matter and because the blades do not require heavy keyway arrangements taught by prior art, and a greater number of blades can be accommodated on given circumference.

The advantageous techniques taught according to this invention may utilize the turbine blades formed from simple round tubing, or the use of blades having their gas-contacting or active portions formed in an operation separate from the forming of the shank portion of the blade, the blade construction in each instance lending itself to use of orientation notches disposed in the shank portions that facilitate the proper positioning of the blades upon the wheel during assembly. The shanks are pierced by suitable holes so as to enable the blades to be secured such as by use of rivets or the like directly to the disc portion of the turbine wheel, thereby making it possible to keep concentration of the weight at the rim portion of the wheel at a minimum.

A turbine wheel according to this invention may comprise a disc portion and a rim portion, with a plurality of blades disposed about the periphery of the rim portion, each of the blades having an active surface arranged to contact a working fluid, and a tang of generally-circular cross-section. A plurality of blades are accommodated about the periphery of the wheel, with their tangs fitted in spaced, radially-disposed holes arrayed about the rim

portion of the wheel, the tangs being of sufficient length as to extend through the rim portion of the wheel, and firmly contact the disc portion of the wheel. By selectively modifying the portion of the blade tang to be fitted against the disc portion of the wheel, the desired blade angle of the buckets of the wheel can be easily and rapidly established. It is therefore to be seen that the practice of this invention makes possible the use of "universal" blades and wheels, inasmuch as standard blades can be affixed at any desired blade angle in a wheel of selected diameter, merely by properly configuring the blade tangs to meet the wheel disc.

Any of a number of mounting hole-tang arrangements can be utilized. For example, each of the spaced holes on the wheel may have at least one slot located in bottom thereof and extending through rim portion of said central wheel member, the tang of each of said buckets having at least one skirt portion configured to extend through a respective slot and thus provided orientation for each bucket of said turbine wheel. The skirt portions are in contact with the disc portion of the central wheel member, and fastening means are provided for securing the skirt or skirts of each bucket directly to the disc portion of wheel, thus obviating the need for securing means at said rim portion, and thus minimizing the weight at the periphery of said turbine wheel.

These and other objects, features, and advantages of this invention may be apparent from a study of enclosed drawings in which:

FIGURE 1 is a fragmentary plan view of a typical rotor according to this invention, in which several blades are shown in place;

FIGURE 2 is a sectional view taken along lines 2—2 in FIGURE 1 to reveal the wheel with and without blades inserted therein, and also revealing a first tang embodiment;

FIGURE 3 is a sectional view taken along lines 3—3 in FIGURE 1 to reveal rivet details;

FIGURE 4 is an edge view of a portion of the rotor of FIGURE 1 revealing the configuration of tang-receiving aperture;

FIGURE 5 is a fragmentary side view of a second embodiment of a tang arrangement of a blade;

FIGURE 6 is an end view taken along lines 6—6 in FIGURE 5;

FIGURE 7 is a fragmentary side view of a third tang embodiment;

FIGURE 8 is an end view taken along lines 8—8 in FIGURE 7;

FIGURE 9 is a fragmentary edge view of a portion of a rotor revealing the tang-receiving slot for a blade according to FIGURE 7;

FIGURE 10 is a side elevational view of a portion of the wheel, taken along lines 10—10 in FIGURE 9;

FIGURE 11 is a side elevational view of a portion of a rotor wheel employed with a blade utilizing a different tang embodiment;

FIGURE 12 is an edge view of the wheel of FIGURE 11;

FIGURE 13 is a side elevational view of a portion of the rotor wheel taken along lines 13—13 in FIGURE 12, and revealing an enlargement on the wheel to prevent a second slot being formed during drilling;

FIGURE 14 is a perspective view of a washer such as may be employed to secure a blade to the rotor wheel;

FIGURE 15 is a cross sectional view of a rotor wheel much like that shown in FIGURE 2 but revealing the manner in which the skirt portions of the blade are riveted to the wheel, as well as the washers used on each side of the wheel to place the rivets in double shear;

FIGURE 16 is a perspective view of a tubular blade weldment created by shearing, forming and welding;

FIGURE 17 is a top view of the blade shown in FIGURE 16;

FIGURE 18 is a side elevational view, in section to reveal the relation of the two major components of the blade assembly;

FIGURE 19 is a perspective view of a blade secured to a fragmentary portion of a rotor, held in place by rivets;

FIGURE 20 is a typical end view of the blade of FIGURE 19;

FIGURE 21 is a sectional view to a somewhat larger scale of an embodiment in which a double jacketed blade is used, utilizing multiple longitudinal passages disposed about the inside of the outer surfaces of the blade to allow the flow of the coolant therethrough; and

FIGURE 22 is a typical end view of the blade according to FIGURE 21.

Referring to FIGURE 1, a portion of a typical turbine wheel **10** is there shown, comprising hub portion **11**, disc or middle portion **12** and rim portion **13**. The wheel **10** may be cast or forged, and as will be understood, this wheel is adapted to be splined, keyed, or otherwise secured upon a suitable shaft extending through mounting hole **14**, thereby enabling the wheel and shaft to be attached tightly together so that each will be capable of transmitting torque to the other.

As seen in FIGURES 2 and 4, a plurality of radially disposed holes **15** are arrayed about the wheel **10**, spaced in the general manner shown in FIGURE 1. These holes are preferably formed by drilling, and each extends through the rim portion **13** and for a short distance into disc portion **12**. These holes are adapted to receive the shank or tang portion **16** of the turbine blades or buckets **20**. The blades may be formed from hollow seamless tubing such as "Iconel X" steel alloy, or alternatively may be cast, with the blade and tang portions being integral. As will be described in greater detail hereinafter, the tang portion of each blade is advantageously secured directly to the disc or middle portion of the wheel by any of several tang arrangements set forth hereinafter.

The blade shown in FIGURE 2 (and FIGURE 15) is manufactured to have a desired aerodynamic configuration for contacting a working fluid, this configuring being accomplished entirely through a forming and drawing operation, such as might be accomplished with suitable dies on a punch press, with the raw stock from which the blade is formed being thin wall tubing of round configuration.

In a first tang embodiment, the tang is slotted so as to create a pair of skirts **16***a* and **16***b*, that are received on opposite sides of the rotor wheel. These skirt portions are somewhat of arcuate cross section and are closely received upon a number of raised, peripherally spaced bosses **17**, which bosses are integral with the disc portion **12** of the wheel, and so located as to be concentric with holes **15** drilled in the rim to receive the tangs of the blades. Note FIGURES 3 and 4.

Each of the bosses **17** is of complementary arcuate configuration with respect to the skirts **16***a* and **16***b* and of a dimension so as to substantially coincide with the blade tangs used. Therefore, upon a blade tang being inserted in a mounting hole, the inner diameter of the skirt or skirts of the tang closely conforms to the respective boss and affords a firm support for the skirt portions, thereby enabling a rivet operation or the like to be performed without tending to crush the tang portion of the blade and thereby weaken it. The rivets can be upset so as to cause the tubular wall of each tang to contact its boss with great force, thereby relieving a portion of the shearing force which would normally act upon the rivet shank.

It should be noted that there must be close correlation between outer dimension of bosses **17** and diameter of the hole **15** drilled directly thereover, because it is by the circumferential juxtapositioning of the drilled hole and boss that arcuate slots **18***a* and **18***b* are formed to a sufficient width to receive the thickness of the blade tangs. As seen in FIGURE 2, the drill used to drill each hole **15** is fed to a depth so as to extend through rim **13** and actually break through to the inner portion **13***a* of the rim, in this instance forming an aperture on each side of the wheel **10**, this bringing about the formation of slots **18***a* and **18***b* mentioned heretofore. Then, upon the tang portion of the blade being inserted into the hole **15** with proper orientation, the skirts **16***a* and **16***b* can extend through arcuate slots **18***a* and **18***b* respectively and extend tightly along the appropriate boss **17**. Rivets **19** shown in FIGURES 2 and 3 are utilized to hold the blade in proper position and may be applied by standard techniques. By virtue of close fitting relationships of skirts and boss, additional restraint against radial forces is provided to counteract the tendency of the wheel to tend to fling the blades outwardly from their sockets. Furthermore, the boss increases the relative stiffness of the bucket shank, thus damping this section, and in so doing decreases the resonant, natural frequency at which a conventional bucket would normally vibrate. Shank vibrations normally force or excite vibratory flutter in the unsupported aerodynamic blade section, so the instant design tends to abate fatigue type failures which are commonly experienced with conventional blade attachments.

Although riveting is preferred, any number of fusion welding techniques may be employed to bond or attach blades to the wheel, or as another alternative, dip-brazing procedures may be employed to secure blades to the wheel, for the capillary attraction so necessary for the thorough penetration of filler material is provided by close proximity which exists between the outer diameter of boss and inner diameter of tang. If desired, the bosses **17** may be formed with serrations to increase the coefficient of friction that exists between mating tang and boss surfaces.

According to this invention, a given wheel of appropriate diameter may serve as the foundation for the creation of any of an infinitely large number of turbine or compressor wheel-blade arrangements. This is because the desired angling of the blades of a wheel can be accomplished by slotting or otherwise configuring the tang of each blade so that the skirts, in this instance skirts **16***a* and **16***b*, bear the angle to the rest of the blade as to cause a correct relationship between the working or active surfaces of the blades and the fluid stream contacted thereby. Obviously, blades according to this invention may be manufactured in large number having tangs with no slot therein, with these basic blades then being convertible into the blading having the specific angle needed for a certain turbine wheel, merely by slotting or otherwise configuring the tang so that the gas-contacting or active portion of the blades will be caused to be disposed so as to meet at the desired angle, the air, hot gas or steam with which the turbine is utilized.

As may be apparent, it may be desired under certain circumstances to make it possible to insert blades with the concave surfaces facing in one direction on the wheel, and impossible for these surfaces to face in the other direction. This may be easily provided by configuring the tang portion of the blade and the boss-and-hole arrangement of the wheel so that there is only one direction on the wheel that the curved portion of the buckets may face.

According to FIGURES 5 and 6 an embodiment is illustrated in which the tang portion of the blade is cut away or formed in such a manner as to create a single

skirt 21. In such instance each blade-mounting hole in the wheel may be equipped with only a single arcuate slot, with the respective boss on the turbine wheel being configured to closely accept the tang of the blade.

The related FIGURES 7 through 10 are associated with an embodiment in which the skirt curves through a considerable arc about the tang, FIGURES 7 and 8 revealing that the skirt 22 may extend for approximately 300 degrees, for example. FIGURE 9 reveals that slot 23 is configured to receive skirt 22, whereas FIGURE 10 shows a side view of the construction, in which a radial slot 25 extends along one side of boss 24. This latter slot may be created during the casting or forging of the wheel as the case may be, and may be of such a dimension that the drilling of the radially disposed tang-receiving hole causes the slots 23 and 25 to merge. The width of slot 25 should coincide with the wall thickness of the blade skirt.

FIGURES 11, 12, and 13 illustrate details of a wheel configured to receive single skirt blades of the general type shown in FIGURE 5, which of course cannot be placed upon the wheel so as to face in the wrong direction. The single skirt of each blade is arranged to be inserted through the appropriate arcuate slot 27, and is secured closely against boss 26 located on the disc portion of the central wheel member. On the side of the wheel opposite boss 26 may be an enlargement 28 that provides sufficient thickness to prevent the drill from breaking through the underside of the rim on the side opposite slot 27 during the creaton of the tang-receiving holes in the rim. A pair of holes 29 are provided to receive the blade-mounting rivets.

In FIGURE 14 is revealed a somewhat arcuately shaped washer 31 of the type to be utilized in FIGURE 15 to place the rivets 39 in double shear. As will be noted from FIGURE 15, a washer 31 is disposed on each side of the wheel at each location of a blade 30, with the upper surface of each washer fitting closely to the under side 33*a* of the wheel rim 33. The rivets 39 used to hold the blades in place are of extra length so as to extend through the wheel, blade skirts 36*a* and 36*b* and both washers 31 in the proper manner illustrated in FIGURE 15. Because of this double shear configuration, each rivet before it could release a blade would have to be sheared between wheel and skirt as well as between washer and skirt. This greater restraint allows turbine operation at higher tip speeds as well as at higher temperatures than were previously permissible. Also heavier blades can be utilized than previously was possible.

Referring to FIGURE 16, an embodiment is here illustrated in which a tubular blade is created utilizing a second piece of metal 34 at the juncture of the working blade surface and the blade tang. This allows the fabrication of a more efficient rotor in some instances, inasmuch as the proper aerodynamic blade configuration can be maintained throughout the effective working portion of the blade without a transition of curvature being involved between the working surface and tang. The tube wall is sheared transversely along surface 35 so that the contour of the working surface may be maintained that extends as desired to the root section of the blade. Then, in order to structurally complete the blade, the substantially circular disc 34 is inserted into the shank of the blade, and welded to each abutting blade portion as indicated in FIGURES 16 through 18.

FIGURES 19 and 20 illustrate the typical appearance of a rotor blade mounted upon the wheel.

Referring to FIGURES 21 and 22, the final embodiment is there illustrated in which a fluid passage 41 is radially disposed in the turbine wheel at each blade location. Inasmuch as the tang of this and all my other embodiments is hollow, a fluid passage 42 is thereby defined in the blade, extending as a continuation of the passage 41. However, this embodiment involves a double wall thickness constituted by inner and outer blade portions 44 and 45, between which a number of passageways 43 are disposed substantially about the entire circumference of the blade, through which air or other suitable fluid can flow to provide blade cooling. This cooling permits conventional blade materials to be used at higher than usual temperatures, or low temperature blade material to be used in normal temperature environments.

This embodiment is preferably centrifugally cast, using for example investment casting techniques in which a wax master is configured as desired and then sprayed or otherwise coated with ceramic. The wax is then melted leaving a ceramic shell into which is centrifugally flung the molten metal of which the blade is constituted. An alternate procedure for making the blades of this embodiment involves the use of a pair of inter-fitting molds and cores, the molds defining the outer configuration of the blade and the inner cores defining the fluid passages and other cavities, causing the blade to be essentially hollow.

The inner and outer blade portions 44 and 45 are maintained at the proper spacing by the use of a number of webs 46, with two or more of these webs preferably extending down into the blade tang as ribs 47 and 48. These ribs not only serve to provide additional blade strength, but also serve as flow directing vanes that cause a desirable distribution of cooling fluid through the passageways 43. One or more holes 49 may be provided at the radially inner portion of each passageway 41 to admit compressor air, ambient air, or an alternate source of suitable coolant fluid into the blades.

As will be apparent, the embodiment according to FIGURES 21 and 22 enables the turbine wheel to be operated within the more efficient realm associated with a high turbine inlet temperature. The radial passages create a natural pump effect and resulting fluid circulation due to the centrifugal force imparted to the fluid mass within the blades.

As will be understood, turbine wheels according to this invention can be manufactured with only simple blade stamping tools, and only basic machine tools such as lathes, drills and reamers being necessary even for mass production. Since the blades of this invention can be made of standard tubing, they not only can be manufactured most economically, but also the blades can be manufactured as "universal" blades in large numbers with but a few basic sizes being involved. The wide range of applicability of blades according to this invention is made possible because the orientation notch or notches of each blade can be cut after the desired blade angle of a given wheel has been established, with only small tools such as punch press and appropriate dies, or only a saw being necessary for this purpose. Conventional fasteners may be employed to fasten the buckets to the disc portion of the wheel, thus making attachment or removal of a blade a simple matter, and eliminating the need for blade fastening means at the periphery of the wheel.

This invention also makes possible a standard wheel body that can be used in multi-staged machines merely by providing each successive wheel stage with blades or buckets whose orientation notches have been cut to provide successively varying blade angle.

As will be apparent from a study of this invention, a preferred method of making a turbine wheel according to this invention may include the steps of forming a ring-like wheel member having disc and rim portions and an array of radially disposed holes spaced about and extending through the rim portion, forming a plurality of bucket members each having a suitably contoured active surface as well as a tang of a dimension to fit in one of said holes and extend through the hole with the end of the tang in contact with said disc portion, contouring the end of each of said tangs so that they will bear a desired angle with respect to the active surface of the blade, installing the bucket members upon said wheel member with the tangs

located in said spaced holes and the ends of said tangs contacting said disc, thereby to dispose said bucket members at an attitude on said rim portion such that their respective active surfaces bear a desired angle with respect to a fluid stream, and securing said tangs directly to said disc member, thereby to eliminate blade fastening means at the rim portion of said turbine wheel.

A number of variations within the spirit of this invention will be apparent to those skilled in this art, so I am not to be limited to the herein disclosed embodiments except as required by the scope of the appended claims.

I claim:

1. In a rotor wheel having a central axis of rotation and comprising a disc portion and a rim portion, a plurality of blades disposed about the periphery of said rim portion, each of said blades having an active surface arranged to contact a working fluid, and a tang of generally circular cross-sectional configuration, a plurality of spaced radially-disposed holes arrayed about said rim portion of said turbine wheel in the plane of said disc portion and extending through said rim portion, the tang of each of said blades being arranged to fit within a respective hole, and extend through said rim portion of said wheel into firm contact with the disc portion of said wheel, a portion of each tang having been removed to enable the remaining portion of the tang to be received closely against said disc portion, the angle said remaining portion of the tang bears to the active surface of the blade determining the angle the active blade surfaces bear to the axis of rotation of the rotor wheel.

2. The rotor wheel arrangement as defined in claim 1 in which a plurality of spaced, radially disposed bosses are arrayed about said disc portion in alignment with said spaced holes, each of said tangs having a longtudinal hole therein, each tang fitting closely upon the respective boss when it has been inserted into one of said holes.

3. The rotor wheel arrangement as defined in claim 2 in which each of said tangs is slotted to create at least one skirt, and means for securing said skirts directly to said bosses.

4. The rotor wheel arrangement as defined in claim 2 in which a radially-disposed slot is established alongside each of said bosses, a portion of the respective blade tang of each blade being accommodated in each slot.

5. A rotor wheel having a central axis of rotation and comprising a disc portion and surrounding rim, said rim being of a substantially greater thickness, taken in the direction parallel to said axis, than the thickness of said disc portion at a location immediately adjacent the rim, a plurality of radially extending holes located in spaced relation about said rim in the plane of said disc portion, each of said holes being of a depth such as to extend radially through the rim of said wheel, said holes being of a diameter slightly greater than the thickness of said disc portion at a location immediately adjacent the rim, thereby to form a substantially arcuate slot on at least one side of the inner portion of the rim, a plurality of blades disposed about said rim, each of said blades having a root portion of a diameter such as to be tightly received in one of said holes, each of said root portions having at least one projecting skirt portion of arcuate cross section extending through the slot of the respective hole in said rim, and contacting at least one side of the disc portion of said rotor wheel, thus to provide orientation of each blade on the wheel, and means for securing each skirt portion directly to said disc portion of said rotor wheel, thereby avoiding the necessity of blade securing means on the rim of said wheel.

6. A rotor wheel having a central axis of rotation and comprising a disc portion and surrounding rim, said rim being of a substantially greater thickness, taken in the direction parallel to said axis, than the thickness of said disc portion at a location immediately adjacent the rim, a pluarity of radially extending holes located in spaced relation about said rim in the plane of said disc portion, each of said holes being of a depth such as to extend radially through the rim of said wheel, said holes being of a diameter slightly greater than the thickness of said disc portion at a location immediately adjacent the rim, thereby to form a substantially arcuate slot on at least one side of the inner portion of the rim, a plurality of blades disposed about said rim, each of said blades having a generally circular root portion of a diameter such as to be tightly received in one of said holes, each of said root portions being hollow and having at least one projecting skirt of arcuate cross-section extending through the slot of the respective hole in said rim, and contacting at least one side of the disc portion of said rotor wheel, thus to provide orientation of each blade on the wheel, a rounded boss on said disc portion in direct alignment with each of said holes, each boss being of a dimension for the respective root portion to fit closely thereover, and means for securing each skirt directly to the respective boss, thereby avoiding the necessity of blade securing means on the rim of said wheel.

7. The rotor wheel arrangement as defined in claim 6 in which said means for securing said skirts to said bosses is rivets.

8. In combination in a turbine wheel, a central wheel member having a disc portion and a rim portion, and a plurality of buckets arranged to be mounted on said rim portion of said central wheel member, each of said buckets being provided with a tang portion, a plurality of radially disposed holes arrayed in spaced relation about the periphery of the rim portion of said central wheel member in the plane of said disc portion, each of said holes being of a diameter as to closely receive the tang of one of said buckets, each of said holes having at least one slot located in the bottom thereof extending through said rim portion of said central wheel member, the tang of each of said buckets having at least one skirt portion configured to extend through a respective slot and thus provide orientation for each bucket of said turbine wheel, said skirt portions being in contact with said disc portion of said central wheel member, and fastening means for securing the skirts of said buckets directly to said disc portion of said wheel, thus obviating the need for securing means at said rim portion, and thus minimizing the weight at the periphery of said turbine wheel.

9. In combination in a turbine wheel, a central wheel member having a disc portion and a rim portion, and a plurality of buckets arranged to be mounted on said rim portion of said central wheel member, each of said buckets being provided with a tang portion, a plurality of radially disposed holes arrayed in spaced relation about the periphery of the rim portion of said central wheel member in the plane of said disc portion, each of said holes being of a diameter as to closely receive the tang of one of said buckets, each of said holes having at least one slot located in the bottom thereof extending through said rim portion of said central wheel member, the tang of each of said buckets being hollow and having at least one skirt portion configured to extend through a respective slot and thus provide orientation for each bucket of said turbine wheel, a rounded boss on said disc portion directly below each of said holes, said tangs fitting closely upon each boss with said skirt portions being in contact with said disc portion of said central member, and fastening means for securing the skirts of said buckets directly to said disc portion of said wheel, thus obviating the need for securing means at said rim portion, and thus minimizing the weight at the periphery of said turbine wheel.

10. The turbine wheel arrangement as defined in claim 9 in which a pair of skirt portions are employed, a pair of curved washers for each tang, with one washer being disposed upon each skirt and contacting the underside of said rim, rivet means extending through each pair of skirts and washers and through the respective boss to secure said buckets upon said wheel, said washers causing said rivet means to be placed in double shear.

(References on following page)

References Cited in the file of this patent

UNITED STATES PATENTS

764,230	Edwards	July 5, 1904
775,108	Elliott	Nov. 15, 1904
927,515	Ehrhart	July 13, 1909
974,160	Kudlich	Nov. 1, 1910
1,516,607	Johanson	Nov. 25, 1924
2,195,325	Carlson	Mar. 26, 1940
2,435,427	Eastman	Feb. 3, 1948
2,647,368	Triebbnigg et al.	Aug. 4, 1953
2,692,563	Kovacs	Oct. 26, 1954
2,865,598	Moseson	Dec. 23, 1958
2,925,248	Stakler	Feb. 16, 1960
2,966,331	Creek	Dec. 27, 1960

FOREIGN PATENTS

365,815	France	Sept. 18, 1906
11,706	Great Britain	of 1912
425,941	Italy	Oct. 17, 1947
138,839	Australia	Sept. 26, 1950
846,035	Germany	June 11, 1952
1,059,290	Germany	June 11, 1959