United States Patent [19]

Day

[11] **3,816,022**

[45] **June 11, 1974**

[54] **POWER AUGMENTER BUCKET TIP CONSTRUCTION FOR OPEN-CIRCUIT LIQUID COOLED TURBINES**

[75] Inventor: **William H. Day**, Scotia, N.Y.

[73] Assignee: **General Electric Company**, Schenectady, N.Y.

[22] Filed: **Sept. 1, 1972**

[21] Appl. No.: **285,631**

[52] **U.S. Cl.** **416/92**, 416/97

[51] **Int. Cl.** **F01d 5/18**

[58] **Field of Search** 416/92, 96, 97, 95, 90; 415/115

[56] **References Cited**

UNITED STATES PATENTS

2,888,241	5/1959	Stalker	416/92
3,446,482	5/1969	Kydd	416/90
3,527,544	9/1970	Allen	416/97
3,606,574	9/1971	Brands et al.	416/97 X
3,658,439	4/1972	Kydd	416/97
3,736,071	5/1973	Kydd	416/97

FOREIGN PATENTS OR APPLICATIONS

800,414	8/1958	Great Britain	416/96

Primary Examiner—Everette A. Powell, Jr.

Attorney, Agent, or Firm—Leo I. MaLossi; Joseph T. Cohen; Jerome C. Squillars

[57] **ABSTRACT**

Nozzle construction is disposed in the passage employed for the discharge of coolant flow from an open-circuit liquid cooled gas turbine. This improved construction relief upon for the recovery of reaction energy from the coolant is shown applied to both unshrouded and shrouded turbine buckets.

8 Claims, 5 Drawing Figures

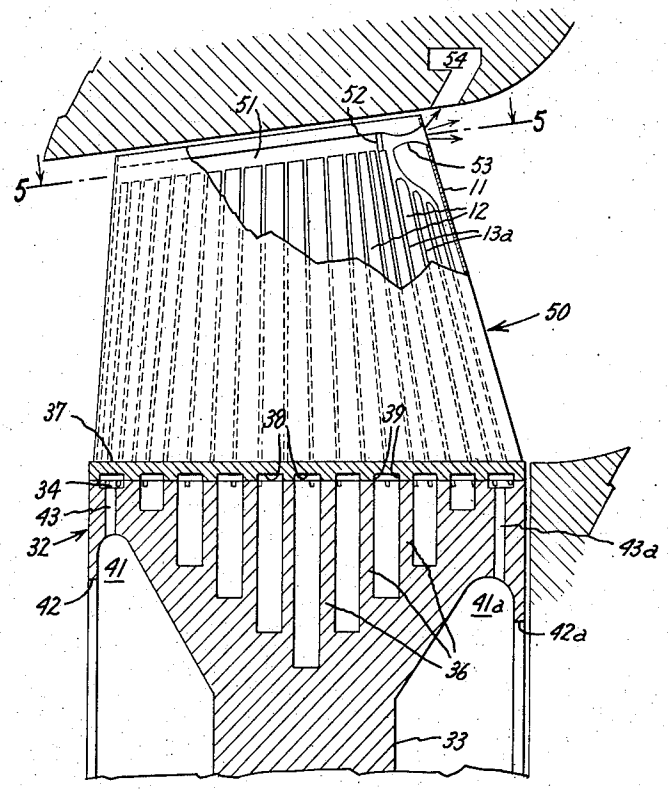


Fig. 1.

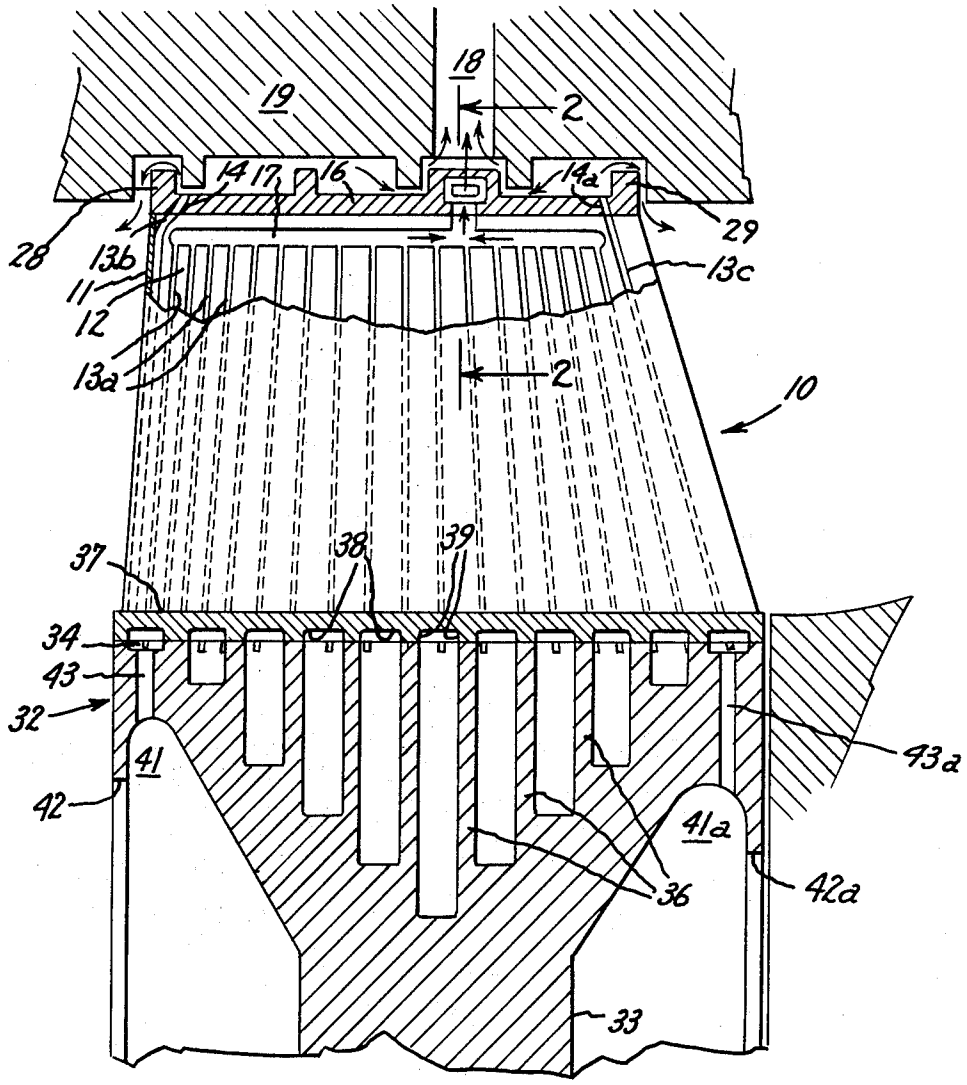

18
19
2
14
17
16
14a
29
28
13b
11
12
13a
13c
2
10
37
38
39
34
43
32
41
42
43a
41a
36
42a
33

Fig. 2.

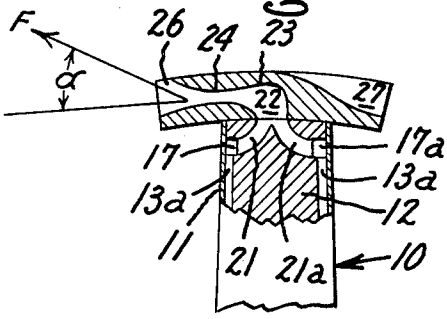


Fig. 5.

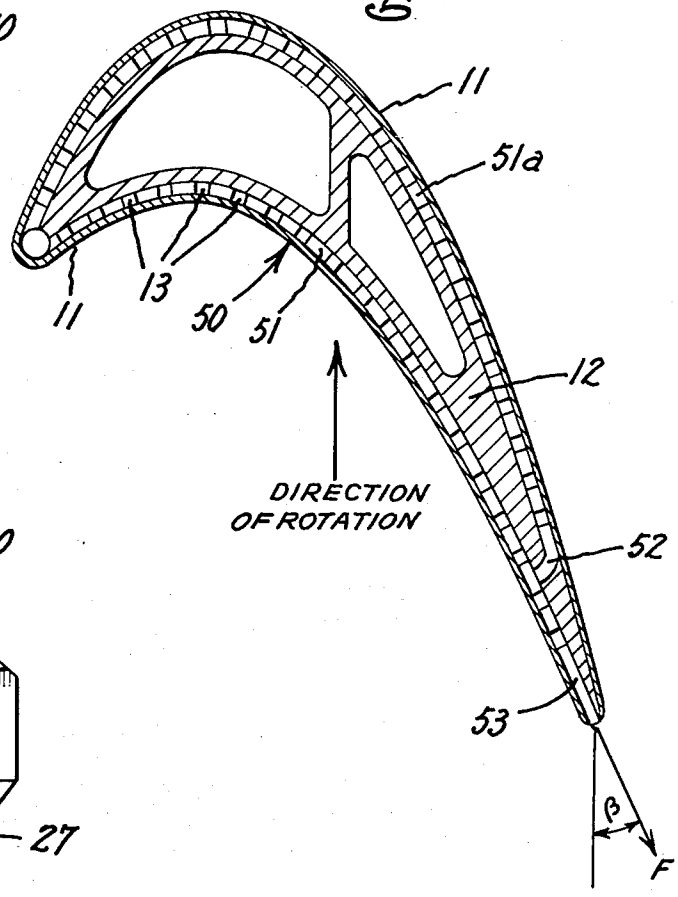


Fig. 3.

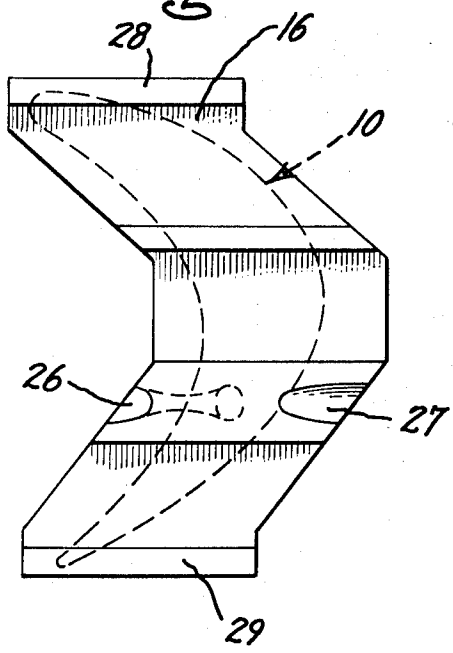
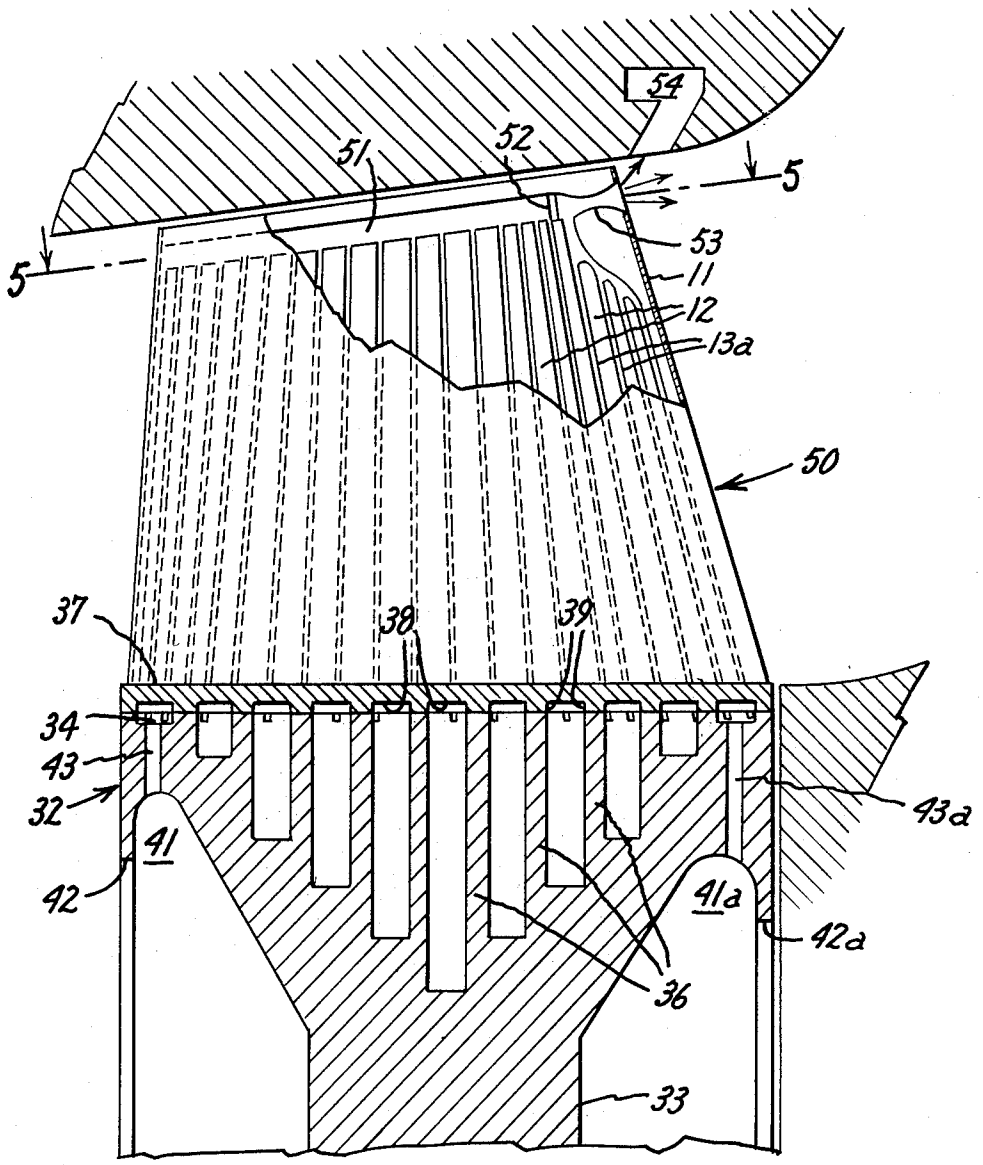


Fig. 4.



POWER AUGMENTER BUCKET TIP CONSTRUCTION FOR OPEN-CIRCUIT LIQUID COOLED TURBINES

BACKGROUND OF THE INVENTION

Structural arrangements for the open-circuit liquid cooling of gas turbine buckets are shown in U.S. Pat. Nos. 3,446,481 — Kydd and 3,446,482 — Kydd. These patents are incorporated by reference.

The provisions for open-circuit liquid cooling disclosed therein are particularly important for the capability offered thereby for increasing the turbine inlet temperature to an operating range of from 2,500° F to at least 3,500° F thereby obtaining an increase in power output ranging from about 100 to 200 percent and an increase in thermal efficiency ranging to as high as 50 percent. Such open-circuit liquid cooled turbine structures are referred to as "ultra high temperature" gas turbines.

The coolant passages shown in the Kydd patents extend radially of the buckets from below the surface of the platforms to the distal ends thereof and are open at both ends. During operation these coolant passages do not run full of liquid coolant. Since all of these coolant passages open at the inner ends thereof into a region of common pressure, when the outer ends of all of these same coolant passages open to the local ambient pressure at various locations around the bucket tip, hot gas will flow into some of these passages and this is highly undesirable.

A solution to this problem is set forth in U.S. Patent Application Ser. No. 93,057 — Kydd now U.S. Pat. No. 3,736,071, filed Nov. 27, 1970 and assigned to the assignee of the instant invention. Bucket tip designs are shown therein for manifolding fluid discharge from open-ended coolant passages in the turbine bucket. The fluid so manifolded (e.g., steam mixed with water in a water-cooled system) is discharged from the trailing end of the bucket into an annular collection slot located in register therewith in the wall of the turbine casing. The collection of coolant by this fluid discharge/collection slot combination to enable recirculation thereof is important from environmental considerations and because of the reduction afforded thereby in the requirement for make-up coolant.

It would be desirable to be able to retain this capability for collecting the coolant (or at least the liquid component thereof) leaving the liquid cooled turbine buckets and at the same time be able to simultaneously recover at least a significant portion of the kinetic energy present in the coolant discharge flow.

Energy recovery from the coolant discharge of elastic fluid turbines has been taught in the art in turbines wherein gas (generally air) is used as the cooling medium. Such power augmenter constructions are described in British Patent Specification Nos. 520,045 and 586,838. However, in a practical sense the velocities of the exiting cooling gas are limited to sub-sonic flow and, because the discharged coolant does not contain a liquid component, no consideration is given to the problem of collecting any portion of the coolant discharge stream.

SUMMARY OF THE INVENTION

The instant invention provides constructions by which not only is the coolant discharge from liquid-cooled gas turbine buckets collected to the extent desired, but simultaneously therewith, the coolant vapor is made to discharge at supersonic flow thereby enabling the efficient recovery of reaction energy therefrom. These dual functions are made possible by combining the capability in this liquid cooled system for increasing the pressure of vapor generated in the system with the use of a convergent-divergent nozzle for discharging the coolant flow from the turbine bucket. By increasing the pressure upstream of the nozzle sufficiently so that the discharging vaporized portion of the coolant discharge flow will be moving at supersonic speeds, a very significant upstream thrust is produced on the bucket acting counter to the downstream force imposed by the working fluid and thereby reducing the axial bending stress on the bucket.

It is to be understood that, where reference is made herein to "vapor," "vaporize" or similar language, the term is intended to embody "gas" or "gasify" or comparable term.

BRIEF DESCRIPTION OF THE DRAWING

The exact nature of this invention as well as objects and advantages thereof will be readily apparent from consideration of the following specification relating to the annexed drawings in which:

FIG. 1 is a transverse sectional view through a liquid cooled gas turbine showing the rotor disk rim, shrouded liquid-cooled turbine bucket affixed thereto and a collection slot in the turbine casing aligned with the turbine blade outlet for the coolant flow;

FIG. 2 is a sectional view taken on line 2—2 of FIG. 1;

FIG. 3 is a view directed radially inward showing the interrelationship between a shroud segment and the turbine bucket connected thereto;

FIG. 4 is a view similar to FIG. 1 showing a second embodiment of the power augmenter of this invention and

FIG. 5 is a sectional view taken on line 5—5 of FIG. 4.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Turbine bucket **10** consists of metal skin **11** bonded to hollow core **12** having spanwise extending grooves **13***a* formed in the airfoil surfaces thereof. The rectangular cooling channels, or passages, **13** defined by skin **11** and grooves **13***a* conduct cooling liquid therethrough at a uniform depth beneath skin **11.**

As shown, cooling channel **13***b* and cooling channel **13***c* (and, possibly, a similar channel, not shown, on the opposite side of the core **12**) in the trailing edge of bucket **10** extend up to the tip of the bucket and communicate with passages **14** and **14***a*, respectively, passing through shroud element **16.**

At the upper ends of cooling channels **13** on the pressure side of bucket **10,** these cooling channels are in flow communication with and terminate at manifold **17** recessed into core **12.** On the suction side of bucket **10,** cooling channels **13** are in flow communication with and terminate at manifold **17***a* (FIG. 2) recessed into core **12.**

Requisite open-circuit discharge of coolant from manifolds **17, 17***a* is insured by the provision of discharge means according to this invention, which place manifolds **17, 17***a* into flow communication with annu-

lar cavity 18 in casing 19. These discharge means consist of passageways 21, 21*a*, which connect to manifolds 17, 17*a*, respectively, and extend in a generally radially outward direction through the tip portion of core 12. Passageways 21 and 21*a* merge upon entering enlarged, shaped passageway 22 in shroud element 16. The coolant flow discharge passes from passageway 22 to cavity 18 via a nozzle comprising converging portion 23, throat 24 and diverging portion 26. Cutaway portion 27 of each shroud element 16 forms the extension of diverging portion 26. The structural interrelationship between nozzle portion 26 and its extension 27 becomes manifest in considering any two abutting shroud elements 16.

Thus, heated coolant (gas or vapor and excess liquid coolant) discharge from manifolds 17, 17*a* passes through passageways 21, 21*a*, shaped chamber 22 and the convergent-divergent nozzle to empty into annular cavity 18 thereby providing for collection of the largest part of the coolant flow discharged from buckets 10. Coolant flow collected in this manner may be removed from cavity 18 and be condensed, cooled and recirculated (in a simple cycle system) or, in the case of a combined steam turbine/gas turbine cycle, the coolant so collected may be conducted to, and form part of, the feed water input to the steam turbine cycle.

Coolant streams conducted through coolant passages 13*b*, 13*c* (and a similar passage, not shown, on the opposite side of the bucket) traverse tip shroud 16 and serve both to cool labyrinth seals 28 and 29, respectively, and to enhance their sealing capability. A small purge of coolant passes into the gas stream via each seal thereby insuring exclusion of the hot working fluid from collection cavity 18.

If the pressure in cavity 18 is maintained below the pressure in the working fluid (either upstream or downstream of bucket 10), the pressure ratio across the power augmenter nozzle in each tip shroud 16 can be increased sufficiently to provide supersonic flow through convergent-divergent nozzle 26. Another way in which the pressure upstream of nozzle 26 is raised sufficiently to produce supersonic flow is by creating an optimum balance between the rate of coolant supply, heat transfer to bucket 10 and the area of throat 24 employed as is taught in U.S. Patent Application Ser. No. 285,633 — Moore, filed Sept. 1, 1972, assigned to the assignee of this invention and incorporated by reference.

Since the direction of the discharge coolant stream is rearward relative to the direction of rotation of bucket 10 the effective reaction force F acting at angle α to the tangent line provides two useful force components. Thus, F cos α represents useful torque and F sin α reduces the centrifugal stress on bucket 10. The reaction energy (F cos α) recovered from the coolant discharge as described hereinabove may actually produce a net gain in power under some operating conditions, but any extent of reaction energy recovery will offset, at least in part, the pumping energy required to accelerate the coolant to bucket tip speed.

The bucket/rotor interconnection does not form part of this invention and other arrangements e.g., dovetail buckets may be preferred.

In the exemplary construction shown, the root end of core 12 consists of a number of finger-like projections or tines 31. These tines 31 may present a generally rectangular profile as shown or each tine may be tapered toward the distal end thereof to present a generally triangular profile. Rim 32 of turbine disk 33 has grooves 34 machined therein extending to various depths and having widths matching the different lengths and widths of bucket tines 31 such that tines 31 will fit snuggly into the completed grooves 34 in an interlocking relationship.

Once the proper fit has been obtained the appropriate amount of brazing alloy is placed in each groove 34 and the buckets are inserted and held in fixed position by a fixture. This fixture is biased to maintain a tight fit between tines 31 and grooves 34 regardless of thermal expansion. Conventional brazing alloys having melting points ranging from 700° to 1,100° C may be used. Single metals, such as copper, may also be used.

Thereafter, the assembly (the rim with all the buckets properly located) is furnace-brazed to provide an integral structure.

Steel alloys may be used for the skin and core, preferably those containing at least 12 percent by weight of chromium for corrosion resistance and heat treatable to achieve high strength.

The cutting of grooves 34 into rim 32 not only provides the requisite configuration for fastening the bucket root and lessens the weight of the rim, but in addition the ribs 36 between grooves 34 provide area on the upper surfaces thereof for attachment thereto of platform elements 37 having cooling channels 38 in juxtaposition with grooves 34 and are interconnected by other cooling channels, not shown. The separating walls 39 between cooling channels 38 are dimensioned to coincide with the width of ribs 36, when in juxtaposition therewith.

Construction for metering of the coolant to the buckets is more fully described in U.S. Pat. No. 3,658,439 — Kydd, incorporated by reference.

As is described in the Kydd U.S. Pat. No. 3,446,481 and Kydd U.S. Pat. No. 3,446,482 cooling liquid (usually water) is sprayed at low pressure in a generally radially outward direction from nozzles (not shown herein, but preferably located on each side of disk 33) and impinges on disk 33. The coolant thereupon moves into gutters 41, 41*a* defined in part by downwardly extending lip portions 42, 42*a*. The cooling liquid accumulates in gutters 41, 41*a* (cooling the portions with which it comes into contact) being retained therein until this liquid has been accelerated to the prevailing disk rim velocity.

After the cooling liquid in gutters 41, 41*a* has been so accelerated, this liquid drains therefrom passing radially outward through holes 43, 43*a* to the underside of platform 37 from where it is introduced into slots 13*a* and cooling channels 13 via a metering system (not shown). Individual holes (not shown) may be provided to interconnect gutter 41 with cooling channel 13*b* to assure greater cooling capability at the leading edge of buckets 10. In transit, the coolant passes over the undersurfaces of platform elements 37 and keeps these elements cool.

As the cooling liquid moves through cooling channels 13 of any given bucket 10 a portion (the amount will depend upon the rate of flow selected) is converted to the gaseous or vapor state as it absorbs heat from the skin 11 and core 12 of the bucket. At the outer ends of cooling channels 13 the vapor generated and any remaining liquid coolant pass into manifolds 17 and 17*a*

and exit from the manifold system as described hereinabove.

FIGS. 4 and 5 set forth a second embodiment of this invention wherein bucket **50** is unshrouded. The rotor, platform and bucket/rotor interconnection are the same as in the embodiment of FIG. **1.** Cooling channels **13** terminate in manifolds **51** and **51***a*, these manifolds being interconnected by passage **52.** Coolant flow received by manifold **51** from cooling channels **13** and from manifold **51***a* is discharged therefrom via convergent-divergent nozzle **53** in flow communication with manifold **51.** In order to accommodate nozzle **53,** one or more of the cooling channel grooves **13***a* are made to merge with adjacent grooves **13***a* in order to conduct coolant flow therethrough to manifold **51.**

As the coolant flow is discharged, nozzle **53** will more accurately direct any liquid content therein into collection slot **54** of casing **56.** Convergent-divergent nozzle **53** is employed, because as has been noted hereinabove in connection with the preferred embodiment, with a liquid cooled system sufficient head is provided by the coolant supply to enable build-up of the pressure upstream of nozzle **53** to a point at which the critical pressure ratio (the ratio of the upstream pressure to the pressure of the ambient) is greater than that required for supersonic flow (e.g., greater than about 2:1).

Also, the shape of the diverging portion of nozzle **43** is such that the liquid component of the discharge stream is readily directed radially and more effectively collected while most of the vapor (or gas) component is ejected in the generally backward (relative to direction of rotation) direction. The total reaction force exerted by the vapor content of the coolant discharge is represented by F and component F cos β represents the useful torque produced, while component F sin β produces an upstream thrust on the bucket reducing the axial bending stress on the bucket because of its counteraction to the downstream force, imposed by the hot gas stream.

The congergent-divergent nozzle constructions in both embodiments may be built into the bucket and shroud castings as part of the casting procedure. In the case of the bucket/shroud construction, the tip shroud may conveniently be cast in two parts later joined together over a circumferentially extending surface. Although it is essential that a convergent-divergent nozzle be used in the unshrouded construction, convergent nozzles may be used as well in the shrouded construction.

A further advantage of the nozzle is that by creating a velocity of the water and stream relative to the bucket comparable to the tip speed, the velocity thereof relative to the stationary parts is reduced. This reduces impact erosion of the stationary parts, permitting longer life and/or the use of softer, cheaper materials than would otherwise be required.

The structural integrity of the bucket as a pressure vessel and the desired boiling temperature of the cooling water must be accounted for in setting the liquid/vapor pressure in the bucket. The best tradeoff is one that permits acceptable mechanical and thermal stresses in the metal while giving maximum relative energy recovery by the nozzle design.

What I claim as new and desire to secure by letters patent of the United States is:

1. In a gas turbine wherein a turbine disk is mounted on a shaft rotatably supported in a casing, said turbine disk extending substantially perpendicular to the axis of said shaft and having turbine buckets affixed to the outer rim thereof with platform means disposed therebetween, said buckets receiving a driving force from a hot motive fluid moving in a direction generally parallel to said axis of said shaft and the driving force being transmitted to said shaft via rotation of said turbine disk, means located radially inward of said platform for introducing liquid coolant within said turbine in a radially outward direction into an open-circuit coolant distribution system comprising cooling channels extending beneath the airfoil surfaces of each of said buckets, metering means located radially inward of and in flow communication with said cooling channels and a manifold and discharge portion located in the tip region of each of said buckets in flow communication with the radially outer ends of cooling channels of the given bucket whereby coolant is metered into, proceeds through and exits from cooling channels into said manifold and discharge portion, the improvement comprising:

a. manifold means located beneath the bucket surface near the tip of each bucket in flow communication with the discharge end of each coolant channel and

b. each of said manifold and discharge portions including a convergent-divergent nozzle disposed to discharge coolant flow from said open circuit coolant distribution system in a rearward direction relative to the direction of rotation of said turbine disk.

2. The improvement of claim **1** wherein the manifold means consists of a slot formed in the bucket core on each side of each turbine bucket, the two slots being interconnected at some point upstream of the convergent-divergent nozzle by a passage extending through the separating bucket core material and said nozzle is located to discharge coolant flow from the trailing edge of said bucket.

3. The improvement of claim **1** wherein each turbine bucket is connected at its distal end to shroud construction and the convergent-divergent nozzle is formed in said shroud construction, said nozzle being disposed to discharge into a cavity formed in the turbine casing.

4. The improvement of claim **3** wherein the manifold structure in the manifold and discharge portion is disposed on both the pressure and suction sides of each bucket and is in flow communication with the nozzle via passageways in the bucket core and shroud construction.

5. A unitary turbine bucket/shroud structure comprising a turbine bucket and a shroud element, said turbine bucket having a network of subsurface cooling channels and manifold structure formed therein, the radially outward ends of said channels being in flow communication with said manifold structure, said shroud element being affixed to the distal end of the core of said turbine bucket and having nozzle construction formed therein, said nozzle construction being in flow communication with said manifold structure and being disposed to discharge flow therefrom in a direction generally opposite to the direction in which said bucket/shroud structure is intended to be moved in use.

6. The unitary turbine bucket/shroud structure of claim **5** wherein the nozzle construction is a convergent-divergent nozzle.

7. The unitary turbine bucket/shroud structure of claim 5 wherein in addition to the cooling channels communicating with the manifold structure, other cooling channels near the leading and trailing edges communicate directly with passages extending through the shroud element in a generally radial direction instead of communicating with the manifold structure and nozzle construction.

8. In the operation of a gas turbine wherein a turbine disk is mounted on a shaft rotatably supported in a casing, said turbine disk extending substantially perpendicular to the axis of said shaft and having turbine buckets affixed to the outer rim thereof with platform means disposed therebetween, said buckets receiving a driving force from a hot motive fluid moving in a direction generally parallel to said axis of said shaft and the driving force being transmitted to said shaft via rotation of said turbine disk, means located radially inward of said platform for introducing liquid coolant within said turbine in a radially outward direction into an open-circuit coolant distribution system by which said coolant is metered into cooling channels in said buckets, proceeds as liquid and vapor through said channels and exits from said channels into manifold and discharge means forming part of said open-circuit coolant distribution system, the improvement comprising:

a. creating and maintaining a pressure differential between said open-circuit coolant distribution system and the ambient to which the coolant flow is discharged, said pressure differential being sufficiently high that the coolant flow reaching said manifold and discharge means is discharged at supersonic velocities and

b. discharging said coolant flow in a rearward direction relative to the direction of rotation of said turbine disk.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,816,022 Dated June 11, 1974

Inventor(s) William H. Day

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Claim 2 (column 6, lines 32-39) should appear as follows:

The improvement of claim 1 wherein the manifold structure in the manifold and discharge portion consists of a slot formed in the bucket core on each side of each turbine bucket beneath the airfoil surfaces, the two slots being interconnected at some point upstream of the convergent-divergent nozzle by a passage extending through the separating bucket core material and said nozzle is located to discharge coolant flow from the trailing edge of said bucket.

Signed and sealed this 19th day of November 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

FORM PO-1050 (10-69)

USCOMM-DC 60376-P69
U.S. GOVERNMENT PRINTING OFFICE : 869-930