# United States Patent [19]

**Holchendler et al.**

[11] **3,902,819**

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[54] **METHOD AND APPARATUS FOR COOLING A TURBOMACHINERY BLADE**


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[52] **U.S. Cl.** .......................... **416/1;** 416/96; 416/97

[51] **Int. Cl.²** .......................................... **F01D 5/18**

[58] **Field of Search** ................................ 416/95–97, 416/92, 96 A, 97 A, 1; 415/114, 115, 1



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[57] **ABSTRACT**

A turbomachinery blade operating at elevated temperature and in a strong centrifugal field is cooled by a coolant loop located within the blade constituting an open, mixed convection, thermosyphon system utilizing water as the coolant and establishing density differentials in the coolant within the loop by injecting cooler water into one portion of the loop and extracting coolant fluid from another portion of the loop to maintain system pressure and coolant mass at desired levels to thereby establish continuous coolant recirculation within the coolant loop.


**19 Claims, 3 Drawing Figures**

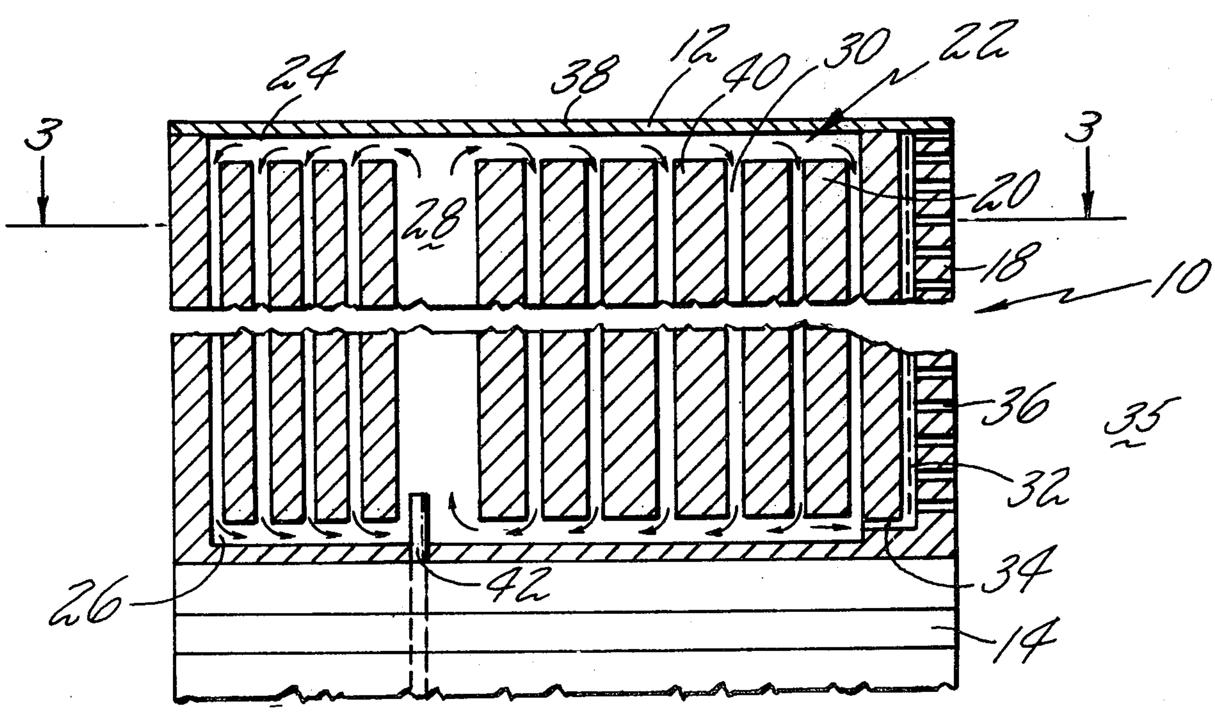


FIG. 1

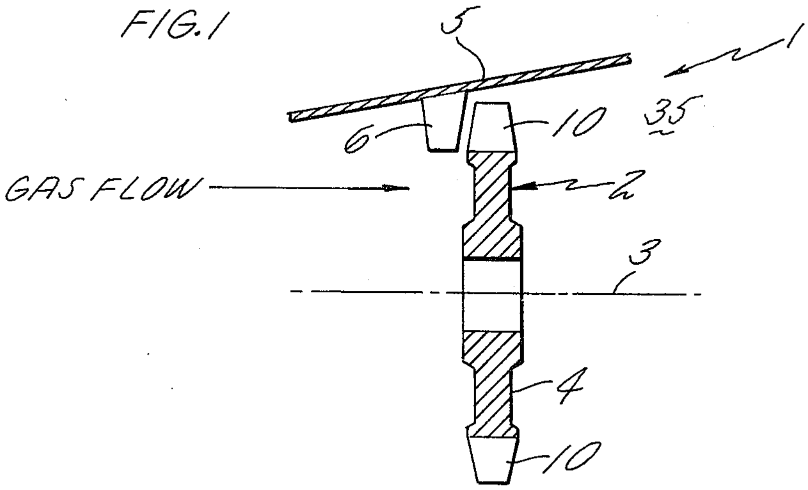



FIG. 3

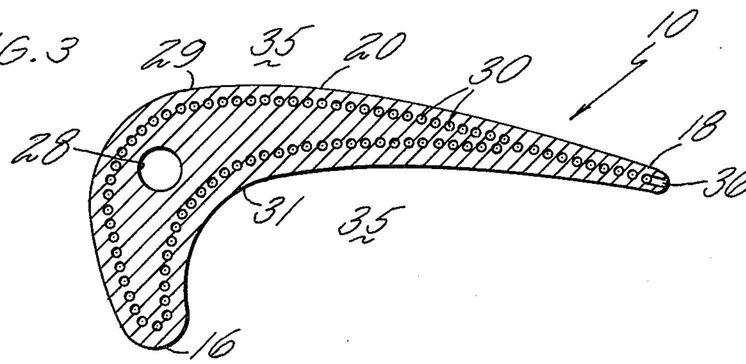
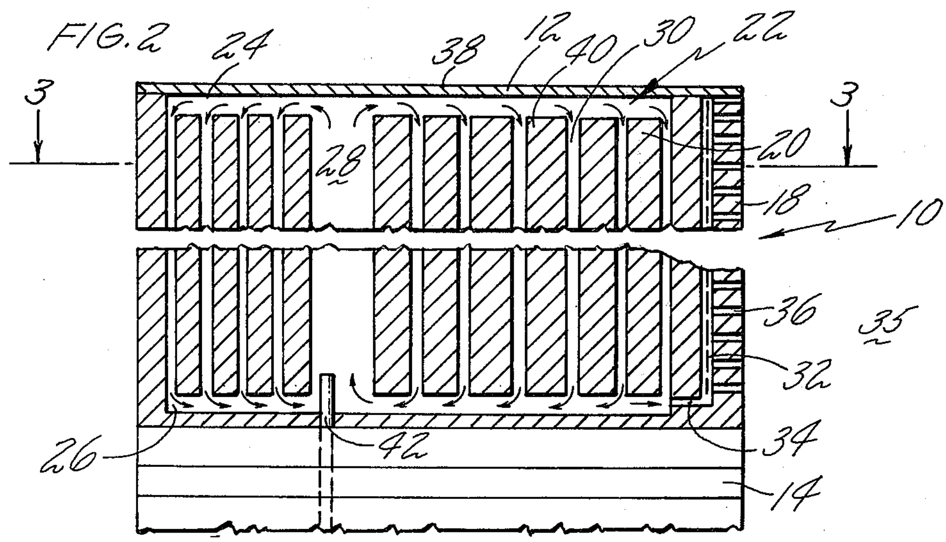



FIG. 2



# METHOD AND APPARATUS FOR COOLING A TURBOMACHINERY BLADE

## BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to turbomachinery blades, such as turbine blades, and more particularly to method and apparatus for cooling such blades.

2. Description of the Prior Art

In the turbomachinery blade cooling art, thermosyphon systems have been used previously. In Ledinegg U.S. Pat. No. **2,667,326**, a closed loop thermosyphon cooling system is used, however, the coolant is evaporated in a single pass through the turbine blade, and thence is returned to a remote heat sink in the turbomachinery disc for condensation prior to recirculation through the turbine blades. Also, geometric separation of the coolant inlet and outlet from the blades is made possible only by the presence of different phases at the inlet and the outlet. Eckert U.S. Pat. No. **2,778,601** teaches a thermosyphon blade cooling system which is open loop and utilizes water as its cooling fluid, however, the system is single pass and the cooling media is passed through the turbine blade but a single time and is then discharged overboard. In addition, no special effort is made to deliberately define and separate the inlet and exit coolant flow location. Bruckmann U.S. Pat. No. **2,779,565** is similar to Eckert, albeit air is used as the cooling media but in single-pass fashion. Schneider U.S. Pat. No. **3,623,825** utilizes liquid metal, without phase change, in a particular portion of a heat exchanger within the blade in a sealed compartment and thereby presents sealing, maintainability, and weight problems. These single pass systems are inefficient and the systems utilizing heat sinks remote from the blade are unnecessarily complicated and heavy.

## SUMMARY OF THE INVENTION

A primary object of the present invention is to provide an improved method and hardware for cooling turbomachinery blading utilizing an open, mixed convection thermosyphon system within the blade.

In accordance with the present invention, the turbomachinery blade coolant is preferably steam at high pressure and at temperature above critical, into which coolant at low temperature, and high pressure is injected in order to create a concentrated heat sink and thereby establish a density differential so as to produce continuous thermosyphon multi-pass pumping of the coolant.

In accordance with a further aspect of the present invention, a selected amount of cooling fluid is discharged from the system at the same rate at which the low temperature coolant is added to the system to maintain system pressure and coolant mass at a selected level. During transient operating conditions, the inlet and exit flow rates may differ.

It is still a further important teaching of this invention that the coolant flow within the blade is at a rate many times as great (frequently tenfold or more) as the rate of injection of low temperature coolant thereby minimizing the variation of coolant temperature in the different parts of the blade, giving a high heat transfer coefficient as required to cool the blade while avoiding the problems associated with change of phase (particularly boiling), and making the cooling system thermodynamically efficient.



It is a very important feature of this invention that the coolant is recirculated within the blade without the need for having heat transferred from the coolant prior to recirculation.

An advantage of this system is that water may be used as the coolant, and therefore our system may use a coolant which has good thermal properties, ready availability especially in stationary and marine installations, which is economical, and which requires no special handling, as is the case with many other coolants.

It is a further important feature of this blade cooling system that the heat sink is positioned solely within the blade, and bears no relationship to the supporting disc or other related turbomachinery.

It is a further feature of this invention that the turbomachinery blade be fabricated so as to include a coolant loop therewithin comprising an outer header extending substantially along the blade tip, an inner header extending substantially along the blade root, and passages or conduits extending between the headers, and further preferably including a blade trailing edge header and a discharge passage or passages joined to the main coolant loop through an orifice so as to permit the extraction of fluid from the cooling loop in a selective fashion so as to maintain system pressure and fluid mass at desired levels and to regulate the mixing process at the inlet location.

According to another feature of our invention, the fluid extracted from the system is used for cooling purposes, and preferably to cool the blade trailing edge.

It is a further feature of this invention to teach a unique coolant loop for a turbomachinery blade in which the coolant remains in a supercritical state as it goes through multiple passes throughout the loop.

Other objects and advantages of the present invention may be seen by referring to the following description and claims, read in conjunction with the accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a showing of turbomachinery utilizing this invention.

FIG. **2** is a cross-sectional drawing through a turbomachinery blade utilizing the present invention but the number of coolant passages have been reduced to better permit description.

FIG. **3** is a view taken along line **3—3** of FIG. **2** and shows a representative number of coolant passages.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. **1** we see turbomachinery unit **1**, which may be a gas or steam turbine or compressor, and which comprises at least one rotor **2** mounted for rotation about axis **3** and including a disc **4** supporting a plurality of blades **10** about the periphery thereof. Rotor **2** is mounted within housing **5**, from which vaned stator **6** projects to control the angle of entry of the gas flowing through turbomachinery **1** as it approaches blades **10**.

Referring to FIGS. **2** and **3** we see turbomachinery blade **10**, which includes blade tip **12**, blade root **14**, leading edge **16**, trailing edge **18**, and airfoil portion **20** extending between root **14** and tip **12**. Blade **10** is adapted to be supported from a rotor disc **2** of a turbomachinery compressor or turbine, for example, to be rotated therewith during turbine engine operation and to have hot gases passed thereover so that the blade **10** is operating both in a high temperature environment and a strong centrifugal force environment. For a more complete description of an illustration of a turbomachinery blade and its associated turbine and/or compressor parts, reference may be had to U.S. Pat. Nos. **2,711,631** and **2,747,367.**

Blade **10** is fabricated so that coolant loop **22** is positioned therewithin and includes outboard header **24** extending along the blade tip **12**, inboard header **26** extending along the blade root **14**, and outflow passage **28** and inflow heat exchanger passages **30** extending between these headers and with passages **30** located adjacent to the blade convex and concave surfaces **29** and **31**. The cooling system also includes blade trailing edge header **32** which communicates with inboard header **26** through choked orifice **34**, and which communicates with the gas flow passage **35** external of blade **10** through a plurality of apertures **36** extending along and through the blade trailing edge **18**. Coolant pressure and temperature levels in loop **22** are controlled by the sizing of orifice **34**. Orifice **34** is preferably adjacent to inner header **26** but could be adjacent to outer header **28**. Blade **10** may be fabricated in any convenient fashion, for example, blade outer portion **38**, which includes blade tip **12** and airfoil section **20** may serve as a blade wall member into which blade internal portion **40** may extend in projecting from root **14** in blade-scabbard fashion, thereby defining those passages enumerated above the blade outer portion **38** and blade inner portion would be sealably connected by welding or the like.

The preferred cooling fluid in coolant passage **22** is water in the form of steam operating at supercritical temperature and pressure to form an open, mixed convection-thermosyphon cooling system. This supercritical steam passes outwardly from inboard header **26** through passage **28** to outboard header **24** and therefrom inwardly through passages **30** to inboard header **26** and recirculation again outwardly through passage **28** in multi-pass fashion. Preferably, passage **28** is located in a central portion of the blade while the heat exchanger passages **30** are located near the blade outer surfaces **29** and **31**. The motive force to create this circulation is derived from the heat sink positioned near the blade root **14** in passage **28**, specifically at the end of tube member **42** through which water, at supercritical pressure but at a temperature lower than the supercritical steam is injected into the inner end of passage **28**. The mixing of this low temperature coolant from conduit **42** serves to lower the temperature of the coolant in conduit **28** below the temperature of the coolant in conduits **30** to establish both a temperature and density differential therebetween, thereby establishing a continuing flow of the coolant in cooling fluid system **22** outwardly through passage **28** into outer header **24**, and then inwardly through passages **30** to inner header **26**, and continued recirculation through this route as desired to effect blade cooling. To maintain the system fluid at desired pressure and total mass, a selected amount of coolant is discharged through orifice **34** into blade trailing edge header **32**, from which it is discharged to gas flow path **35** through blade trailing edge apertures **36** for the purpose of cooling the blade trailing edge. Orifice **34** is sized so that the rate of coolant so discharged is at the same flow rate at which the low temperature coolant is entering the system through conduit **42**. Low temperature coolant for conduit **42** may be stored and/or supplied in any convenient fashion, such as within or from the rotor disc **2**. In this fashion, an open, mixed convention thermosyphon cooling system is established. This system therefore effects coolant (supercritical steam) recirculation by low temperature coolant (water) injection and this provides a uniqueness to our system over other known thermosyphon systems in that our system establishes a flow rate in coolant which is on the order of **10** times as great as the flow rate of the injected low temperature coolant and this has the advantages of minimizing the variation of coolant temperature in the different parts of blade **10**, giving the high heat transfer coefficients required to cool the blade while avoiding the problems associated with change of phase of the coolant, particularly boiling, and making the cooling system thermodynamically efficient.

The present coolant system is said to be open because the coolant fluid is being discharged from the system through trailing edge ports **36**, is said to be mixed convection since the system operates by both free and forced convection, and is said to be a thermosyphon because the continuous pumping and recirculation of the coolant is brought about by the functioning of the heat sink to establish density differentials within the cooling system **22**.

In the present invention, the heat added to blade **10** during operation for given external (gas-side) conditions, is proportional to the temperature level and flow rate of the recirculating coolant which is proportional in turn, to the flow rate of injected coolant. It will therefore be seen that this system functions as a convective (or thermal) amplifier.

The three main elements of this blade cooling system are: (**1**) a coolant loop **22** within the blade **10**, (**2**) a low temperature coolant injection system (conduit **42**) which is used to produce the pumping force to circulate the coolant in the loop **22**, and (**3**) a discharge orifice system **32–36** to exhaust spent coolant to the turbomachinery gas path and maintain the required coolant pressure and mass level in the blade. The cooling of the blade is primarily accomplished by the transfer of heat to the supercritical water flowing radially inwardly through the heat exchanger passages **30**.

By way of explanation of the operation of this system on the thermosyphon principle, let us assume that supercritical steam in inner header **26** is at **950°F**, and that water at **100°F** is introduced thereinto through conduit **42** in the lower part of outflow passage **28** so as to produce a mixed temperature therein of **900°F**. This **900°** water will flow into tip header **24** and then flow back to the inner header **26** through exchanger tubes or passages **30** wherein heat transfer from the passage walls causes the supercritical steam to be elevated to the **950°** temperature by the time it reaches inner header **26**. It will therefore be seen that the mean or average temperature of the supercritical steam in the heat exchanger passages **30** is **925°** and that the temperature of the supercritical steam in passage **28** is **900°**, giving a **25°F** temperature differential. This temperature differential produces a density differential so that the more dense supercritical steam at **900°** will be acted upon to a greater degree by the centrifugal force generated by the rotating rotor **2** than the less dense supercritical steam in heat exchanger conduits **30**, thereby establishing the pumping force action of the thermosyphon principle which will cause the fluid to so continue to circulate through coolant loop **22**, so long as this temperature differential, and hence the density differential, is maintained. To maintain this temperature differential, the cool water at **100**°F is continuously injected into the inner end of passage **28** and supercritical steam is discharged from the system at an equal rate to maintain the pressure and mass of the coolant in loop **22** at desired levels. To obtain maximum benefit from the supercritical steam being discharged from the system, we pass that steam through the trailing edge header and out the trailing edge of the blade so that it cools the trailing edge of the blade.

It is important to note that in our construction the cooling fluid (steam) can be held totally in the supercritical range at all times throughout its many passes through the cooling loop, thereby avoiding boiling problems. A second advantage of operation in the supercritical range is that the operating temperature is high enough so that overcooling the blade does not occur which would extract too much heat from the gas flowing over the blade and diminish the cycle efficiency. However, we are maintaining the blade cool enough to insure its structural integrity.

We wish it to be understood that we do not desire to be limited to the exact details of construction shown and described, for obvious modifications will occur to a person skilled in the art.

We claim:

**1.** A turbomachinery blade adapted to be mounted for rotation on a disc and to have hot gas pass thereover so as to thereby be subjected to both centrifugal force and high temperature including:

**1.** a coolant loop within the blade,

**2.** a cooling fluid filling said loop,

**3.** heat sink establishing means acting upon the cooling fluid in one portion of said loop to establish a temperature and hence a density differential between the cooling fluid in different parts of said coolant loop to thereby establish a continuous circulatory flow and recirculation of cooling fluid within the coolant loop utilizing the thermal syphon principle, and

**4.** wherein said heat sink establishing means comprises a means for injecting a coolant at lesser temperature than the cooling fluid into said coolant loop at a selected location, and means to discharge cooling fluid from the coolant loop at the same rate that coolant is being injected into the coolant loop to thereby maintain selected pressure level and coolant mass in the coolant loop.

**2.** A blade according to claim **1** wherein the cooling fluid is steam above critical temperature and pressure and wherein the coolant is water above critical pressure and at low temperature.

**3.** A blade according to claim **2** wherein the fluid extracted from the coolant loop is discharged through the blade walls.

**4.** A blade according to claim **3**, which blade has discharged slots in the blade trailing edge and wherein the fluid is discharged through said trailing edge slots.

**5.** A blade according to claim **1** wherein said blade comprises an outer cover defining the blade tip and airfoil section walls and an inner member inserted thereinto in blade-in-scabbard fashion and sealably connected thereto, with both the blade outer cover portion and the blade inner portion being selectively shaped to define said coolant loop.

**6.** A blade according to claim **1** and including means to control coolant circulation rate and temperature, rate of heat removal from and the temperature of the blade.

**7.** A blade according to claim **1** and including means to control the amount of coolant discharged from the coolant loop.

**8.** The method of cooling a turbomachinery blade utilizing the thermosyphon principle including the steps of:

**1.** providing a plurality of substantially radially extending passages in the blade interior joining a header extending along the blade tip and a header extending along the blade root,

**2.** filling said passages with fluid which will be in the supercritical state at blade operating conditions, and

**3.** establishing a density differential between the fluid in at least one of said passages and the fluid in the remaining passages to establish continuous circulation and recirculation of fluid radially inwardly through the passages having the less dense fluid and radially outwardly through the passage having the more dense fluid to thereby cool the blade.

**9.** A turbomachinery blade adopted to be mounted for rotation on a disc and to have hot gas passed thereover so as to thereby be subjected both to centrifugal force and high temperature including:

**1.** a blade root adopted to be connected to the blade disc,

**2.** a blade airfoil section shaped to define the blade tip, the blade leading edge and trailing edge and attached to the blade root to extend radially outwardly therefrom when the blade is mounted on the disc and shaped to define therewithin a selectively shaped passage system including a series of substantially radially extending passage joining an outboard header and an inboard header,

**3.** a blade tip located at the end of the blade airfoil section opposite to the blade root,

**4.** a fluid which will operate at a supercritical state at blade operating conditions, and

**5.** means to establish a density differential in the fluid in said passages and thereby establish continuous circulatory flow of said fluid radially outwardly through at least one of said radial passages, through said outboard header, radially inwardly through at least one of said radial passages and said inboard header in multi-pass, recirculation fashion.

**10.** The method of cooling a turbomachinery blade utilizing the thermosyphon principle including the steps of:

**1.** providing a plurality of substantially radially extending passages in the blade interior joining a header extending along the blade tip and a header extending along the blade root,

**2.** filling said passages with fluid,

**3.** establishing a density differential between the fluid in at least one of said passages and the fluid in the remaining passages to establish continuous circulation and recirculation of fluid radially inwardly through the passages having the less dense fluid and radially outwardly through the passage having the more dense fluid to thereby cool the blade, and wherein said last step includes cooling the temperature of the fluid in at least one of the passages by direct heat sink injection to increase its density so that, in accordance with the thermosyphon principle, the more dense fluid will flow radially outwardly to the tip header and the less dense fluid will flow radially inwardly to the root header establish blade coolant circulation.

**11.** The method of cooling a turbomachinery blade utilizing the thermosyphon principle including the steps of:

1. providing a plurality of substantially radially extending passages in the blade interior joining a header extending along the blade tip and a header extending along the blade root,
2. filling said passages with fluid,
3. establishing a density differential between the fluid in at least one of said passages and the fluid in the remaining passages to establish continuous circulation and recirculation of fluid radially inwardly through the passages having the less dense fluid and radially outwardly through the passage having the more dense fluid to thereby cool the blade, and

wherein the cooling fluid is supercritical and wherein water at a temperature less than the supercritical is introduced to one of the passages to establish a heat sink to produce the desired density differential, and wherein supercritical steam is bled from the system at the same rate that cooling water is added to the system to maintain the coolant mass pressure, and the density differential substantially constant in the system.

**12.** The method of cooling a turbomachinery blade utilizing the thermosyphon principle including the steps of:

1. providing a plurality of substantially radially extending passages in the blade interior joining a header extending along the blade tip and a header extending along the blade root,
2. filling said passages with fluid,
3. establishing a density differential between the fluid in at least one of said passages and the fluid in the remaining passages to establish continuous circulation and recirculation of fluid radially inwardly through the passages having the less dense fluid and radially outwardly through the passage having the more dense fluid to thereby cool the blade, and

including the additional step of controlling the density differentials so established in the fluid so as to control the recirculation rate of the cooling fluid in the passages, the operating temperatures of the fluid being circulated, the rate of heat removal from the blade into the cooling fluid, and blade metal temperature.

**13.** The method of cooling a turbomachinery blade utilizing the thermosyphon principle including the steps of:

1. providing a plurality of substantially radially extending passages in the blade interior joining a header extending along the blade tip and a header extending along the blade root,
2. filling said passages with fluid,
3. establishing a density differential between the fluid in at least one of said passages and the fluid in the remaining passages to establish continuous circulation and recirculation of fluid radially inwardly through the passages having the less dense fluid and radially outwardly through the passage having the more dense fluid to thereby cool the blade, and

wherein the cooling fluid is supercritical and wherein water at a temperature less than the supercritical is introduced to one of the passages to establish a heat sink to produce the desired density differential, and wherein supercritical steam is bled from the system at the same rate that cooling water is added to the system to maintain the coolant mass pressure, and the density differential substantially constant in the system, and, further, wherein the heat sink is positioned remote from the system bleed so as to achieve maximum effective mixing with single phase fluids and maintain constant steady state circulation rates.

**14.** A turbomachinery blade adapted to be mounted for rotation on a disc and to have hot gas passed thereover so as to thereby be subjected both to centrifugal force and high temperature including:

1. a blade root adapted to be connected to the blade disc,
2. a blade airfoil section shaped to define the blade tip, the blade leading edge and trailing edge and attached to the blade root to extend radially outwardly therefrom when the blade is mounted on the disc and shaped to define therewithin a passage system including a series of substantially radially extending passages joining an outboard header and an inboard header,
3. a blade tip located at the end of the blade airfoil section opposite to the blade root,
4. a fluid filling said headers and said passages for circulation therein, and
5. means to establish a density differential in the fluid in said passages and thereby establish continuous circulatory flow of said fluid radially outwardly through at least one of said radial passages, through said outboard header, radially inwardly through at least one of said radial passages and said inboard header in multi-pass, recirculation fashion, and

wherein said density differential establishing means including:

1. means to inject a cooling fluid into one of said passages said cooling fluid being at a lesser temperature than the temperature of the circulating fluid in the other passages to thereby establish a temperature differential and hence a density differential therebetween and thereby produce thermosyphon circulation and recirculation of fluid in the gravity field, and
2. means to extract fluid from said passage system at the same rate that the cooling fluid is being introduced to said passage system.

**15.** A turbomachinery blade adapted to be mounted for rotation on a disc and to have hot gas passed thereover so as to thereby be subjected both to centrifugal force and high temperature including:

1. a blade root adapted to be connected to the blade disc,
2. a blade airfoil section shaped to define the blade tip, the blade leading edge and trailing edge and attached to the blade root to extend radially outwardly therefrom when the blade is mounted on the disc and shaped to define therewithin a passage system including a series of substantially radially extending passages joining an outboard header and an inboard header,
3. a blade tip located at the end of the blade airfoil section opposite to the blade root,

4. a fluid filling said headers and said passages for circulation therein, and
5. means to establish a density differential in the fluid in said passages and thereby establish continuous circulatory flow of said fluid radially outwardly through at least one of said radial passages, through said outboard header, radially inwardly through at least one of said radial passages and said inboard header in multi-pass, recirculation fashion, and

wherein said density differential establishing means including:

1. means to inject a cooling fluid into one of said passages said cooling fluid being at a lesser temperature than the temperature of the circulating fluid in the other passages to thereby establish a temperature differential and hence a density differential therebetween and thereby produce thermosyphon circulation and recirculation of fluid in the gravity field, and
2. means to extract fluid from said passage system at the same rate that the cooling fluid is being introduced to said passage system, and, further,

wherein said blade has at least one aperture in the blade trailing edge and wherein the extracted fluid is discharged through apertures in the blade trailing edge to cool the blade trailing edge.

16. A turbomachinery blade adapted to be mounted for rotation on a disc and to have hot gas passed thereover so as to thereby be subjected both to centrifugal force and high temperature including:

1. a blade root adapted to be connected to the blade disc,
2. a blade airfoil section shaped to define the blade tip, the blade leading edge and trailing edge and attached to the blade root to extend radially outwardly therefrom when the blade is mounted on the disc and shaped to define therewithin a passage system including a series of substantially radially extending passages joining an outboard header and an inboard header,
3. a blade tip located at the end of the blade airfoil section opposite to the blade root,
4. a fluid filling said headers and said passages for circulation therein, and
5. means to establish a density differential in the fluid in said passages and thereby establish continuous circulatory flow of said fluid radially outwardly through at least one of said radial passages, through said outboard header, radially inwardly through at least one of said radial passages and said inboard header in multi-pass, recirculation fashion, and

wherein said density differential establishing means including:

1. means to inject a cooling fluid into one of said passages said cooling fluid being at a lesser temperature than the temperature of the circulating fluid in the other passages to thereby establish a temperature differential and hence a density differential therebetween and thereby produce thermosyphon circulation and recirculation of fluid in the gravity field, and
2. means to extract fluid from said passage system at the same rate that the cooling fluid is being introduced to said passage system, and, further,

wherein said blade has at least one aperture in the blade trailing edge and wherein the extracted fluid is discharged through apertures in the blade trailing edge



to cool the blade trailing edge, and, still further, wherein said fluid extraction means includes an orifice joining one of said headers to a blade trailing edge header which is connected to the hot gas stream through said blade trailing edge apertures.

17. A turbomachinery blade adapted to be mounted for rotation on a disc and to have hot gas passed thereover so as to thereby be subjected both to centrifugal force and high temperature including:

1. a blade root adapted to be connected to the blade disc,
2. a blade airfoil section shaped to define the blade tip, the blade leading edge and trailing edge and attached to the blade root to extend radially outwardly therefrom when the blade is mounted on the disc and shaped to define therewithin a passage system including a series of substantially radially extending passages joining an outboard header and and inboard header,
3. a blade tip located at the end of the blade airfoil section opposite to the blade root,
4. a fluid filling said headers and said passages for circulation therein, and
5. means to establish a density differential in the fluid in said passages and thereby establish continuous circulatory flow of said fluid radially outwardly through at least one of said radial passages, through said outboard header, radially inwardly through at least one of said radial passages and said inboard header in mulit-pass, recirculation fashion, and

wherein said density differential establishing means including:

1. means to inject a cooling fluid into one of said passages said cooling fluid being at a lesser temperature than the temperature of the circulating fluid in the other passages to thereby establish a temperature differential and hence a density differential therebetween and thereby produce thermodyphon circulation and recirculation of fluid in the gravity field, and
2. means to extract fluid from said passage system at the same rate that the cooling fluid is being introduced to said passage system, and, further,

wherein said blade has at least one aperture in the blade trailing edge and wherein the extracted fluid is discharged through apertures in the blade trailing edge to cool the blade trailing edge, and, still further, wherein said fluid extraction means includes an orifice joining one of said headers to a blade trailing edge header which is connected to the hot gas stream through said blade trailing edge apertures, and wherein said one header is the inboard header.

18. A turbomachinery blade adpated to be mounted for rotation on a disc and to have hot gas passed thereover so as to thereby be subjected both to centrifugal force and high temperature including:

1. a blade root adapted to be connected to the blade disc,
2. a blade airfoil section shaped to define the blade tip, the blade leading edge and trailing edge and attached to the blade root to extend radially outwardly therefrom when the blade is mounted on the disc and shaped to define therewithin a passage system including a series of substantially radially extending passages joining an outboard header and an inboard header,

3. a blade tip located at the end of the blade airfoil section opposite to the blade root,
4. a fluid filling said headers and said passages for circulation therein, and
5. means to establish a density differential in the fluid in said passages and thereby establish continuous circulatory flow of said fluid radially outwardly through at least one of said radial passages, through said outboard header, radially inwardly through at least one of said radial passages and said inboard header in multi-pass, recirculation fashion, and

wherein said density differential establishing means including:

1. means to inject a cooling fluid into one of said passages said cooling fluid being at a lesser temperature than the temperature of the circulating fluid in the other passages to thereby establish a temperature differential and hence a density differential therebetween and therebyproduce thermosyphon circulation and recirculation of fluid in the gravity field, and
2. means to extract fluid from said passage system at the same rate that the cooling fluid is being introduced to said passage system, and, further, wherein said blade has at least one aperture in the blade trailing edge and wherein the extracted fluid is discharged through apertures in the blade trailing edge to cool the blade trailing edge, and, still further, wherein said fluid extraction means includes an orifice joining one of said headers to a blade trailing edge header which is connected to the hot gas stream through said blade trailing edge apertures, and wherein said orifice is caused to operate in chocked condition.

19. A turbomachinery blade adapted to be mounted for rotation on a disc and to have hot gas passed thereover so as to thereby be subjected both to centrifugal force and high temperature including:

1. a blade root adapted to be connected to the blade disc,
2. a blade airfoil section shaped to define the blade tip, the blade leading edge and trailing edge and attached to the blade root to extend radially outwardly therefrom when the blade is mounted on the disc and shaped to define therewithin a passage system including a series of substantially radially extending passages joining an outboard header and an inboard header,
3. a blade tip located at the end of the blade airfoil section opposite to the blade root,
4. a fluid filling said headers and said passages for circulation therein, and
5. means to establish a density differential in the fluid in said passages and thereby establish continuous circulatory flow of said fluid radially outwardly through at least one of said radial passages, through said outboard header, radially inwardly through at least one of said radial passages and said inboard header in multi-pass, recirculation fashion, and

wherein said density differential establishing means including:

1. means to inject a cooling fluid into one of said passages said cooling fluid being at a lesser temperature than the temperature of the circulating fluid in the other passages to thereby establish a temperature differential and hence a density differential therebetweeen and thereby produce thermosyphon circulation and recirculation of fluid in the gravity field, and
2. means to extract fluid from said passage system at the same rate that the cooling fluid is being introduced to said passage system, and

wherein said system circulatory fluid is steam above critical pressure and temperature and wherein said lower temperature cooling fluid is water above critical pressure and at low temperature.

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