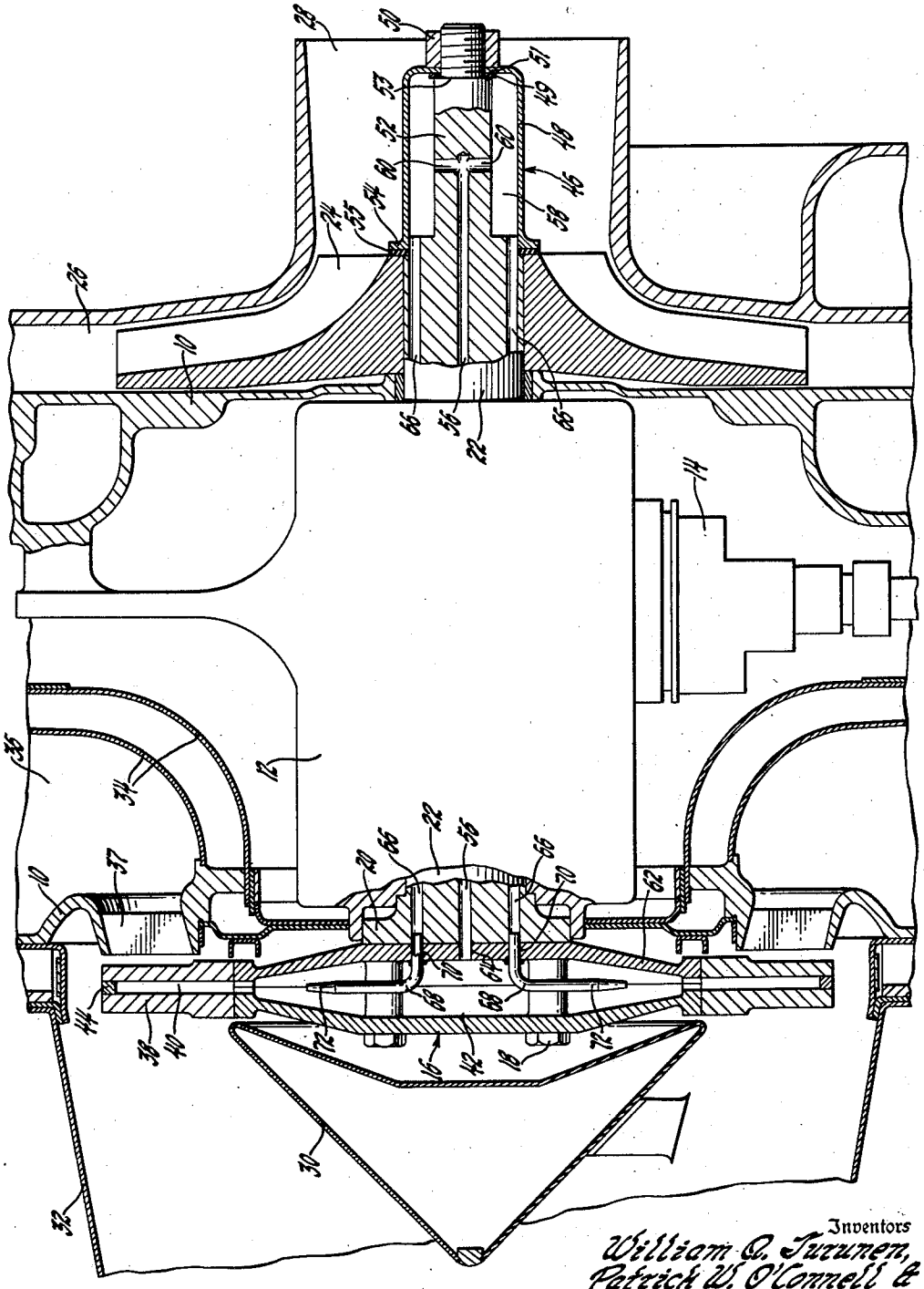
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TURBINE BLADE COOLING SYSTEM

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TURBINE BLADE COOLING SYSTEM

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This invention relates to elastic fluid turbines and particularly to a turbine blade cooling system wherein cooling of the blades is accomplished through the use of a completely sealed coolant and a condenser which is common to all the blades.

Cooling of the turbine blades has long been one of the major problems in the design of high speed gas turbine engines. In recent years the extensive use of gas turbines in turbojet and turboprop engines has considerably complicated the problems arising in connection with the cooling of turbine blades because of the high speed of rotation and the extreme temperatures encountered.

It is therefore a principal object of the invention to provide a cooling system for elastic fluid turbines in which blade temperatures are substantially reduced so as to greatly diminish the temperature differential between the turbine blades and the central portions of the turbine wheel. This cooling is accomplished in accordance with this invention by the provision of a completely sealed coolant or heat transfer agent in a turbine engine having turbine blades provided with coolant passages which communicate with a common condenser. Such an arrangement permits the sealed coolant to rapidly transfer heat from the turbine blades to the condenser surface, thus permitting the most effective use of an air stream or other sceondary cooling means.

A further object of this invention is to provide a turbine blade cooling system which tends to minimize sudden temperature surges of short duration, such as may be experienced at the start of turbine operations. The system thus provided functions as a thermal dampener.

These and other objects are best attained in accordance with the invention through the use of a sealed coolant which vaporizes within the blade passages when the blades reach the vaporization temperatures of the coolant. The coolant vapor being lighter than the coolant in the liquid phase is displaced radially inwardly thereby because of centrifugal force and is forced through connecting passages to the common condenser where it is liquified. This liquid coolant is next returned by centrifugal force to the coolant passage in the turbine blades, thus completing the cooling cycle. The heat taken from the hot turbine blades by the vaporization of the coolant is thereby transferred to the common condenser from where it may be removed by any suitable secondary fluid. In this manner, the system utilizes to fullest advantage the large thermal gradient between the hot turbine blades in the gas stream and the relatively cool condenser.

Inasmuch as any cooling normally involves an energy loss, it is desirable to cool the blades only to the maximum permissible operating temperature. The selection of a proper coolant is important in attaining this type of operation. A sealed coolant which boils at approximately the desired blade temperture is preferable. Air or another suitable fluid may be passed over the outside surfaces of the condenser to keep its temperature below the boiling point of the internal coolant. This permits more efficient use of air cooling than is normally obtainable in turbines heretofore used because the condenser may be designed to have heat transfer surfaces considerably larger than the surfaces of air-cooled turbine blades.

Other objects and advantages of the invention will more fully appear from the following description of a preferred embodiment of the invention taken in conjunction with the accompanying drawing which shows a rather diagrammatic longitudinal sectional view of a turbosupercharger provided with a sealed coolant system embodying the invention.

Referring more specifically to the drawing, there is shown a turbosupercharger having a frame **10** in which is rigidly mounted a bearing support or housing **12**. This bearing support contains appropriate ball or other bearings to which a lubricant is supplied through passages in an oil supply jacket **14**. The rotor includes a turbine wheel, indicated generally by **16**, which is secured by bolts or screws **18** to a hub **20** at the rearward end of a rotatable shaft **22**. An impeller **24** serving as a centrifugal compressor is shrink-fitted, splined or otherwise suitably mounted on the opposite or forward end of the shaft and is driven thereby to supply air under pressure through radially extending passages **26** to a diffuser, which is not shown. This air, of course, enters the compressor through the large air inlet opening **28** at the forward end of the turbosupercharger.

A tail cone **30** and an exhaust or tail pipe **32** are provided at the turbine or rearward end of the turbosupercharger in a conventional manner. Appropriate heat shields **34** are shown as located between the turbine wheel and the compressor and, with the shell **10**, define ducts **36** for the conveyance of the combustion gases to nozzle blades **37** and thence to the turbine wheel. It will be understood, of course, that this blade cooling system embodying the invention is not restricted to use in a turbosupercharger and that it is appropriate for almost any turbine engine or other turbine machine. In other words, it is immaterial to the present invention what sort of combustion chamber the air flows through between the compressor and the turbine wheel.

A plurality of turbine wheel blades **38** are affixed to the outer periphery of the turbine wheel **16** by welding or other suitable means. Each turbine wheel blade is provided with a coolant passage **40** which radially extends through its central portion and communicates with a chamber **42** centrally located within the turbine wheel. The tip of each of these blades is sealed with a welded plug, as indicated at **44**, or in any other appropriate manner.

A heat exchanger or condenser, indicated generally by **46**, having an outer casing or jacket **48** is provided at the compressor end of the shaft **22**, the condenser jacket being rigidly secured to the shaft in any suitable manner, such as by a collar or nut **50** on the threaded end of the reduced condenser portion **52** of the shaft. An annular gasket **49** is shown as positioned between the end wall **51** of the condenser jacket **48** and the annular shoulder **53** on the shaft, the gasket being axially compressed therebetween to seal the system and prevent coolant leakage. The opposite end of the condenser **46** may likewise be sealed by another annular gasket **55** positioned between a radially extending annular flange **54** formed on the outer surface of the condenser jacket and the adjacent face of the compressor impeller. This flange construction also serves to prevent axial movement of the impeller. Hence the shaft fitted with the threaded collar **50** partially functions as a tie rod to maintain these rotor parts in assembled position. It will be understood, of course, that the condenser and other parts of the cooling system may be sealed or located in a manner other than that shown and hereinbefore described.

Extending longitudinally within the shaft is a generally

centrally located tubular passage or duct **56** which provides communication between the turbine wheel chamber **42** and the annular condenser chamber **58** defined by the condenser jacket **48** and the shaft portion **52**. The chamber **42** provides radially extending passages connecting duct **56** with the passages **40** in the blades. In the modification of the invention shown in the drawing, radially extending ducts **60** in the condenser portion of the shaft connect the inner shaft passage **56** with the condenser chamber **58**. The inner wall **62** of the turbine wheel **16** is provided with an opening **64** in its inner face which registers with the central passage **56** and functions as a continuation thereof.

A plurality of other axially extending ducts or passages **66** are disposed within the shaft near its outer peripheral surface. These outer ducts extend throughout the entire length of the enlarged portion of the shaft and permit the chamber **42** in the turbine wheel to communicate with the condenser chamber **58** at points immediately adjacent to the inner surface of the condenser jacket **48**. Tubes **68** defining radially extending passages are positioned in the turbine ends of the outer ducts **66** and function as extensions thereof. These tubes extend into the turbine wheel chamber **42** through openings **70** provided in the inner wall **62** of the turbine wheel and may be secured to the wheel or shaft hub **20** by brazing or other suitable means. The portions of the tubes **68** within the turbine wheel are bent to extend radially outwardly and the outer ends are shown as tapered to form nozzles **72**. These nozzles are preferably aligned with the passages **40** in the turbine blades to provide optimum flow of the fluid cooling medium from the condenser to the hollow blades.

Provision of a number of ducts **66** is preferable to a construction in which the coolant is returned to the turbine through a single annular passage in the shaft because it maintains the static and dynamic balance of the rotor to a greater extent. The number of tubes **68** may be equal to the number of blade passages **40** if desired, but need not be.

A suitable quantity of an appropriate coolant, which would usually be in the liquid state under atmospheric pressure at room temperatures, is contained within the sealed system provided by the condenser **46**, the turbine wheel chamber **42** and the various passages. Normally only a relatively small proportion of these chambers and passages constituting the sealing system could be occupied by the coolant in the liquid state, the amount of coolant preferably being sufficient, when completely in the liquid phase, to occupy the blade passages **40** and a small portion of the condenser chamber **58**. In this manner the weight of the apparatus is kept at a minimum, and the internal pressure due to vaporization of the coolant does not become excessive under operating conditions. Of course, the amount of coolant to be used in various applications is dependent in each case upon the type of coolant employed, the cooling rate desired, and other operating conditions. These fatcors will be hereinafter considered more fully in conjunction with the discussion of the coolants which can be used in the system.

Upon commencing operation of the turbosupercharger, the liquid coolant within the sealed system is thrown outwardly into the blade passages **40** and against the inner peripheral wall of the condenser jacket **48** by centrifugal force due to the rotation of the rotor. The liquid coolant remains in contact with the inner walls of the heated turbine wheel blades **38**, which are exposed to the hot combustion gases, until the blades become sufficiently heated to create convection currents in the coolant. As the coolant is heated it becomes less dense, of course, and this difference in density between the hot and cold portions of the coolant establishes an automatic circulation which is supplemented by the centrifugal force due to the high velocity of rotation.

When the turbine blades **38** reach the vaporization temperature of the coolant the portion of the coolant in contact with the walls of the blade passages **40** vaporizes. The coolant portion which remains in the liquid state, being heavier than the coolant in the vapor phase, then displaces the latter within the blade passages due to the effects of centrifugal force, thereby forcing the vapor into the turbine wheel chamber **42**. The pressure caused by the constant vaporization of the coolant thus drives the vaporized coolant into the turbine end of the central passage **56** in the shaft and through this passage into the condenser **46**. Centrifugal force and the vapor pressure of the vaporized coolant drive this liquid coolant radially outwardly through ducts **60** in the shaft and against the inner peripheral surface of the condenser jacket **48**. The condenser is preferably located in a position where it is exposed to a cold air stream, thus causing the vapor to rapidly condense and cool on the inside of the condenser jacket wall.

The liquified coolant is next driven by centrifugal force and the pressure of the gaseous coolant entering the condenser through ducts **60** into the outer passages **66** in the turbine shaft. This liquid is then forced, primarily by centrifugal force into tubes **68** and is discharged from nozzles **72** back into the coolant passage **40** in the turbine blades, thus completing the coolant cycle. The heat removed from the hot turbine blades by the vaporization of the coolant is thereby transferred to the common condenser. As this cycle is repeated the turbine blades reach and maintain a constant temperature which will be accurately controlled as a result of the above-described circulatory action.

It will be realized, of course, that vaporization of the coolant need not occur along the full length of the blades and may not occur under some conditions in the blade passages due to the centrifugal pressure at these points being greater than the vapor pressure of the coolant. Under these conditions, convection cooling will take place to the point where vaporization can occur.

It will also be understood that, depending upon the design, operating temperatures of the turbine and the type of coolant used, a portion of the coolant in some instances may be condensed within turbine wheel chamber **42** and/or the passage **56**. This condensation of the coolant before it reaches the condenser in no way interferes with the proper and efficient operation of this cooling system. Any coolant which condenses in the turbine wheel chamber is thrown outwardly by centrifugal force into the blade passages **40**, thus permitting the heat exchanging cycle to continue with no detrimental effects.

If a coolant is employed which has a boiling point above the temperature of the turbine blades, the cooling of the blades is dependent upon the differences in density between the hot and cold portions of the liquid coolant. These density differences, in conjunction with the centrifugal force due to the high rotational velocity of the turbine engine, cause an automatic circulation of the coolant within the engine, thus transferring heat from the hollow turbine wheel blades to the relatively cool condenser.

Selection of the proper internal coolant is therefore of major importance, of course. Among the requirements of an ideal coolant are those relating to boiling point, stability, and freezing point. The boiling point of the selected coolant should be at approximately the same temperature at which it is desired to hold the turbine wheel blades. Of course, the coolant should also be chemically stable and should not undergo any changes in its properties under operations which would permit it to attack the blades or other metal parts. The freezing point of the coolant is preferably as low as possible in every case, it being desirable to use a coolant having a freezing point below any temperature the turbine may encounter during shutdown. If conditions should warrant the use of a coolant which is a solid

under atmospheric pressure at room temperatures, provision should be made to equally distribute the solidified coolant circumferentially upon stopping the turbine and thus provide for static and dynamic turbine balance upon the resumption of turbine operation.

Density is another consideration in the selection of a proper coolant. Inasmuch as the pressure developed in the blade passages due to centrifugal force varies directly as the density of the coolant, this density should be as low as possible to avoid high stresses. A high heat of vaporization and a high specific heat are also desirable in a liquid coolant. Accordingly, distilled water, sulphur, mercury, phosphorus and sodium are example of coolants which give satisfactory results for this type of cooling under particular conditions of operation and design.

While the described embodiment of the present invention constitutes a preferred form, it is to be understood that other forms might be adopted, all coming within the scope of the following claims.

We claim:

1. A turbine rotor construction comprising a rotatable shaft, an annular condenser chamber connected to said shaft and rotatable therewith, a turbine wheel mounted on said shaft and spaced axially of the shaft from the condenser chamber, a plurality of rotor blades circumferentially disposed on the outer peripheral surface of said turbine wheel and affixed thereto, each of said blades having a coolant passage in its central portion which is sealed at its outer end, said turbine wheel being provided with radially extending passages communicating with the passages in said blades, said shaft having axially extending ducts therein connecting the condenser with the radially extending passages in the turbine wheel, at least one of said axially extending ducts communicating with a radially outer portion of said condenser chamber for conducting a sealed coolant from said condenser chamber to the radially extending passages in the turbine wheel, at least one other of said ducts communicating with a radially inner portion of said condenser chamber to convey the coolant from said turbine wheel passage to said condenser chamber.

2. In a gas turbine engine, a rotor construction comprising a rotatable shaft, a generally cylindrical casing coaxial with and surrounding a portion of said shaft and forming an annular condenser chamber therewith, said casing being affixed to and rotatable with said shaft, a turbine wheel mounted on said shaft, a plurality of rotor blades circumferentially disposed on the outer periphery of said turbine wheel and affixed thereto, each of said blades having a coolant passage in its central portion which is sealed at its outer end, said turbine wheel being provided with radially extending passages communicating with the passages in said blades, said shaft having a generally centrally located tubular duct extending longitudinally therein to provide communication between one of the radially extending passages in the turbine wheel and the annular condenser chamber near its radially inner portion for conveying a sealed coolant in its gaseous phase from said turbine wheel passage to said condenser chamber, and a plurality of other longitudinally extending ducts disposed within the shaft near its outer periphery and connecting the radially extending passages in the turbine wheel with the condenser chamber at points immediately adjacent the generally cylindrical inner surface of the casing for conducting the said sealed coolant in its liquid phase from said condenser chamber to said radially extending passages.

3. In an engine, in combination, a gas turbine comprising a turbine wheel, the wheel including a disk and hollow turbine blades mounted on the disk and closed at the end remote from the disk; a compressor including a rotor and provided with an inlet passage; a condenser mounted on the said rotor in the inlet passage in heat exchange relation with the fluid flowing into the compressor; means defining passages connected to the condenser and the turbine blades for circulation of a coolant between the condenser and the turbine blades; the condenser, the passage defining means, and the blades defining a closed system; and a normally liquid coolant of small volume relative to that of the system sealed therein, the coolant being adapted to be vaporized in the turbine wheel and condensed in the condenser.

4. An engine comprising a gas turbine comprising a turbine wheel, the wheel including a disk and hollow turbine blades mounted on the disk and closed at the end remote from the disk; the engine being provided with a fluid inlet passage; a shaft mounting the turbine wheel for rotation; a condenser mounted on the shaft in the inlet passage in heat exchange relation with fluid flowing into the engine; the shaft and the turbine disk defining passages for circulation of a coolant between the condenser and the turbine blades; the condenser, the passages in the shaft and the turbine disk, and the blades defining a closed system; and a normally liquid coolant of small volume relative to that of the system sealed therein, the coolant being adapted to be vaporized in the turbine wheel and condensed in the condenser.

5. In an engine, in combination, a gas turbine comprising a turbine wheel, the wheel including a disk and hollow turbine blades mounted on the disk and closed at the end remote from the disk; a compressor including a rotor and provided with an inlet passage; a shaft mounting the turbine wheel and compressor rotor for rotation; a condenser mounted on the shaft in the inlet passage in heat exchange relation with fluid flowing into the compressor; the shaft defining passage means for circulation of a coolant between the condenser and the turbine wheel, and the turbine disk defining passage means between the passage means in the shaft and the turbine blades; the condenser, the passage means in the shaft and the turbine disk, and the blades defining a closed system; and a normally liquid coolant of small volume relative to that of the system sealed therein, the coolant being adapted to be vaporized in the turbine wheel and condensed in the condenser.

6. An engine comprising a gas turbine comprising a turbine wheel, the wheel including a disk and hollow turbine blades mounted on the disk and closed at the end remote from the disk; the engine being provided with a fluid inlet passage; a heat exchanger structurally connected to and rotatable with the wheel disposed in heat exchange relation with fluid flowing through the inlet passage into the engine; means defining passages connected to the condenser and the turbine blades for circulation of a coolant between the heat exchanger and the turbine blades; the heat exchanger, the passage defining means, and the blades defining a closed system; and a coolant sealed within the said system.

7. In an engine, in combination, a gas turbine comprising a turbine wheel, the wheel including a disk and hollow turbine blades mounted on the disk and closed at the end remote from the disk; a compressor including a rotor and provided with an inlet passage; a shaft mounting the turbine wheel and compressor rotor for rotation; a heat exchanger mounted on the shaft in the inlet passage in heat exchange relation with fluid flowing into the compressor; the shaft defining passage means for circulation of a coolant between the heat exchanger and the turbine wheel and the turbine disk defining passage means between the passage means in the shaft and the turbine blades; the said heat exchanger, the passage means in the shaft and the turbine disk, and the blades defining a closed system; and a coolant sealed within the said system.

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