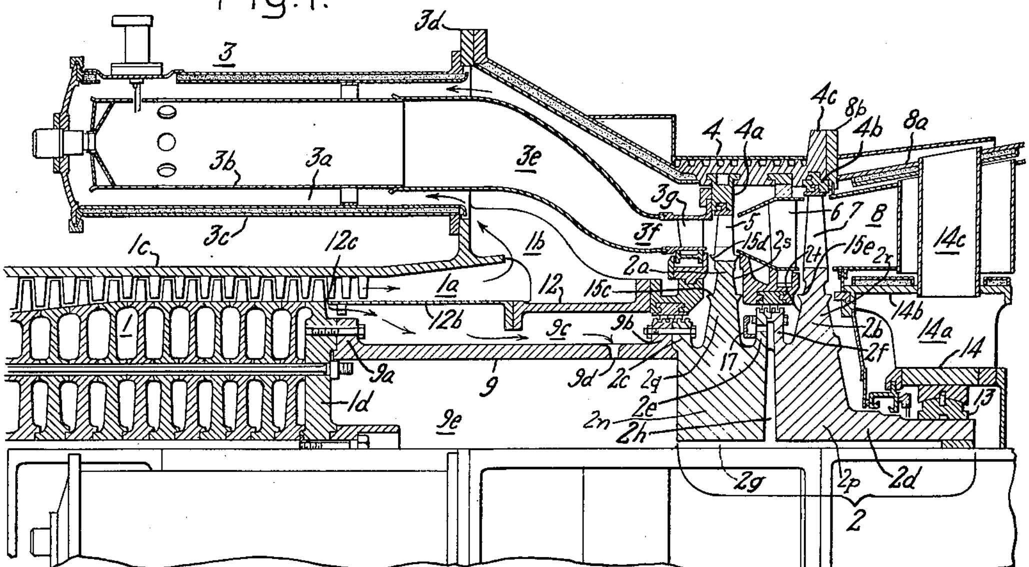
July 10, 1962 G. W. SCHEPER, JR 3,043,561

TURBINE ROTOR VENTILATION SYSTEM

Filed Dec. 29, 1958

Fig. 1.



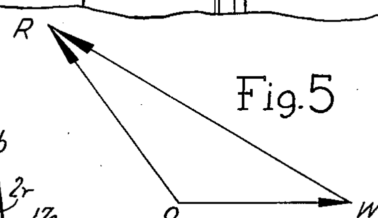


Fig. 5

Fig. 2.

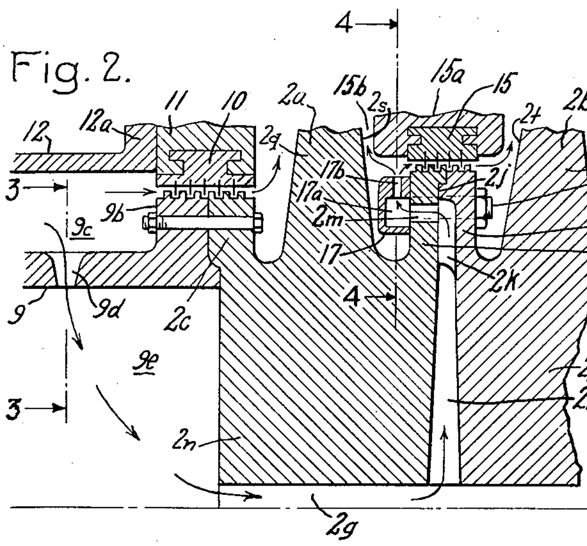


Fig. 3.

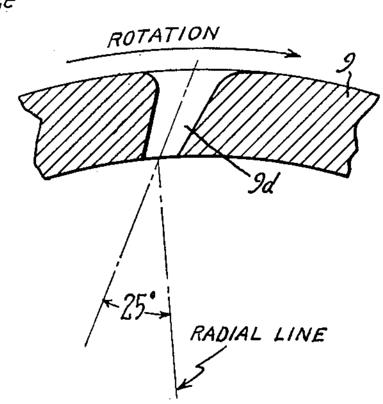
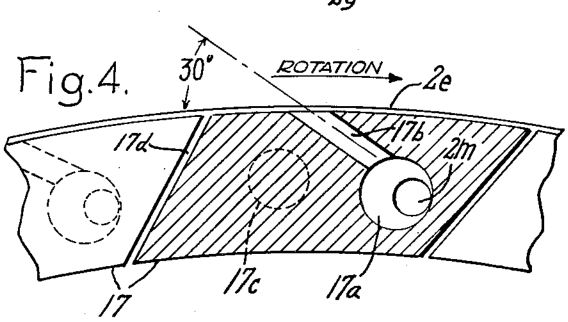


Fig. 4.



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TURBINE ROTOR VENTILATION SYSTEM

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This invention relates to elastic fluid turbine powerplants, particularly to an arrangement for supplying preheating and cooling fluid to the multiple disk type rotor of a gas turbine powerplant.

The rotor of a gas turbine powerplant having an output on the order of 13,000 H.P. may for instance be about 50 inches in diameter, designed to have a normal rated speed of 4,800 r.p.m. The first stage buckets of such a rotor may operate at an average temperature on the order of 1,200° F., and the rim of the first stage wheel may attain temperatures on the order of 1,000° F. Because of the enormous centrifugal forces generated at these speeds, complicated by the thermal stresses added by the high temperatures and the substantial temperature gradients set up by the cooling systems employed to protect the turbine from excessive temperatures, the rotor must be fabricated of carefully chosen high temperature alloy materials. A problem which has become of increasing importance in recent years is the existence of a previously unknown "transition temperature" below which certain otherwise desirable high temperature alloys show very markedly lower impact strength than the normal properties they attain at temperatures above this critical value. In particular, certain ferritic high temperature alloys exhibit undesirably high "transition temperature." A number of rotors in steam and gas turbine service had failed, with extremely serious consequences, before it was decided that these machines had apparently been brought up to full rated speed so quickly that the alloy of which the rotor was fabricated had not had a chance to achieve its full strength before attaining rated speed. accordingly, it has been found necessary to impose certain limiting rates of change of temperature, or requirements that the operators in some manner preheat the rotor before bringing it to normal rated speed. Thereafter, in order to operate the gas turbine continuously at its most efficient temperature level, it is necessary to provide a cooling system for the high temperature turbine rotor, in order that maximum safe temperatures for the rotor material will not be exceeded.

Accordingly, an object of the present invention is to provide an improved system for preheating the high temperature alloy rotor of a gas turbine powerplant during the starting cycle so that the alloy material is quickly brought above the "transition temperature," so that its full normal srength will be available before the rotor is brought up to rated speed.

Another object is to provide an improved cooling system for the high temperature alloy rotor of a gas turbine powerplant, of great simplicity from the standpoint of changes in the turbine structure required, while entailing a minimum expenditure of pressure energy of the cooling fluid by optimum utilization of a minimum quantity of coolant flow.

Other objects and advantages will become apparent from the following description, taken in connection with the accompanying drawings in which—

FIG. 1 is a partial longitudinal sectional view of a gas turbine powerplant having a rotor preheating and cooling system incorporating the invention;

FIG. 2 is an enlarged detail view of a portion of FIG. 1;

FIG. 3 is a detail sectional view taken at the plane 3—3 in FIG. 2;

FIG. 4 is a detail view taken at the plane 4—4 in FIG. 2; and

FIG. 5 is a velocity diagram for the invention.

Generally stated, the invention is practiced by taking a small quantity of preheating and cooling air from the discharge passage of the compressor of the gas turbine powerplant, admitting it to a central chamber in the high temperature rotor by way of a circumferential row of nozzles disposed in the rotor at an angle so as to extract thermal energy from the cooling air and at the same time impart rotational energy to the rotor, conducting the coolant fluid through cooling passages in the high temperature rotor, and discharging it by way of a plurality of nozzles which are also directed rearwardly so as to extract additional thermal energy from the coolant and impart additional rotational energy to the rotor.

Referring now more particularly to the drawings, FIG. 1 illustrates the invention as applied to a gas turbine powerplant comprising a multi-stage axial flow compressor **1**, a two-stage axial flow turbine rotor **2**, and a combustion system represented by the single combustion chamber or "combustor" **3**.

The axial flow compressor **1** may be of any suitable construction, and may for instance have on the order of 16 stages, and a discharge pressure in the neighborhood of 100 pounds per square inch, absolute. The annular discharge passage **1*a*** delivers high pressure air past a circumferential row of supporting struts **1*b*** into an annular air supply passage **3*a*** defined between the inner liner **3*b*** and the outer cylindrical housing **3*c*** of the combustor **3**, as indicated by the flow arrows in FIG. 1. As will be understood by those acquainted with gas turbine construction, the combustor **3** is a cylindrical or "can-type" combustor, for instance of the type described in Patent 2,601,000, issued in the name of A. J. Nerad on June 17, 1952, and assigned to the same assignee as the present application. It will be understood that there are ordinarily a number of these combustors circumferentially spaced around the axial flow compressor casing **1*c***, in radially spaced relation thereto and secured to a circumferentially extending supporting flange **3*d***. Each of the inner liners **3*b*** discharges hot motive fluid into a "fish-tail" transition piece **3*e***, the discharge ends of which cooperate at **3*f*** to define an annular passage discharging into the stationary nozzle ring **3*g***.

The casing of the turbine includes an outer casing member **4** provided with a suitable air or water cooling system (not shown) and supporting a segmental shroud ring **4*a*** which surrounds with a small clearance the circumferential row of buckets **5** on the first stage turbine wheel **2*a***. Casing **4** also supports an intermediate row of stationary nozzle blades **6** which discharge the motive fluid to the second stage buckets **7**. Spent motive fluid is discharged through an annular expanding diffusing passage **8**. The downstream end of casing **4** supports a segmental shroud ring **4*b*** defining appropriate close clearances with the tips of the buckets **7**. The outer wall structure of the discharge casing **8** is illustrated at **8*a*** as having an upstream end flange **8*b*** appropriately secured to the downstream flange **4*c*** of the casing **4**.

The rotor structure, to which the present invention particularly relates, includes a cylindrical member **9**, having at one end a flange **9*a*** sceured to the abutting end disk **1*d*** of the axial flow compressor **1**. The opposite end of the connecting cylinder **9** has a flange **9*b*** secured to an abutting flange **2*c*** of the first stage bucket-wheel **2*a***.

As will be better apparent in FIG. 2, the periphery of the flange **9*b*** of the cylindrical member **9** and the abutting flange **2*c*** of the bucket wheel **2*a*** defines a plurality of circumferential grooves, the annular lands between which form a labyrinth seal with a segmental sealing member

10 supported in a circumferential groove formed by a ring member 11 connected at one end to a flange 12a of a cylindrical member 12 supported from the inner ends of the struts 1b. The other end portion of the seal support member 11 supports the inner periphery of the high temperature nozzle ring assembly 3g (FIG. 1). The outer periphery of the high temperature nozzle ring is connected to the segmental shroud ring 4a in a manner which will be apparent from the drawing.

The downstream side of the second stage bucket-wheel 2b is provided with an axial extension 2d supported in a journal bearing 13 carried in a housing 14 which is in turn supported by struts 14a from a cylindrical member 14b which is in turn carried by radially extending struts 14c extending across the exhaust gas discharge passage 8, with their outer ends supported in the outer casing member 8a.

Further details of the axial flow compressor 1, the combustion system, and the stationary casing, shroud, and intermediate nozzle assembly are not necessary to an understanding of the present invention, and the arrangement of these components will be sufficiently apparent from the drawing.

The bucket-wheels 2a, 2b are fabricated separately and bolted together by means of abutting circumferential flange portions 2e, 2f. The periphery of these flanges define annular labyrinth sealing teeth cooperating with a segmental sealing ring member 15 carried in a casing 15a supported from the inner ends of the intermediate nozzle blades 6.

The special arrangement for circulating preheating and cooling air through the high temperature turbine rotor includes the following.

The cylindrical inner wall 12b of the compressor discharge passage 1a defines an annular clearance space at 12c through which high pressure air is admitted to the annular chamber 9c defined between the walls 12, 12b and the connecting cylinder member 9. Adjacent its right-hand end, the cylinder 9 defines a circumferential row of nozzles 9d. As illustrated more particularly in FIG. 3, these nozzles are holes drilled and reamed to have a slight inward taper so as to define a contracting nozzle directing a jet inwardly and with a substantial tangential absolute velocity component. Specifically, the axis of the nozzle defines approximately a 250° angle with a radial line. With a compressor last stage rotor discharge pressure of approximately 90 p.s.i.a. maintained in the chamber 9c, there will be a pressure drop across the nozzles 9d with the downstream pressure inside cylinder 9 maintained at approximately 45 p.s.i. By thus arranging the nozzles 9d at a sufficient angle to the radial, i.e. "backwards" with reference to the clockwise direction of rotation noted in FIG. 3, the inwardly directed jets impart rotational energy to the cylinder 9. The work energy thus extracted from the cooling air reduces its temperature substantially.

It may be noted that there are three of the nozzles 9d, each of a minimum diameter of .80 inch, and the cylinder 9 has an approximate diameter of 26 inches and is 2 inches thick, in the powerplant shown in the drawings.

Referring again to FIGS. 1 and 2, from the central chamber 9e, cooling air flows to the right through a central axial passage 2g in the hub 2n of the first stage bucket-wheel 2a. It need now be observed that the first and second stage bucket-wheels 2a, 2b have hub portions 2n, 2p and web portions 2q, 2r spaced axially to define a radially extending annular cooling air passage 2h. It will also be seen that the abutting annular hub flange portions 2e, 2f have an interfitting rabbet portion at 2j for maintaining accurate concentricity. This abutting flange portion is provided with a plurality of radially extending slots 2k which admit the cooling air flow to axial holes 2m spaced around the flange 2e. The cooling air is discharged through a circumferential row of nozzles 17b defined in special members 17 the shape of which is shown more particularly in FIG. 4.

The nozzle member, indicated generally as 17 in the drawings, comprises a trapezoidal shaped block, the beveled end portion of which substantially abuts a mating beveled end of the next adjacent nozzle block, as shown at 17d in FIG. 4. The right-hand half of the block 17 defines a circular recess 17a communicating with the air inlet port 2m, and discharges through a nozzle 17b, the latter preferably formed as a simple drilled and reamed passage because of the difficulty of machining a contracting tapered nozzle in this location. Here it will be seen that the axis of the nozzle 17b is at an angle of approximately 30° to a tangent to the periphery of the flange 2e. Thus the jets discharged from the circumferential row of nozzles 17b again impart rotational energy to the wheel. Here also there is a pressure drop, from about 45 p.s.i. in the chamber 17a to about 30 p.s.i. in the annular space 15b defined between the web porton 2q of the bucket wheel 2a and the adjacent interstage packing housing 15a. The work done by the backwardly directed jets from the nozzles 17b again reduces the temperature, perhaps by about 50° F. It may be noted that there are 24 nozzles 17 in the machine shown, and the diameter of the holes 17b is about .40 inch.

A typical vector diagram for the nozzle of FIG. 4 may be seen in FIG. 5, it being understood that the same type of analysis applies to the nozzle of FIG. 3. Vector OW represents the absolute velocity of the nozzles in a tangential direction as determined by their distance from the rotor axis and the rotor r.p.m. Vector WR is the exit velocity of the gas relative to the nozzle. The resultant OR is the absolute velocity of the gas as it leaves the nozzle. The change between the tangential component of absolute gas velocity OR and the tangential absolute velocity component of the gas entering the nozzle will impart rotational energy to the rotor. The energy thus lost by the gas serves to reduce its temperature.

A second function of the segmental blocks 17 is to serve as the head of a bolt member, shown in dotted lines at 17c in FIG. 4, which bolt passes through the flanges 2e, 2f to hold the bucket-wheels together.

The cooling air in the annular space 15b escapes by two paths. The first is radially outward along the web 2q of the wheel 2a and past annular sealing rings identified 15c, 15d in FIG. 1. The second path of escape for the cooling air is through the segmental packing 15, the rate of such flow being determined by the packing clearance. This coolant passes radially outward along the upstream face 2t of the second stage wheel 2b, past annular sealing ring 15e. Thus the cooling flow is brought into intimate contact with both the downstream surface 2s of wheel 2a and the upstream surface 2t of wheel 2b. The downstream surface of second stage wheel 2b is cooled by a portion of the outer casing cooling air which enters chamber 14a through hollow struts 14c.

Thus it will be apparent that with this special cooling flow path optimum structural simplicity is attained, as compared with arrangements used in the prior art in which the cooling air was taken from an intermediate stage of the compressor and conducted by external piping to the annular spaces adjacent the upstream and downstream sides of the bucket-wheel web portions. With the present invention, no such external piping is required; and, instead, high pressure air from the discharge of the axial flow compressor is conducted by a simple and direct supply path to a central bore of the bucket-wheel, where centrifugal force acting on the cooling air in the annular cooling passage between the first and second stage wheels facilitates circulation of the cooling flow. With the specially arranged nozzles 9d, 17b, the high pressure of the cooling air flow is utilized to impart rotational energy to the rotor, and this work energy extracted from the cooling flow reduces its temperature substantially so as to improve its cooling capacity. With a rate of cooling air flow on the order of 2 pounds per second, a total temperature drop on the order of 90° F. is obtained from the two sets of nozzles, and at the same time approximately 60 H.P. of mechanical energy is imparted to the rotor.

Thus it will be seen that the cooling function may be performed with a minimum quantity of coolant extracted from the compressor discharge flow, and with minimum structural complications.

A second important advantage of the invention lies in the fact that the "cooling air flow" described above may also be employed to "preheat" the rotor during the starting cycle. As described above, it is important to quickly bring the high temperature alloy rotor up past its "transition temperature," above which it develops its optimum strength characteristics. With a ferritic high temperature alloy such as, for instance, one composed of 12% chronium, 1% molybdenum, 1% tungsten, 0.25% vanadium, and the balance iron, this transition temperature may be on the order of 130° F.

With the invention, during a normal starting cycle in which the combustors are ignited at a "firing speed" on the order of 900 r.p.m. followed by controlled acceleration to self-sustaining idling speed of about 3800 r.p.m., the above-described flow of "cooling air" around the first stage bucket-wheel **2a** will now effectively serve to raise the temperature of the highly stressed inner bore portion **2g** of the bucket-wheel past its transition temperature before the rotor is brought to full speed of about 4800 r.p.m. and full bucket temperature of about 1200° F.

With this preheating arrangement, the radial temperature gradient produced by the strong heating of the rim of the wheel through the buckets **5** will be reduced thereby providing an additional benefit of reduction in transient tensile stress at and near the bore of the wheel and reduction in transient compressive stress at the rim.

Thus the preheating arrangement serves to avoid problems which would otherwise arise from stressing the wheel highly while it is still below its "transition temperature," with further benefits derived from the standpoint of the transient thermal stresses created in the respective hub and rim portions.

Thus it will be apparent that, using only extremely simple structure, the invention provides means for performing effectively the turbine rotor cooling function in normal operation, as well as providing simple means for preheating the rotor to attain optimum strength qualities in the high temperature alloy during the starting cycle and minimize the thermal stresses created.

While only one specific embodiment of the invention has been described herein, it will be obvious that many modifications and substitutions of equivalents may be made. It is, of course, intended to cover by the appended claims all such modifications as fall within the true spirit and scope of the invention.

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

1. In a rotor cooling arrangement for an elastic fluid turbine, a source of elastic fluid under pressure having an initial absolute tangential velocity component, a turbine rotor having at least one turbine bucket-wheel for converting fluid pressure energy to rotational energy, said turbine rotor having a cylindrical rotor member defining a first central chamber disposed to supply cooling fluid to the bucket-wheel, a wall member spaced radiallly from said cylindrical rotor member to define a second coolant fluid supply chamber, passage means admitting fluid under pressure from said source to the second coolant fluid supply chamber, first nozzle means disposed in said cylindrical rotor member and directed backwardly with respect to the direction of rotation of the rotor and so constructed and arranged as to have a first tangential absolute velocity component at turbine rated speed and to receive fluid from the second supply chamber and to discharge jets of fluid having a second tangential velocity component relative to said first nozzle means into said first chamber with a third resultant tangential absolute velocity component, the bucket-wheel defining cooling passages receiving fluid from said first chamber and discharging through a plurality of second nozzle means disposed circumferentially around the wheel, said second nozzle means being so constructed and arranged as to have a fourth tangential absolute velocity component at turbine rated speed and to direct jets of coolant having a fifth tangential velocity component relative to said second nozzle means with a resultant sixth tangential absolute velocity component, the construction and arrangement of said nozzle means being such that the total change between said initial and said third velocity components and between said third and said sixth velocity components of the jets through said first and second nozzle means impart rotational energy to the turbine rotor while the energy thus lost by the jets reduces the temperature of the coolant fluid.

2. In a turbine rotor cooling arrangment for a gas turbine powerplant, a compressor supplying air under pressure, a turbine rotor having at least one turbine bucket-wheel for converting fluid pressure energy to rotational energy, said turbine rotor including a cylindrical member defining a first central chamber disposed to supply cooling fluid to the bucket-wheel, a wall member spaced radially from said cylindrical rotor member to define a second coolant fluid supply chamber, passage means admitting air under pressure from the discharge passage of the compressor to said second chamber with an initial tangential absolute velocity component, first nozzle means disposed in said cylindrical rotor member and directed backwardly with respect to the direction of rotation of the rotor and so constructed and arranged as to have a first tangential absolute velocity component at turbine rated speed and to receive fluid from said second chamber and arranged to discharge jets of coolant having a second tangential velocity component relative to said first nozzle means into said first chamber with a third resultant tangential absolute velocity component, the bucket-wheel defining cooling passages communicating with said first chamber, and second nozzle means disposed circumferentially around the bucket-wheel, said second nozzle means being so constructed and arranged as to have a fourth tangential absolute velocity component at turbine rated speed and communicating with said wheel cooling passages, said second nozzle means also being constructed and arranged to discharge jets of coolant having a fifth tangential velocity component relative to said second nozzle means from the bucket-wheel with a sixth resultant tangential absolute velocity component, the construction and arrangement of said nozzle means being such that the total change between said initial and said third velocity components and between said third and said sixth velocity components of the jets through said first and second nozzle means impart rotational energy to the turbine rotor while the energy thus lost by the jets reduces the temperature of the coolant fluid.

3. In a high temperature turbine rotor cooling arrangement, a bucket-wheel having hub and web portions and a circumferential row of blade members, the hub portion defining a central axial passage, a cylindrical rotor member projecting axially from the upstream side of said hub portion and defining a central chamber communicating with the axial passage in the bucket wheel hub, a source of elastic fluid under pressure having an initial tangential absolute velocity component, said cylindrical rotor member defining a first plurality of circumferentially spaced nozzle means directed backwardly with respect to the direction of rotation of the rotor and so constructed and arranged as to have a first tangential absolute velocity component at turbine rated speed and to direct jets of cooling fluid having a second tangential velocity component relative to said first nozzle means into said central

chamber with a third resultant tangential absolute velocity component, the downstream side of the bucket-wheel hub portion including a circumferential portion supporting a second plurality of circumferentially spaced nozzle means, said second nozzle means being so constructed and arranged as to have a fourth tangential absolute velocity component at turbine rated speed and to discharge jets of cooling fluid having a fifth tangential velocity component relative to said second nozzle means into the space adjacent the downstream surface of the bucket-wheel web portion with a sixth resultant tangential absolute velocity component, the hub portion of the rotor also defining radially extending passage means for conducting cooling fluid from the central axial passage to the second nozzle means, the construction and arrangement of said nozzle means being such that the total change between said initial and said third velocity components and between said third and said sixth velocity components of the jets through the first and second nozzle means impart rotational energy to the bucket-wheel while the energy thus lost reduces the temperature of the cooling fluid.

4. In a high temperature turbine rotor cooling arrangement, two separately fabricated bucket-wheels having abutting hub portions defining adjacent circumferentially extending connecting flanges, the upstream bucket-wheel having a central axial pasage for supplying coolant fluid to an annular clearance space defined between adjacent central hub portions of the wheels, a source of coolant fluid under pressure having an initial tangential absolute velocity component, a cylindrical rotor member connected to the upstream side of the first stage bucket-wheel and defining a first central chamber for supplying cooling fluid to said central axial passage, said cylindrical rotor member having a plurality of circumferentially disposed first nozzle means directed backwardly with respect to the direction of rotation of the rotor and so constructed and arranged as to have a first tangential absolute velocity component at turbine rated speed and to direct jets of cooling fluid having a second tangential velocity component relative to said first nozzle means into said first central chamber with a third resultant tangential absolute velocity component, and second nozzle means disposed on the abutting flanged portions of the bucket-wheels and connected to receive cooling fluid from said annular clearance space, said second nozzle means being so constructed and arranged as to have a fourth tangential absolute velocity component at turbine rated speed and being arranged to discharge jets of cooling fluid having a fifth tangential velocity component relative to said second nozzle means with a sixth resultant tangential absolute velocity component, the construction and arrangement of said nozzle means being such that the total change between said initial and said third velocity components and between said third and said sixth velocity components experienced by the cooling fluid in traversing said first and second nozzle means respectively impart rotational energy to the rotor while reducing the temperature of the cooling fluid.

5. A two-stage high temperature turbine rotor comprising first and second stage bucket-wheels fabricated separately and havng abutting circumferential hub flange portions, means securing said hub flange portions together, the first stage bucket-wheel having a central axial passage for cooling fluid, a cylindrical rotor member disposed at the upstream side of the first stage wheel and extending axially to define a central coolant supply chamber, said cylindrical rotor member having a plurality of circumferentially disposed first nozzle means having a first tangential absolute velocity component at turbine rated speed for directing jets of cooling fluid having a second tangential velocity component relative to said first nozzle means inwardly into said central chamber with a resultant third tangential absolute velocity component backwardly relative to the direction of rotation, said hub flange securing means comprising a plurality of fastener members disposed circumferentially around said abutting hub flange portions of the bucket wheels, each of said fastener members comprising a bolt portion disposed through said abutting hub flange portions to secure the bucket-wheels together, said bolt portion including a head member disposed at one side of the abutting flange portions, the head member defining a recess and second nozzle means having a fourth tangential absolute velocity component at turbine rated speed and communicating with the recess, said second nozzle means being arranged to discharge a jet of cooling fluid having a fifth tangential velocity component relative to said second nozzle means with a sixth resultant tangential absolute velocity component backwardly relative to the direction of rotation into the space adjacent the periphery of the abutting hub flange portions, said wheel hub flange portions defining passages for conducting coolant from said central axial passage to the recesses of the respective head members, whereby the jets through the first and second nozzle means impart rotational energy to the rotor while the energy thus lost by the jets reduces the temperature of the coolant fluid.

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