June 14, 1960 B. ECKERT ET AL 2,940,257

COOLING ARRANGEMENT FOR A COMBUSTION TURBINE

Filed March 12, 1954 2 Sheets-Sheet 1

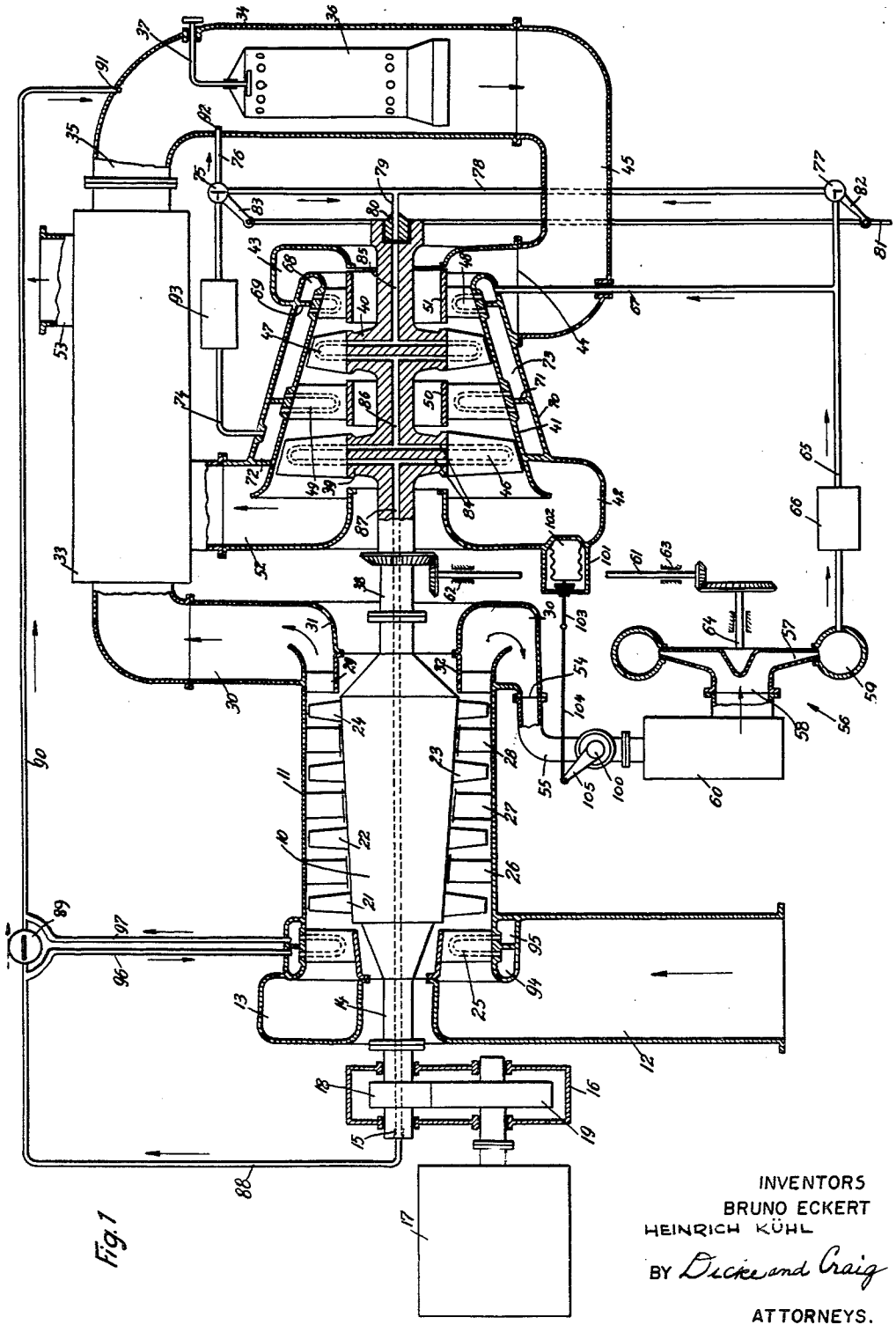


Fig. 1

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Fig. 2

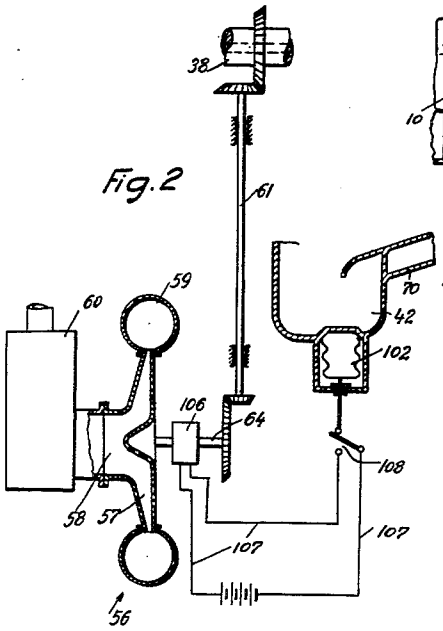


Fig. 4

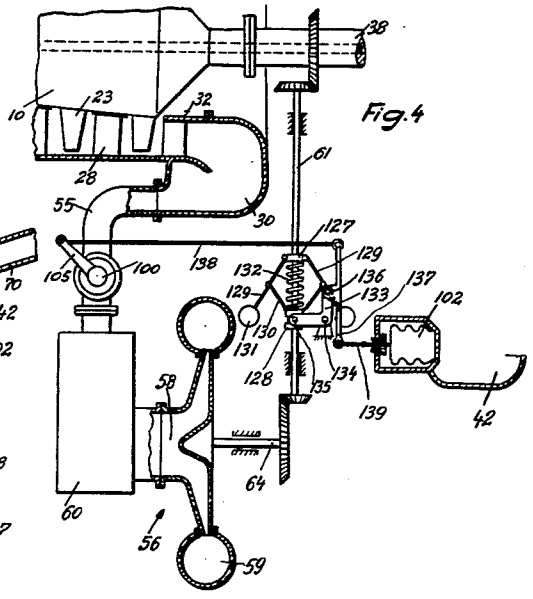


Fig. 3

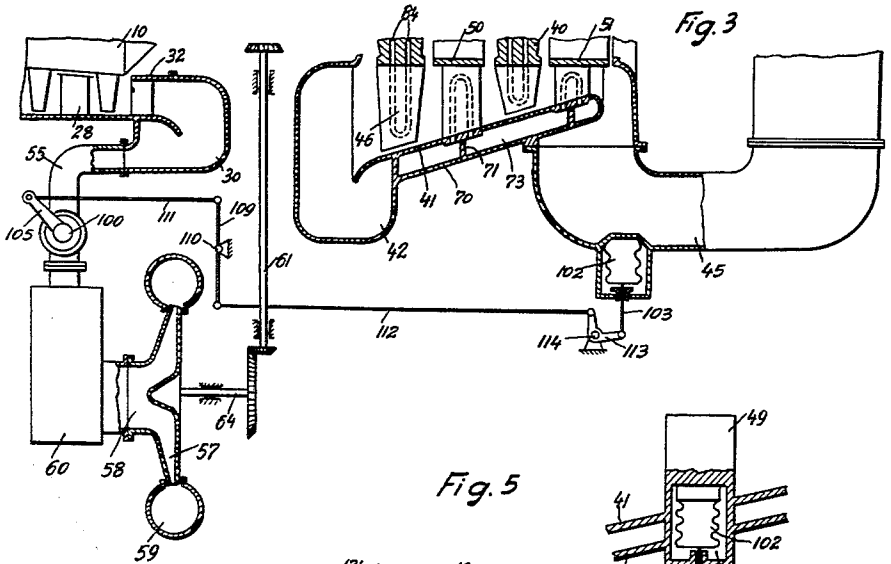
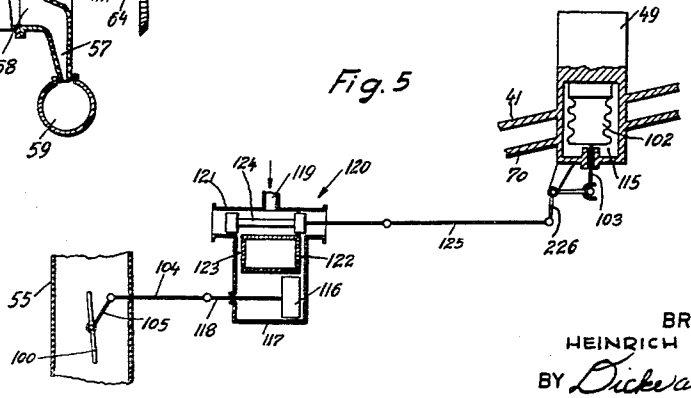


Fig. 5



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COOLING ARRANGEMENT FOR A COMBUSTION TURBINE

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Claims priority, application Germany Mar. 27, 1953

5 Claims. (Cl. 60—39.66)

Our invention relates to a combustion turbine and, more particularly, to the cooling system thereof. More specifically, our invention relates to a combustion turbine of the type in which the vanes are provided with interior ducts included in a conduit system for a gaseous cooling medium, such system extending from an inlet to at least one outlet and being substantially sealed therebetween from the gas stream cooperating with the vanes.

Experience has shown that in practice combustion turbines are frequently operated during a fraction of the total time of operation only under such conditions as require the full cooling effect. Therefore, it is the object of the present invention to improve the efficiency of operation of the turbine by controlling the cooling function in dependence on the temperature of the gas stream flowing through the turbine, or in dependence on the temperature of the turbine vanes.

It is another object of the present invention to render the cooling function independent of the speed of operation of an auxiliary compressor which is included in the cooling conduit system.

Further objects of the present invention will appear from the description following hereinafter of a number of preferred embodiments of the invention with reference to the accompanying drawings in which a number of examples is represented as being illustrative of the various aspects of our invention.

In the drawings,

Fig. 1 is a more or less diagrammatical axial section through the turbine equipped with our improved cooling system,

Fig. 2 is a partial view similar to that of Fig. 1 showing modified controlling means for the cooling air flow, so much of Fig. 1 being shown only as is necessary for an understanding of the modification,

Fig. 3 is a partial view similar to that of Fig. 1 of another modification in which the governing means responsive to the temperature of the vanes is disposed at a point located in the gas stream between the burner and the turbine section,

Fig. 4 is a partial view similar to that of Fig. 1 of another modification in which the controlling means controlling the flow of cooling air is governed by both, temperature-responsive means and speed-responsive means, and

Fig. 5 is a sectional view of a modification similar to Fig. 1 except that the temperature-responsive means is mounted in one of the stationary vanes of the turbine and governs the cooling air valve indirectly.

The combustion turbine illustrated in the drawings as a type adapted to be equipped with our novel cooling system is composed of a compressor section and of a turbine section, both sections having a common rotor journalled in the stator for rotation at a high speed by suitable bearings not shown, the stator comprising suitable housing sections to be described hereinafter.

Within the compressor section the rotor has the form of a slightly conical body 10 and is surrounded by a substantially cylindrical stationary coaxial housing 11, both confining between them an annular space for air or another oxygen-containing gaseous medium which enters the housing 11 through an intake pipe 12 extended by an annular casing 13 communicating with the annular space between rotor body 10 and housing 11. The body 10 is integral with a coaxial shaft of reduced diameter which may be composed of a number of sections, such as 14 and 15, and extends through the annular casing 13 and suitable sealing means and bearings not shown into a stationary transmission casing 16 for transmission of the power produced by the combustion turbine to the driven mechanism 17 which may be that of a vehicle, a vessel, or an aircraft in which the power plant is installed, or any other machine. By way of example, the transmission is shown as including a pair of gears 18 and 19, one of which is fixed to shaft section 15 of the turbine, whereas the other one is connected to the mechanism 17.

A plurality of sets of circumferentially distributed vanes, such as 21, 22, 23 and 24, fixed to the rotor body 10 and radially projecting therefrom outwardly alternate with sets of circumferentially distributed stator vanes, such as 25, 26, 27, 28 and 29, which are fixed to the housing 11 extending inwardly therefrom. Upon rotation of the rotor body 10, the vanes 21 to 29 act on the stream of air entering from the left through casing 13 and urge the stream to the right thereby compressing the air feeding the same into a substantially annular receiver casing 30. The receiver casing 30 may be integral with the cylindrical housing 11 and has a flanged inner wall 31 to which a cylindrical ring 32 is bolted. This ring extends into close proximity of the adjacent outer edge of larger diameter of body 10 and is thus inwardly spaced from housing 11 confining therewith the inlet port of the receiver casing 30. It will be noted that the inner ends of the stationary vanes 29 of the compressor section are fixed to the cylindrical ring 32.

The compressed air is passed from casing 30 through a heat-exchanging device 33, and after having been preheated therein enters a transverse conduit 34 at a point 35 which is axially spaced from the receiver casing 30. The conduit 34 includes a burner 36 in which a suitable liquid combustible, such as oil, fed through a pipe 37 is burnt to convert the stream of pre-heated air into a gas stream of a high temperature for operation of the turbine section.

The rotor of the turbine section which is coaxially fixed to the rotor body 10 comprises a shaft 38 journalled in suitable bearings not shown and provided with a pair of spaced substantially cylindrical portions 39 and 40 of enlarged diameter.

The portions 39 and 40 of the turbine rotor are surrounded by a substantially conical housing 41 which is flaring towards the compressor section, its ends communicating with annular casings 42 and 43 through which the rotor shaft 38 extends, the casing 42 facing the receiver casing 30 being slightly spaced therefrom, whereas the annular casing 43 which communicates with the end of smaller diameter of housing 41 has an inlet port 44 which is connected with the discharge end of conduit 34 by a U-shaped tubular member 45.

Each of the cylindrical sections 39 and 40 of the turbine rotor carries a set of circumferentially distributed vanes 46, or 47 respectively, extending radially into close proximity of housing 41. The latter carries two sets of circumferentially distributed inwardly extending stationary vanes 48, and 49 respectively, which alternate with the sets 46 and 47 of vanes, as will appear from Fig. 1. The inner ends of vanes 49 are fixed to a cylindrical ring 50, while the inner ends of vanes 48 are fixed to a cylin-

drical ring 51. Both rings are substantially flush with the periphery of the cylindrical rotor sections 39 and 40 and extend into close proximity thereof.

The annular casing 42 is provided with an outlet port 52 which is connected to the heat-exchanging device 33 and communicates with an exhaust duct 53 thereof.

The combustion turbine operates as follows:

The air entering the intake pipe 12 is guided by the annular casing 13 into the annular space between rotor body 10 and housing 11 and is compressed therein and fed in compressed condition into the receiver casing 30. From there the stream of compressed air flows through the heat-exchanging device 33 and, after having been pre-heated, enters the conduit 34 constituting the combustion chamber. By the combustion of fuel therein supplied through pipe 37 the compressed air is highly heated. The heated compressed gas stream is admitted through annular casing 43 to the turbine section and is directed by the stationary vanes 48 onto the rotor vanes 47. Upon issue therefrom, the stream of gases is again acted upon by the stator vanes 49 and is directed upon the rotor vanes 46 whence it is collected in the annular casing 43 and from there flows through the heat-exchanging device 33 to the exhaust duct 53, and in this way pre-heats the compressed air flowing from casing 43 to outlet 35. During its passage through between the alternating stator vanes 48, 49 and rotor vanes 47 and 46, the gas stream expands, its heat energy being transformed into mechnical energy.

For the purpose of cooling the vanes 46, 47, 48 and 49, a conduit system is provided having an inlet 54 which communicates with the receiving casing 30 fed with compressed air. A tube 55 extends from such inlet to an auxiliary and additional rotary compressor 56 which is preferably of the centrifugal type comprising an impeller wheel 57 having a central intake 58 and discharging peripherally into a spiral housing 59. Preferably, a cooling device 60 operable by cooling water or cooling air is interposed between the tube 55 and the intake 58 so that the compressed air enters the intake 58 at a comparatively low temperature.

The auxiliary rotary compressor is preferably driven by the rotor of the turbine. In the embodiment shown, a lay shaft 61 mounted in stationary journals 62 and 63 is adapted to be driven through a pair of bevel gears by the turbine shaft 38 and is geared to the impeller shaft 64 of the auxiliary compressor by a second set of bevel gears.

The compressed air is conducted from the spiral casing 59 through a pipe 65 in which a dust filter 66 may be inserted, and through a branch pipe 67 into an end chamber 68 provided by a partition 69 in the interior of a hollow jacket 70 which surrounds housing 41, the remainder of the interior space of such jacket being further subdivided by another partition 71 into chambers 72 and 73. Each of the vanes 46, 47, 48 and 49 is provided with a U-shaped interior duct. The ducts of the vanes 48 communicate through adjacent ports disposed on either side of partition 69 in housing 41 with the chambers 68, and 73 respectively. The ducts of the vanes 49 communicate through adjacent ports disposed on either side of partition 71 in housing 41 with the chambers 73, and 72 respectively. A pipe 74 leads from chamber 72 of jacket 70 to a three-way valve 75 which is connected by a pipe 76 to an outlet 92 communicating with conduit 34. Therefore, the cooling air entering chamber 68 of jacket 70 through pipe 67 will first flow through the interior ducts of the vanes 48 and enter chamber 73. From there it will flow through the interior ducts of stationary vanes 49 and will enter chamber 72. From there it will flow into the combustion chamber provided by conduit 34 if the valve 75 is so set as to connect pipes 74 and 76.

The pipe 65 which is fed with compressed air from the auxiliary compressor leads to a valve 77. Thence a pipe 78 extends to valve 75. Pipe 78 has a branch 79 which is connected with a stationary mouth-piece 80 which contacts the end face of rotor section 38 and communicates with a longitudinal bore thereof. The two valves 75 and 77 are preferably connected by common setting means, such as a link 81 pivotally connected to arms 82 and 83 of the rotatable valve members. When the valves are adjusted as shown, valve 77 is closed, while valve 75 disconnects pipe 76 from and connects pipe 78 to pipe 74 thus permitting the cooling air that has passed the interior ducts of the stationary vanes 48 and 49 to enter pipe 78 from pipe 74 and to flow through mouth-piece 80 into the internal longitudinal duct of the turbine rotor.

This longitudinal central duct is interrupted at the centers of the cylindrical rotor sections 39 and 40 by suitable plugs, thus forming separate sections 85, 86 and 87 of the central duct. The ends of such sections adjacent such plugs are connected by radially and outwardly extending bores 84 to circumferentially distributed pairs of ports provided on the periphery of the cylindrical rotor sections 39 and 40, each pair of such ports communicating with the ends of the U-shaped interior duct of a rotor vane 46, or 47 respectively. Therefore, the air entering the central duct section 85 from mouth-piece 80 will first flow through a plurality of radial bores 84 to the interior ducts of vanes 47 and from there will return through a plurality of radial ducts to the central duct section 86 of the rotor. From there the air will flow through a plurality of radial ducts 84 to the interior ducts of vanes 46 and from there will return through a plurality of radial ducts 84 to the central duct section 87 of the rotor.

The central duct section 87 leads through rotor body 10 and shaft sections 14 and 15 and communicates with a stationary mouth-piece not shown fixed to a pipe 88 which may be connected by a valve 89 to a pipe 90 leading to an outlet 91 which communicates with conduit 34.

By raising link 81, the two valves 75 and 77 may be turned through 90°, whereby they are so set as to disconnect pipe 78 from and connect pipe 76 to pipe 74 and as to connect pipes 78 and 65. With this setting, the air issuing from the jacket 70 will be discharged into the combustion chamber of the turbine and the central duct 85 will be supplied with fresh air from pipe 65.

From the foregoing description it will appear that the improved conduit system for a gaseous cooling medium, such as air, includes the interior ducts of the turbine vanes 46, 47, 48 and 49 and extends from the inlet 54 to either the outlet 69 alone or to both outlets 91 and 92 depending on the setting of link 81. Moreover, it will appear that between the inlet 54 and the outlets 91, 92, the conduit system for the cooling air is substantially sealed from the gas stream flowing through pipe 12, casing 13, housing 11, casing 30, heat-exchanging device 33, conduit 34, tube 45, casing 43, housing 41, casing 42, and exhaust duct 53.

Moreover, it will appear that the inlet 54 communicates with the stream of compressed gas produced by the compressor section. The conduit system includes two sections, to wit a stator section composed of the ducts of the stationary turbine vanes 48 and 49, of the jacket 70, and of the pipes 67 and 74, and a rotor section composed of the ducts of the rotary vanes 46 and 47, of the central ducts sections 85, 86, 87, of the radial bores 84, and of the pipes 78, 88 and 90. Depending on the setting of link 81, the two sections thus described are either disposed in series or are disposed in shunt. Hence, the valves 75 and 77 are provided for optionally connecting such conduit system sections in shunt or in series.

If desired, a cooling device 93 may be inserted in pipe 74 for the purpose of re-cooling the air issuing from the jacket 71 before such air is fed to the rotor through mouth-piece 80 when the valves 75 and 77 are set as shown.

With this setting, the cooling device 93 is included in

pipe 74 of the cooling conduit system between the stator section and the rotor section thereof. Moreover, it will appear that from point 54 located at the air stream between the compressor section and the heat-exchanging device 33 the improved cooling conduit system extends to the points 91 and 92 which are located between the heat-exchanging device 33 and the burner 36.

It has been found that under extremely cold weather conditions ice may form on the stator vanes 25 of the compressor section. The improved cooling conduit system may be used as a remedy for this condition. For this purpose, the vanes 25 are provided with interior U-shaped ducts communicating with chambers 94 and 95 provided by a suitable partition in a jacket of casing 11, the chamber 94 communicating with pipe 88 by a pipe 96 and the chamber 95 communicating by a pipe 97 with pipe 90. Therefore, when the valve 89 is closed, the air issuing from the rotor after having been passed through the turbine vanes and having thus reached a comparatively high temperature may be passed through the interior ducts of the stationary vanes 25, thus preventing the formation of ice thereon. The heated vanes 25, in their turn, will pre-heat the stream of air to be compressed to a point where the formation of ice on the other vanes, such as 21, 26 and 22, is precluded. When the valve 89 is opened, however, it will short-circuit the interior ducts of the stationary vanes 25 nearest the inlet casing 13 and thus prevent the heating thereof.

The internal combustion turbine provided with a cooling system so far described is the sole invention of one of us and, therefore, forms the subject matter of a separate copending patent application Serial No. 415,927 filed on March 12, 1954.

Experience has shown that in practice internal combustion turbines are frequently operated during a fraction of the total time of operation only under such conditions as require the full cooling effect. Therefore, it is the object of our invention to improve the efficiency of operation of the turbine by controlling the cooling function in dependence on the temperature of the gas stream flowing through the turbine, or in dependence on the temperature of the turbine vanes. For that purpose, we may provide tube 55 with a throttle valve 100 which is controlled in dependence on the temperature prevailing in the turbine section. To this end, the end wall of casing 42 may be provided with an aperture in which a cylindrical casing 101 is inserted which includes a thermostat 102. The casing 101 slightly projects into the casing 42 and its marginal portions are fixed to the inner end of the thermostat element 102. The outer end thereof its fixed to a link 103 which extends through an opening provided in the end wall of casing 101 and is connected by a link 104 to an arm 105 of the throttle valve 100. When the gas stream passing through casing 42 has its highest temperature, the thermostat element 102 is fully expanded holding the throttle valve 100 in the position shown in which it is fully opened thus providing for the maximum cooling effect. A reduction of the temperature of the gas stream issuing from the turbine section results in a contraction of the thermostat element 102, whereby the throttle valve 100 is turned in clockwise direction thereby being closed more or less, thus reducing the cooling effect. Preferably, the thermostat element 102 and the throttle valve 100 are so correlated that the temperature of the gas stream passing through the casing 42 is kept practically constant.

Thus, the throttle valve 100 constitutes controlling means which control the flow of the cooling medium through the system of cooling ducts. The temperature-responsive element 102 so governs the controlling means 100 as to reduce the flow of the cooling medium as the temperature in casing 42 tends to decrease.

In Fig. 2 there is shown a modified temperature-controlling system in which the throttle 100 is omitted, an electrically controlled electromagnetic clutch 106 being interposed between shaft 64 and impeller 57 of the auxiliary compressor. The winding of clutch 106 is included within an electrical circuit 107 in series with a battery and with a switch 108 which is adapted to be closed by expansion of the thermostat element 102 inserted in the peripheral wall of casing 42. Closing of switch 108 results in engagement of clutch 106. When the temperature of the air stream issuing from the turbine section drops below a certain degree, the thermostat element 102 will contract thus permitting a spring (not shown) to open switch 108, whereby the clutch 106 will be deenergized. As a result, the auxiliary compressor 56 is stalled to disable the cooling system. Hence, it will appear that in this embodiment of the present invention the stream of cooling air will be intermittently interrupted in a manner keeping the temperature passing through casing 42 substantially constant.

In lieu of governing the air-flow-controlling means in dependence on the temperature of the gases issuing from the turbine section, such controlling means may be governed in dependence on the temperature prevailing at the entrance end of the turbine section, for instance in casing 43. That is illustrated in Fig. 3 showing a tubular member 45 equipped with the thermostat element 102. In this embodiment, the linkage cooperatively connecting the element 102 to the arm 105 of the throttle valve 100 comprises a two-armed lever 109 fulcrumed on a stationary pivot 110 and having one arm connected to arm 105 by link 111 and having its other arm connected by a link 112 to one arm of a bell crank 113. This bell crank is fulcrumed on a stationary pivot 114 and has its other arm connected to link 103 of thermostat 102. Here again contraction of element 102 due to a drop of the temperature passing to the turbine section through tube 45 results in a clockwise adjustment of the throttle valve 100 thus reducing the cooling effect.

In Fig. 5 we have illustrated another embodiment in which the temperature-responsive element 102 is directly subjected to the temperature of one of the stationary turbine vanes 49. For this purpose, the latter projects outwardly through the jacket 70 of housing 41 and is provided with an internal chamber 115 in which the element 102 is encased. The link 103 thereof is suitably connected with the throttle valve 100.

Power-driven means may be provided to operate valve 100 under control by the temperature-responsive element 102 in order to relieve the latter from mechanical stresses. In the embodiment shown in Fig. 5, such power-driven means comprises a piston 116 movable in a cylinder 117 and having a piston rod 118 connected with arm 105 of throttle valve 100 by link 104. A fluid under pressure, such as compressed air derived from receiver casing 30, or a liquid supplied from any suitable source, such as a pump, is admitted from a pipe 119 under control by a valve mechanism 120 to one end or the other of cylinder 117. To this end, the valve mechanism comprises a housing 121 communicating at its center with pipe 119 and having spaced ports communicating with the ends of cylinder 117 by ducts 122 and 123. Moreover, the valve mechanism 120 includes a slidable piston 124 connected by link 125 and bell crank 126 to link 103. The piston 124 has a peripheral recess which is in permanent communication with pipe 119 and is adapted to alternatively connect same with duct 122 or duct 123 to thereby cause piston 116 to move one way or the other to either open or close the throttle valve 100.

It is understood, of course, that the chamber 115 is sealed from the internal U-shaped cooling duct provided in vane 49.

When the temperature of vane 49 drops below a certain limit, element 102 will contract and will rock bell crank 126 anti-clockwise thereby passing piston 124 towards the right, thus admitting fluid under pressure to duct 122 and connecting duct 123 with the open end of casing 121. As a result, the fluid under pressure from pipe

119 will shift piston 116 to the left thereby closing throttle 100 and thus cutting off the cooling air flowing through the U-shaped interior duct of vane 49 permitting the temperature of such vane to increase again until element 102 will cause throttle 100 to be opened.

Since the air pressure in the inlet 54 of the cooling conduit system drops when the rotary speed of the turbine rotor drops thus reducing the pressure and the speed of flow of cooling air through the cooling system, it is desirable to control the flow of the cooling medium in dependence on the speed of operation of the turbine. In Fig. 4 we have shown a modified embodiment of our invention in which such control is effectuated.

Shaft 61 which, as shown in Fig. 1, is geared to shaft 38 of the turbine rotor is provided with a speedometer of the centrifugal type comprising a collar 127 fixed on shaft 61 and a grooved collar 128 slidable on shaft 61, pairs of links 129 and 130 being pivoted to such collars respectively and to each other, the links 129 carrying flyweights 131 at their ends which, upon increase of the rotary speed, will lift the links 129, 130 and the grooved collar 128 contrary to the tendency of a helical spring 132 inserted between the collars and surrounding shaft 61. A bell crank 133 fulcrumed on a stationary pivot 134 has a horizontal arm provided with a yoke having studs 135 engaging the peripheral groove of collar 128 and has a vertical arm carrying a pin 136 on which a substantially upright two-armed lever 137 is mounted. The upper arm of lever 137 is connected by link 138 to the arm 105 of the throttle valve 100, while the lower arm of lever 137 is connected by link 139 to the temperature-responsive element 102.

In this embodiment, the throttle valve 100 is partly closed when the turbine operates at normal speed and normal temperature. A reduction of the speed of the internal combustion turbine permits spring 132 to lower collar 128 and to thereby rock bell crank 133 anti-clockwise moving pin 136 and link 138 to the left, whereby the throttle 100 is opened unthrottling the flow of air to thereby compensate the reduction of the effectiveness of the auxiliary compressor 56. An increase of the normal speed has the opposite effect resulting in upward displacement of collar 128 and movement of link 138 to the right to thereby close throttle valve 100. When the temperature of the gas stream passing through casing 42 increases causing the temperature-responsive element 102 to expand, the two-armed lever 137 is rocked in clockwise direction thus closing throttle valve 100.

Obviously, the flow of cooling air through the vanes may be controlled in dependence on other factors influencing the temperature of the gases entering the turbine section, such as the pressure and/or the temperature prevailing in the intake pipe 12, or the pressure and/or the temperature prevailing in the inlet 54 or the like by providing governing means responsive to such factors and by connecting such governing means with the controlling means, such as throttle valve 100.

From the above explanation it will be appreciated that our invention affords a possibility of so controlling the cooling air as to feed so much air only through the cooling conduit system as is required to keep the temperature of the vanes and/or the casing within the permissible limits. At the same time, this control leads to an improvement of the efficiency of the auxiliary compressor when the turbine is operated under partial load, because the throttling of the cooling air reduces the quantity of air to be compressed. Therefore, the full energy required to cool the turbine under load will not be needed when the internal combustion turbine is operated under partial load conditions.

While we have described our invention with reference to a number of preferred embodiments thereof, we wish it to be clearly understood that the same is not limited to the details thereof, but is capable of numerous modifications within the scope of the appended claims.

What we claim is:

1. In a combustion turbine having stationary vanes and rotary vanes, a conduit system for conducting a gaseous cooling medium in heat exchange relationship to said vanes, feeding means to feed a gaseous cooling medium through said system, controlling means coordinated to said system and connected to control the flow of said medium therethrough, and governing means responsive to both the temperature of said vanes and the speed of operation of said feeding means and connected to govern said controlling means to reduce said flow as said temperature tends to decrease and to compensate the effect of variations of said speed on said flow.

2. The combination claimed in claim 1 in which said controlling means comprise a valve connected for adjustment to said governing means.

3. The combination claimed in claim 1, wherein said turbine further comprises a compressor section adapted to produce a stream of compressed air, a burner to heat said stream, a turbine section including said stationary and rotary vanes operable by said heated stream and connected to actuate said compressor section, conducting means to conduct said stream from said compressor section past said burner through said turbine section to an exhaust duct, said conduit system conducting said gaseous cooling medium in heat exchange relationship to said vanes from an inlet to an outlet, said inlet and said outlet communicating with said conducting means between said compressor section and said burner, said feeding means including an auxiliary compressor included in said conduit system for feeding said compressed gaseous cooling medium through said system, and wherein said governing means is responsive to the temperature prevailing at a point located in said stream between said burner and said exhaust duct.

4. The combination claimed in claim 3, in which said point is located between said turbine and said exhaust duct.

5. In a combustion turbine having stationary vanes and rotary vanes, a conduit system for conducting a gaseous cooling medium in heat exchange relationship to said vanes, feeding means to feed a gaseous cooling medium through said system, controlling means coordinated to said system and connected to control the flow of said medium therethrough, and governing means responsive to both the temperature of said vanes and the speed of operation of said turbine and connected to govern said controlling means to reduce said flow as said temperature tends to decrease and to compensate the effect of variations of said speed on said flow.

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