

July 22, 1952

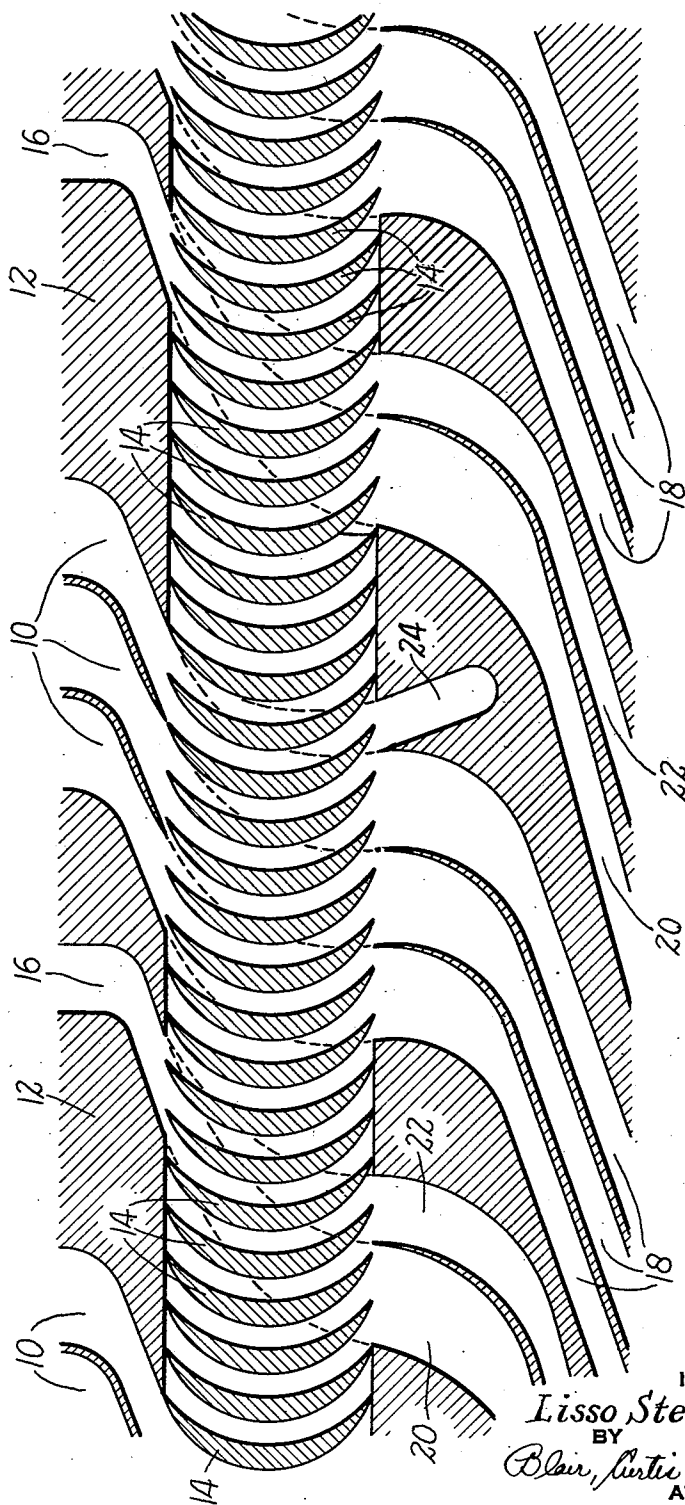
L. S. MIMS
MULTISTAGE GAS TURBINE BLADE COOLING WITH
AIR IN HIGH-PRESSURE TURBINE STAGES

2,603,948

Filed Oct. 31, 1947

4 Sheets-Sheet 1

Fig. 1.



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4 Sheets-Sheet 2

Fig. 2.

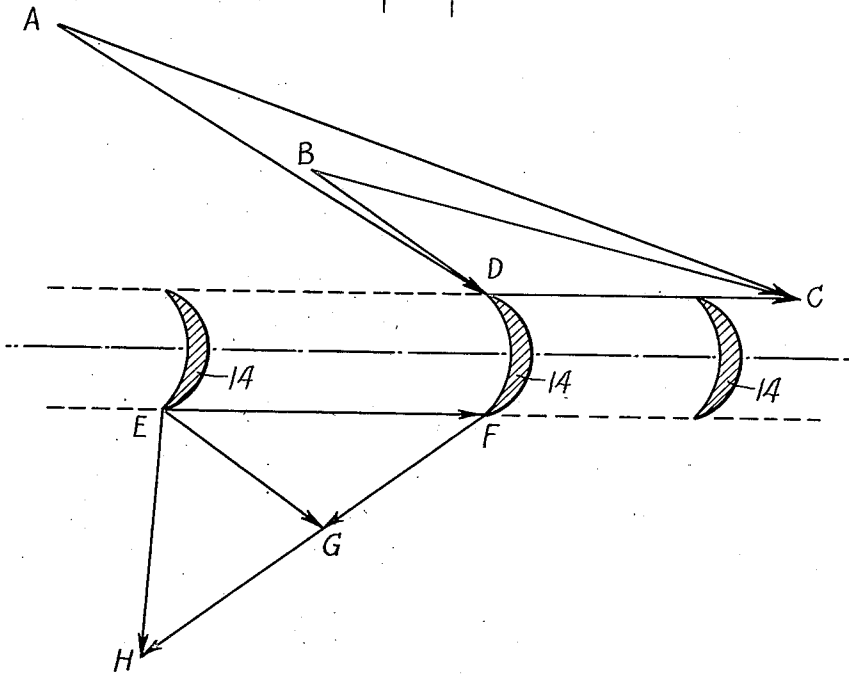
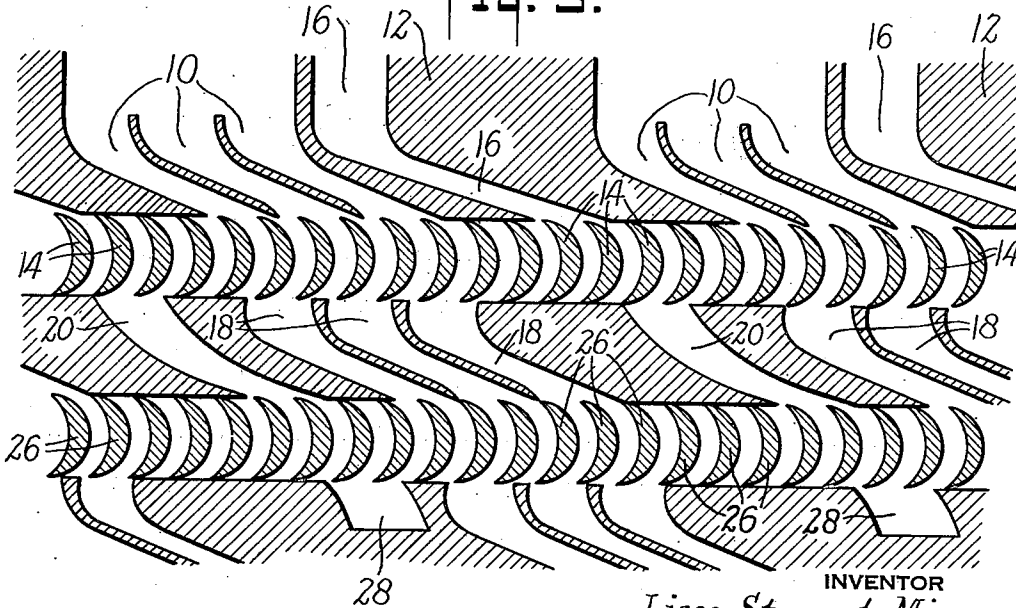


Fig. 3.



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4 Sheets-Sheet 3

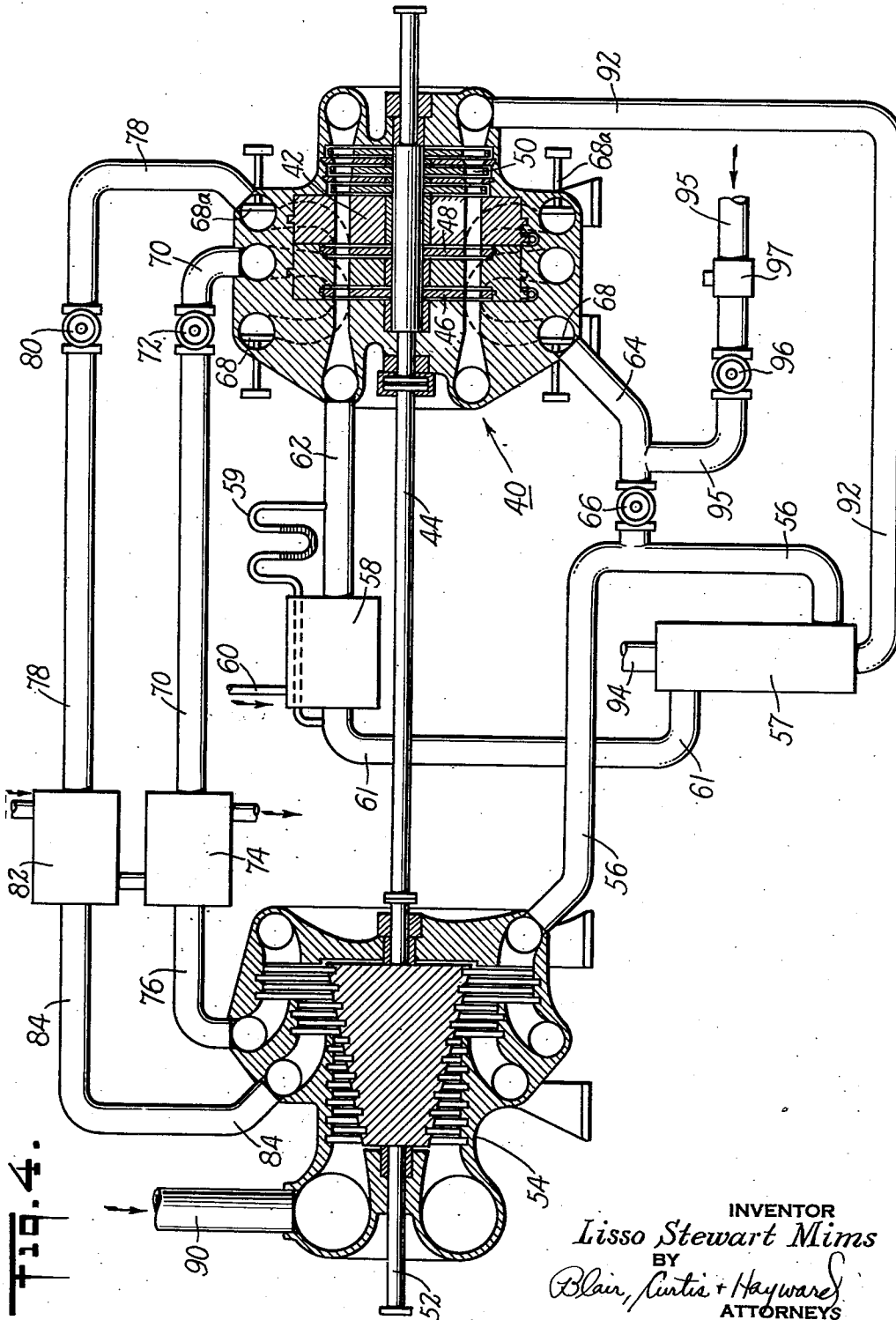


Fig. 4.

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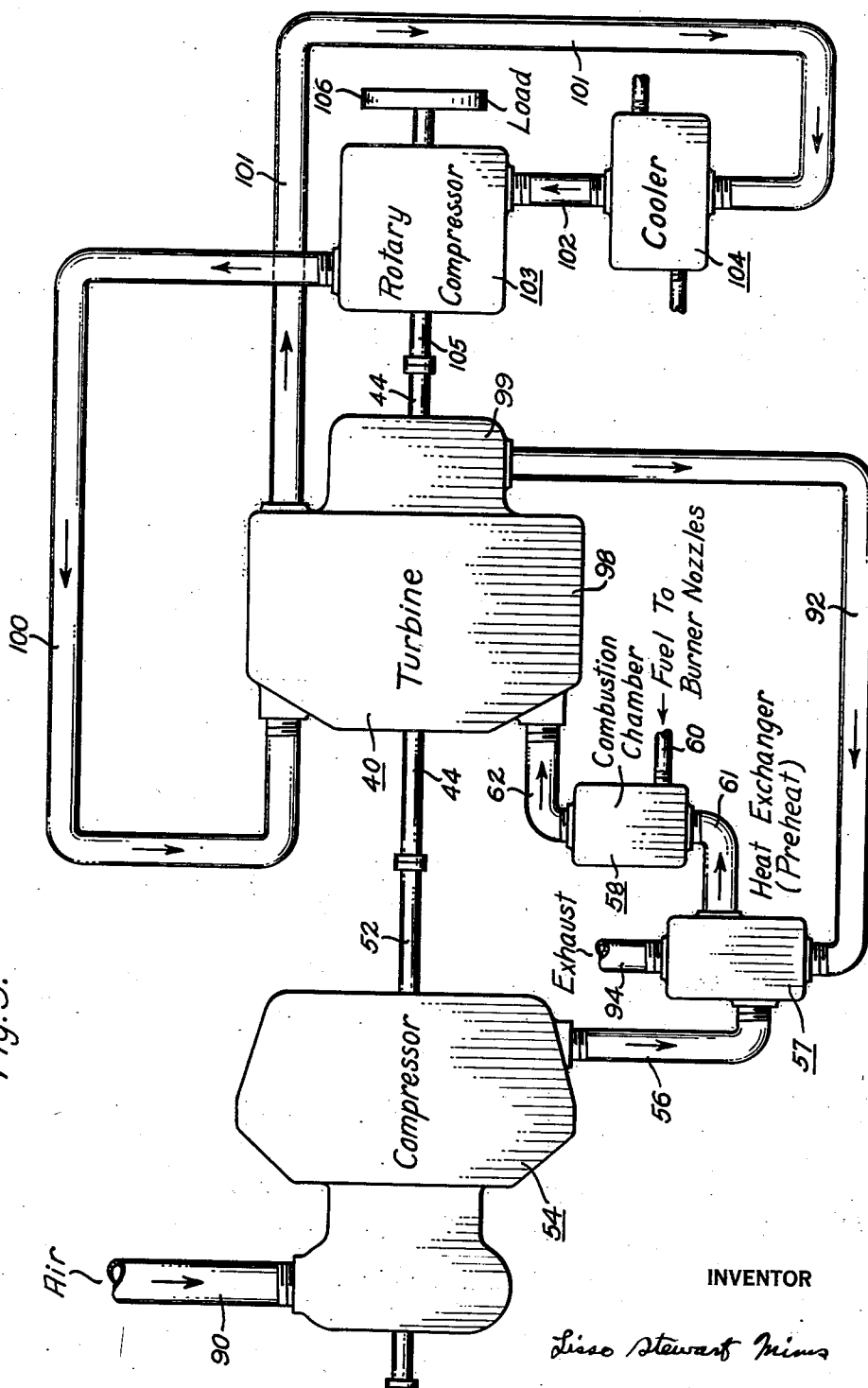
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4 Sheets-Sheet 4

Fig. 5.



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MULTISTAGE GAS TURBINE BLADE COOLING WITH AIR IN HIGH-PRESSURE TURBINE STAGES

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Application October 31, 1947, Serial No. 783,249

2 Claims. (Cl. 60—39.52)

1

This invention relates to turbines and more particularly to a gas or steam turbine incorporating means for cooling the blades of the turbine to improve the operating efficiency thereof.

In recent years there has been a considerable and increasing interest in the gas turbine for a variety of different applications. Thus the gas turbine is used as the prime mover in various gas turbine cycles, as a compressor drive for supercharging internal combustion engines, and as a blower or compressor drive in many industrial plants. It has been proposed for use in marine, locomotive and aviation propulsion, including jet propulsion, and in the operation of electrical generators in stationary power plants. The gas turbine supercharger has been used in connection with diesel and Otto cycle engines in many applications.

Since it is a heat engine the gas turbine obeys the fundamental thermodynamic law that the energy available to a heat engine, and hence its thermal efficiency increases with the difference between the temperature at which heat is supplied to the engine and temperature at which heat is exhausted from the engine. The exhaust temperature is rather definitely limited because of the fact that it cannot, as a practical matter, go below the ambient temperature and is usually considerably above ambient temperature in order to decrease the bulk and cost of the equipment. The temperature of the gas supplied to the turbine is limited by the physical characteristics of the materials of which the turbine is constructed and their ability to resist high temperatures without deterioration. For example, the "creep" characteristics of the material of which the turbine blades are composed constitute one such limitation.

With a view toward increasing the temperature of the gas supplied to gas turbines, various methods have been suggested for cooling the blading and rotor so that higher gas temperatures can be used without causing the blading and rotor to deteriorate. However, the methods and apparatus previously proposed have been unsatisfactory for one reason or another. For example, they have unduly complicated the construction of the turbine, or have been excessively costly, or have reduced the efficiency of the turbine in some respects that offsets the gain in efficiency due to the use of higher gas supply temperatures.

It is accordingly an object of the present invention to provide a gas turbine incorporating therein apparatus for cooling the blading of the turbine without unduly complicating its construc-

2

tion. It is another object of the invention to provide a simple and efficient apparatus for cooling the blading and rotor of a gas turbine to permit higher gas supply temperatures to be used. It is still another object of the invention to provide a turbine wherein a cooling medium for cooling the turbine blades is so supplied to the blades that it assists in driving the turbine rotor and said cooling means is supplied by the cycle components at a minimum cost in work to the cycle. Other objects of the invention will be in part obvious and in part pointed out hereafter.

The objects of the invention are achieved in general by causing a series of jets of relatively cooled compressed gas, e. g., air to pass through the blading of the turbine. Since the temperature of the rotor discs is always below the blading temperature, cooling of the blading by passing jets of relatively cooled compressed gas through the blading in accordance with the present invention automatically eliminates the need for rotor cooling. The compressed air or other gas is caused to pass through a series of nozzles interposed between hot gas nozzles constructed like those used in conventional gas turbines of the impulse type and arranged at such an angle with respect to the plane of the turbine rotor that the cooling air jets strike the concave surfaces of the blades. The air nozzles are preferably arranged at a sufficiently smaller angle with respect to the plane of the rotor than the gas nozzles to cause the gas and air jets to have nearly the same angle of incidence relative to the blades as they strike the blades.

The cooling air and hot gas are removed separately at the discharge side of each stage of the turbine and both hot gas and cooling air are passed separately through successive stages of the turbine. The cooling air is preferably passed through only the first few stages of the turbine, since its cooling function is completed by the time it reaches the second or third stage and there is no advantage, and in fact a positive disadvantage, in causing the air to pass through all of the stages of the turbine. Hence it is usually desirable that the cooling air be removed from the turbine after the second or third stage.

The many objects and advantages of the present invention may be best understood and appreciated by reference to the accompanying drawings which illustrate a preferred embodiment of the invention and wherein:

Fig. 1 is a diagrammatic developed view of the blading of one stage of a gas turbine incorporating the present invention taken on the center

3

line of the blading and showing the arrangement of the gas and air nozzles and discharge ducts;

Fig. 2 is a velocity diagram illustrating the preferred relationship between the gas and air velocities;

Fig. 3 is a developed diagrammatic view similar to Fig. 1 but showing two stages of the turbine;

Fig. 4 is a diagram of a turbine cycle that may be used with advantage in combination with a turbine incorporating the present invention; and

Fig. 5 shows an alternative arrangement of a turbine cycle incorporating the features of the present invention.

Referring to the drawings and more particularly to Fig. 1, hot gas to drive the turbine is fed through a series of nozzles 10 in a nozzle block 12 to the curved impulse type blades 14 at such an angle that the hot gas strikes the concave surfaces of the blades. Formed in the nozzle block 12 between successive groups of gas nozzles 10 are the air nozzles 16 which are supplied with relatively cool compressed air from a suitable source. Since the compressed air is at a lower temperature than the hot gas, its velocity at the discharge end of the nozzle 16 will be less than the velocity of the gas at the discharge end of nozzles 10. In order to prevent the air from exerting a retarding influence on the blades 14, I have found it desirable to arrange the nozzles 16 at a somewhat smaller angle with respect to the plane of rotation of the blades 14 than the angle of the nozzles 10.

The desired relationship between air and gas velocities is illustrated by the velocity vector diagram of Fig. 2. Referring to Fig. 2, AC represents the absolute velocity of the gas, BC the absolute velocity of the air, AD the gas velocity relative to the blading, BD the air velocity relative to the blading, and DC the velocity of the blades. From the diagram it is apparent that although the absolute air velocity BC is considerably less than the absolute gas velocity AC, it is possible to make the air jet nozzle angle BCD sufficiently smaller than the gas jet nozzle angle ACD to cause the angle ADC to be the same for both gas and air jets and thereby cause the cooling air to supplement the action of the gas in driving the blades. Since, however, a small nozzle angle gives improved diagram efficiency, it is desirable in practice to use a compromise such that the angles ADC and BDC are nearly but not quite equal.

At the discharge side of the blading FG is the velocity of the air relative to the blading, FH the relative velocity of the gas, EG the absolute air velocity, EH the absolute gas velocity, and EF equals DC, the blade velocity. From this diagram it is apparent that the gas must be turned through a larger angle than the air in going through the nozzles between the first and the second stage.

Referring again to Fig. 1, the hot gases pass through the blades 14 and are removed through the hot gas discharge ducts 18 which as shown, may merge into nozzles for supplying hot gas to the next successive stage of the turbine. Air from the air nozzles 16 passes through the blades 14, thereby cooling the blades, and is discharged through ducts 20 which may merge into air nozzles for supplying air to the next stage of the gas turbine.

It is evident that a certain amount of intermingling of the hot gas and air will occur within the turbine rotor which produces an effect that can be characterized as a fringe effect. The boundaries of these areas in which mixing occurs are indicated by dotted lines in Fig. 1. Thus a certain amount of hot gas is entrapped between

4

the blades 14 after they pass the discharge ducts 18. This entrapped gas is at a lower pressure than the flowing stream of hot gas because of the suction effect of the gas stream. When the blades 5 have moved to a point opposite air nozzles 16, the entrapped hot gas comes in contact with entering compressed air from the nozzles 16 and compression of the hot gas and intermixing of the hot gas and air occurs. The resulting mixture of hot gas and air may be removed through a duct 22 which may also merge into a nozzle for supplying the gas-air mixture to the next stage of the turbine. Since the temperature of the gas-air mixture is intermediate between that of the hot gas and that of the air, the angle of the nozzle portion of duct 22 will have a value that is between those of the hot gas nozzles and of the air nozzles respectively. In succeeding stages this mixture acts as a dividing curtain, impinging on entrained gas, and in turn being scavenged by cooling air.

Air that is left between the blades 14 after they pass air discharge duct 20 comes in contact with hot gas flowing from the next successive gas nozzle 10 and is admixed therewith to form a second fringe effect, i. e., an air-gas mixture. This second mixture is at a higher pressure than the main stream of air because after being acted on by the suction effect of the air stream it is 30 compressed by the rapidly moving gas stream from the next gas nozzle. As this mixture would properly pass through a nozzle with an angle smaller than the gas immediately following, and would thereby mix with it, it is more conveniently removed from the turbine through duct 24 and is not passed on to the next stage of the turbine. The duct 24 acts as a diffuser to convert the velocity of this mixture into pressure. The air-gas mixture entering duct 24 is desirably recycled as described hereafter in connection with Fig. 4.

The manner in which the air and gas are passed through successive stages of a multi-stage turbine is indicated in Fig. 3 of the drawings. In Fig. 3 as in Fig. 1 hot gas flows through the nozzles 10, the blades 14 and through the blades to the discharge ducts 18 which merge into nozzles for conducting the hot gas to the blades 26 of the second stage of the turbine. Relatively cool compressed air flows through the air nozzles 16 to the blades 14 and thence through the air discharge ducts 20 which merge into nozzles for supplying cooling air to the blading 26. From the blading 26 air passes to a discharge duct 28, which acts as a diffuser to convert velocity into pressure, and is conducted out of the turbine. As indicated above, it is desirable that the cooling air be removed as soon as it has reached a stage in the turbine where the working gas has expanded down to a temperature low enough to be handled by un-cooled blades; early removal of the cooling medium reduces the net work necessary to supply the cooling medium and this in turn increases the over-all cycle efficiency. The disposition of the removed cooling air is described below in connection with Fig. 4.

In the embodiment of Fig. 3 entrained air that mixes with the incoming hot gas stream is permitted to flow with the hot gas into the next stage of the turbine, and hot gas that is entrained in the blading and mixes with cooling air is caused to flow with the remainder of the cooling air to the next successive stage of the turbine. In many cases this mixing of the

5

fringe effect gas and air can be permitted without serious loss of efficiency.

It should be noted that as the air and gas pass from stage to stage through the turbine their temperatures tend to approach one another. Hence in order to preserve the desired relationship between the directions of the gas and air jets the angle of the gas and air nozzles should approach one another in progressive steps from stage to stage.

An illustrative cycle incorporating a turbine having the air cooling nozzles of the present invention is shown in Fig. 4 of the drawings. Referring to Fig. 4, the numeral 40 generally designates a gas turbine having a rotor 42 mounted on a shaft 44 and comprising the air-cooled first stage blading 46 and air-cooled second stage blading 48 as well as the additional stages of blading 50 that are not air-cooled. Blading 50 may be impulse type with inter-stage diaphragms, as shown, or it may be of the reaction type wherein the rotor and stator blading is similar and no diaphragms are used. The turbine 40, and more particularly the shaft 44 thereof, is directly coupled to the shaft 52 of a rotary air compressor 54 which receives a supply of atmospheric air through a pipe 90.

Compressed air from the compressor 54 passes through the pipe 56 to a heat exchanger or regenerator 57 wherein it is preheated by exhaust gases as described below, and thence through pipe 61 to a combustion chamber 58 to which fuel is supplied through a fuel supply pipe 60. The compressed fuel-air mixture is burned in the combustion chamber 58 and hot gases flow through the pipe 62 to the inlet of the gas turbine 40. A manometer 59 responsive to the pressure drop across the combustion chamber is provided to indicate the flow therethrough. A portion of the compressed air from compressor 54 passes through a branch conduit 64 containing a regulating valve 66 to the turbine 40 without passing through the regenerator 57 or the combustion chamber 58, and thus comprises a source of relatively cool compressed air for cooling the blading. Valves such as the valve 68 may be provided at the individual air nozzles to regulate the flow of air to the nozzles individually. Valves 68a should also be provided to seal off the outlet ducts of the jets not in use. The cooled air supplied through pipe 64 may, if desired, also be used for other cooling purposes such as cooling the bearings or stator of the turbine.

The air from pipe 64 and hot gas from pipe 62 pass through the blading of the first stage 46 as indicated in Figure 1. Both the hot gas and cooling air pass on to the blading of the second stage 48 as does the mixture of entrained gas and air. The mixture of entrained air and gas is removed between the first and second stages through a pipe 70 containing a regulating valve 72 and thence through an air-cooler 74 wherein the air-gas mixture is cooled with cooling water. From the air-cooler 74 the mixture is caused to flow through pipe 76 to the compressor 54. Since this gas is at a relatively high pressure it is admitted into the compressor at such a point that it passes through only the last few stages of the compressor.

From the discharge side of the second stage blading 48 the cooling air and the gas-air mixture are removed through a pipe 78 containing a regulating valve 80 and pass through an air-cooler 82 wherein they are cooled with cooling

6

water. The air-gas mixture from the second stage is allowed to pass on to the third stage with the gas. After the cooling mixture has been cooled it passes through a pipe 84 to the air compressor 54. Since this mixture has a pressure intermediate between that of atmospheric air and the air recirculated from the first stage, it is introduced into the compressor 54 at an intermediate point.

As described above, the compressed air supplied from the compressor 54 passes through pipe 56 and regenerator 57 to the intake of the combustion chamber 58. In the regenerator 57 the incoming air is heated by the exhaust gases from the gas turbine which, after leaving the second stage blading 48, pass through the blading 50, then through a pipe 92 to the regenerator, and thence through pipe 94 to the stack.

Connected to the air pipe 64 there is a branch pipe 95 having a regulating valve 96 and check valve 97, the pipe 95 being supplied with air under pressure from a suitable source. The air pipe 95 may be used to start the compressor-turbine 54-40 by opening valve 96 to cause compressed air to flow through the turbine air nozzles and thereby rotate the rotor 40 and the rotor 54. When the pressure in the system builds up sufficiently, valve 96 is closed. In the early stages of the starting operation, the main compressor would rotate at lower than rated speeds, and hence would deliver lower than rated capacity. In starting ordinary uncooled cycles, fuel flow to the combustors has to be greatly decreased below rated flow in order to prevent excessive temperatures in the turbine, due to supplying too much heat to too little air. In the case of the cooled cycle, however, the fuel flow to the combustors need be decreased only slightly as the ratio of cooling gas to working gas is higher under starting conditions than after rated conditions have been realized. This use of comparatively higher fuel flow, in starting, supplies energy to the system faster, and makes for less time consumed in starting. The compressor-turbine may also be started by coupling a suitable electric starting motor or the like to the shaft 44.

It is to be understood that the foregoing description is illustrative only and that numerous changes may be made within the scope of the invention. Thus in Fig. 1 the air nozzles are shown as disposed between groups of three hot gas nozzles, but it is apparent that the gas and air nozzles may be arranged alternately or the air nozzles bunched at one point on the rotor or any other suitable arrangement of the nozzles utilized. The cycle of Fig. 4 is merely an illustrative cycle. The present invention can also be used with advantage in compound cycles including high and low pressure combustion chambers, turbines, and compressors as well as in very simple structures wherein the cooling air is caused to pass through all stages of a small turbine and progressively assumes the temperature and pressure of the hot gas as it flows through the turbine. In the latter case the cooling air is removed with the exhaust hot gas.

As indicated at the beginning of the present specification the structure of the present invention is not limited to the use of combustion gases and air; steam may be used as the working fluid or the cooling fluid or both. For example, relatively high temperature steam may be caused to flow through the nozzles 10 of Fig. 1 and relatively low temperature steam through

7

the nozzles 16 to produce desired cooling of the blades.

Another illustrative cycle incorporating a turbine having the air cooling arrangement of the present invention is shown in Fig. 5 of the drawings. Referring to Fig. 5 the numeral 40 generally designates a gas turbine having a group of rows of cooled blades included in that portion of the turbine labeled 98 and an uncooled portion labeled 99. The turbine shaft 44 is coupled at one end to the shaft 52 of a rotary air compressor 54 which receives a supply of atmospheric air through a pipe 90 and is coupled at the other end to the shaft 105 of a rotary compressor 103. The other end of shaft 105 is connected to a coupling 106 from which can be obtained useful power.

Compressed air from compressor 54 passes through the pipe 56 to a heat exchanger or regenerator 57 wherein it is preheated by the heat from the exhaust gases in the same manner detailed in the description of Fig. 4. After the passing through the pipe 61 from the regenerator to the combustion chamber 58 and thence through pipe 62, the hot gases enter the high temperature end of the turbine. The gases are exhausted from the turbine by pipe 92.

In the cooling gas portion of the cycle gas is compressed in the compressor 103, fed to the turbine's cooling nozzles by pipe 100, removed at an intermediate point in the turbine by pipe 101 which conducts these gases to a gas cooler 104. Pipe 102 transmits the cooled gases from the cooler back to compressor 103. It is thus seen that the cooling gases follow an essentially closed circuit and will, after the cycle has been in operation for a time, reach a chemical equilibrium with the hot driving gases. The cooling gases, when this equilibrium condition has been reached, will contain portions of the products of combustion emanating from combustion chamber 58.

Since many embodiments might be made of the present invention and since many changes might be made in the embodiment disclosed herein, it is to be understood that the foregoing description is to be interpreted as illustrative only and not in a limiting sense. Numerous modifications within the scope of the invention will be apparent to those skilled in the art.

I claim:

1. In a gas turbine cycle including a com-

8

pressor and a turbine having a rotor and rows of curved radial blades driven by jets of hot gas directed by nozzles against said blades, the combination which comprises nozzles disposed at spaced points between the hot gas nozzles and adapted to direct jets of cooling gas against the blades, means for delivering fluid under pressure from the compressor to the last mentioned nozzles of the first row of blades and means for separately withdrawing the cooling gas from the turbine upstream of the last stage of the turbine, means for delivering to the compressor at a point downstream of the main compressor inlet the cooling gas separately withdrawn from the turbine and heat exchange means for cooling the cooling fluid in its cycle.

2. In a gas turbine cycle including a main compressor, an auxiliary cooling gas compressor, and a turbine having a rotor and rows of curved radial blades driven by jets of hot gas directed by nozzles against said blades, the combination which comprises nozzles disposed at spaced points between the hot gas nozzles and adapted to direct jets of cooling gas against the blades, means for delivering fluid under pressure from the auxiliary cooling gas compressor to the last mentioned nozzles of the first row of blades, means for separately withdrawing the cooling gas from the turbine upstream of the last stage of the turbine, means for delivering to the auxiliary compressor the cooling gas separately withdrawn from the turbine, and heat exchange means for cooling the cooling fluid in its cycle.

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