

- [54] **REGENERATIVE GAS TURBINE SYSTEM**
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[58] Field of Search **60/39.23, 39.65,**
60/39.51

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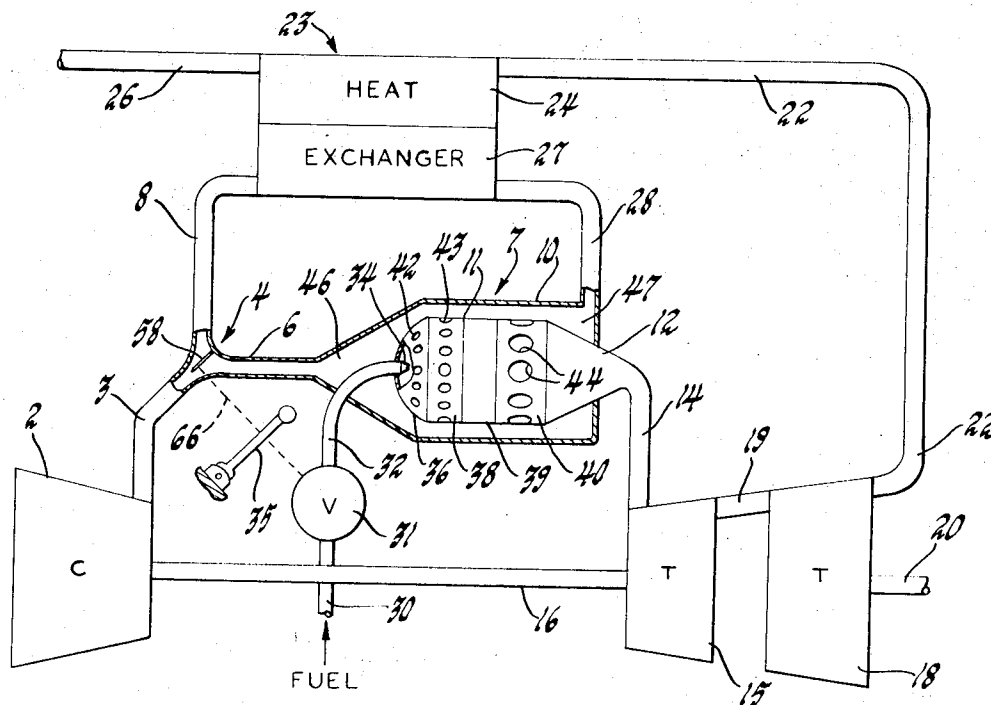
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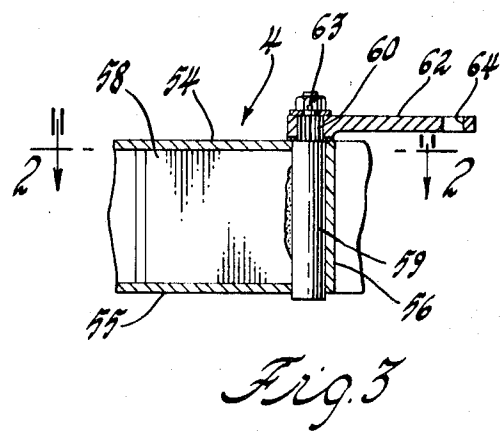
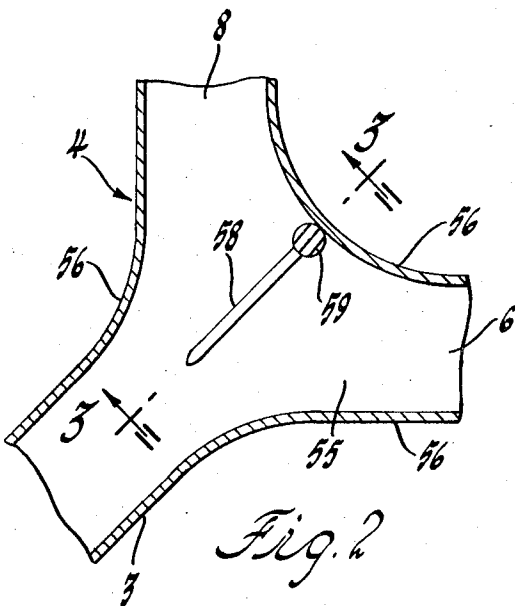
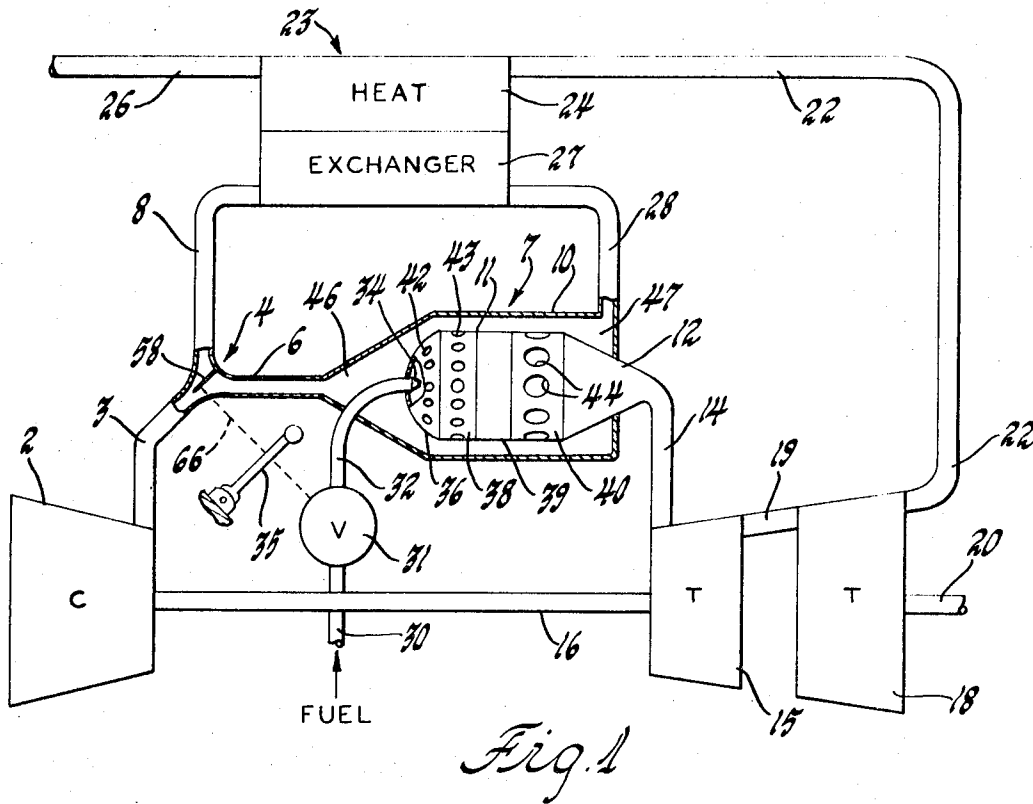
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[57] **ABSTRACT**

A regenerative gas turbine engine with combustion apparatus including a conventional combustion liner has the compressor connected to the combustion apparatus so as to supply primarily air unheated by the regenerator to the combustion zone of the liner and primarily air heated by the regenerator to the dilution zone of the liner, to reduce generation of oxides of nitrogen. An adjustable valve provides for varying the ratio of unheated to heated air.

3 Claims, 3 Drawing Figures





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REGENERATIVE GAS TURBINE SYSTEM

My invention is directed to regenerative gas turbine engines, and particularly to improving the cleanness of combustion of such engines.

Since gas turbines are continuous combustion engines and ordinarily supply a considerable excess of air over stoichiometric to the combustion apparatus, they are naturally capable of cleaner combustion; that is, of an exhaust having less of constituents which may be considered pollutants, than engines of intermittent combustion types, particularly intermittent combustion engines operating at or near stoichiometric fuel to air ratios.

However, the combustion apparatuses of gas turbine engines ordinarily operate by burning the fuel in which is termed the combustion zone of the combustion apparatus, in which the fuel is atomized and burned in a minor portion of the air. Downstream in the flow through the combustion apparatus, in what is called the dilution zone, additional air is introduced and mixed with the combustion products to cool them and produce the turbine motive fluid. It has not appeared feasible, for various reasons which need not be gone into here, to distribute the fuel through the entire body of air flowing through the engine and thus achieve combustion at a low fuel to air ratio.

Experience has shown that the continuous flow gas turbine combustion apparatus provides an engine exhaust almost entirely free of carbon monoxide and unburned fuel or fuel constituents. However, the high temperature of combustion causes some formation of nitrogen oxides by combination of the nitrogen and oxygen present in the air supplied to the engine. The higher the temperature in the combustion zone, the greater the tendency for formation of nitrogen oxides.

This problem is accentuated when the engine includes a regenerator or recuperator or, in other words, a heat exchanger by which heat is transferred from the engine exhaust to the air flowing from the engine compressor to the combustion apparatus. The heat exchanger, which will be referred to hereafter as a regenerator, is a practical necessity in some applications as a means to improve the fuel economy of the engine. However, since the regenerator raises the temperature of the air entering the combustion apparatus, the problem of nitrogen oxide formation is aggravated.

My invention is based upon the concept that the air flowing to the combustion apparatus should be divided and most or all of the air for direct combustion; that is, the primary combustion air, should by-pass the regenerator so as to remain relatively cool; and that the remainder of the air flowing through the engine be passed through the heat exchanger and then be supplied to the combustion apparatus for dilution purposes. While this can be shown to result in some lowering of thermal efficiency or fuel economy of the engine, it is a way to lower percentages of nitrogen oxide because of the lower maximum temperature in the combustion zone. The fuel consumption is much the same, and the cooler combustion air does not rise to so high a temperature in the flame.

However, since the ratio of fuel to air varies with the power output of the engine, a smaller proportion of the air is needed for the primary combustion zone at light loads. Therefore, I provide valve means to vary the ratio of air by-passing the regenerator to that flowing

through it, so as to maintain the maximum efficiency of regeneration consonant with minimization of nitrogen oxide generation as load varies.

The general nature of my invention should be apparent from the foregoing, but it will be made more clear to those skilled in the art from the succeeding detailed description and accompanying drawings of the preferred embodiment of the invention.

The principal objects of my invention are to minimize undesirable constituents in the exhaust of a gas turbine engine, to lower the maximum temperature in the combustion zone of a regenerative gas turbine combustion apparatus, to improve the cleanness of the exhaust of a gas turbine engine without undue sacrifice of operating efficiency of the engine, and to provide a simple and effective arrangement for dividing the air flow from the compressor of a gas turbine engine between a first path into the primary combustion zone and a second path through a regenerative heat exchanger into the dilution zone of the combustion apparatus of the engine.

Referring to the drawings:

FIG. 1 is a schematic diagram of a regenerative gas turbine engine incorporating the invention.

FIG. 2 is a sectional view of an air flow controlling valve taken on the plane indicated by the line 2—2 in FIG. 3.

FIG. 3 is a sectional view of the valve taken on the plane indicated by the line 3—3 in FIG. 2.

FIG. 1, except for the improvement which forms the subject matter of my invention, illustrates a typical regenerative gas turbine engine of the free turbine type. The engine includes an air compressor 2 which discharges through a compressed air conduit 3 to a valve 4 which controls the division of flow between a first compressed air conduit 6, leading to combustion apparatus 7, and a second compressed air conduit 8. The combustion apparatus 7 includes an outer case 10 and a combustion liner or flame tube 11, the combustion liner being enclosed within the outer case for flow of air from within the case into the liner. The combustion liner includes an outlet or transition portion 12 from which combustion products are discharged from the combustion apparatus through a conduit 14 into a first or high pressure turbine 15. Turbine 15 drives the compressor 2 through a shaft 16.

The exhaust from turbine 15 is supplied to a second or low pressure turbine 18. While ordinarily these two turbines are integrated structurally, they are illustrated here as being connected through a combustion products conduit 19. The turbine 18 drives a shaft 20 which may be connected to drive any load including, for example, the driving wheels of a self-propelled vehicle. The two turbines may be mechanically coupled together, or a single turbine driving shafts 16 and 20 may be used. The low pressure exhaust from turbine 18 is conducted through suitable ducting 22 to a heat exchanger 23 where the exhaust gas flows through one pass 24 of the heat exchanger to an atmospheric exhaust 26. The heat exchanger may be of any suitable type such, for example, as a rotary regenerator or a fixed recuperator. As employed in a conventional gas turbine engine, its purpose is to recover heat from the hot low pressure exhaust gases and heat the compressed air flowing from the compressor to the combustion apparatus so as to reduce the fuel consumption required to provide the high temperature motive fluid.

The second compressed air conduit 8 previously referred to leads to a compressed air pass 27 of the heat exchanger 23 from which the heated compressed air flows through a conduit 28 to the combustion apparatus 7.

Fuel from a suitable source of fuel under pressure is led through a fuel line 30, a fuel control represented as a fuel controlling valve 31, and a line 32 to a fuel spray nozzle 34 at the upstream end of the combustion liner 11. The valve 31 may be taken as a symbolic representation of suitable fuel controlling means for the engine which may, of course, include such usual components as maximum and minimum flow limiters and governing devices but which, in any usual case, includes a throttling valve which ultimately controls the rate of flow of fuel to the combustion apparatus. The fuel controller 31 is represented as being set to the desired power level by a control input 35 which may be a hand lever or an accelerator pedal of a vehicle.

The combustion apparatus 7, except as specifically pointed out below, is of a well known type in which the case 10 contains the compressed air which is diffused and flows at relatively low velocity within the case, flowing through openings in the liner 11 to the interior of the liner. Fuel is sprayed into the air within the liner by the nozzle 34, is burned, and the resulting combustion products are discharged through the outlet portion 12 of the combustion apparatus. The liner 11 is preferably made up of a number of sections; a dome 36, and successive rings such as 38, 39, and 40. The forward part of the liner, which might correspond approximately to the portion enclosed by the dome 36, the first ring 38, and some or all of the second ring 39, may be considered the primary combustion zone of the liner within which fuel is burned. The downstream portion of the liner which would include at least the ring 40, constitutes the dilution zone.

The sections 36, 38, 39, 40, and 12 of the liner may be connected by suitable means to admit film cooling air to flow along the inner surface of the liner, as is well known. Means for admission of primary or combustion air to the combustion zone of the liner are indicated schematically as by small ports 42 in the dome and 43 in ring 38. A ring of large air ports 44 in the ring 40 serve to admit dilution air to the downstream portion of the combustion liner. Such combustion liner structure is well understood by those skilled in the art and will not be further described here. Mention may be made of the following U.S. patents which disclose combustion apparatus having combustion liners of the type referred to: Gaubatz, U.S. Pat. No. 2,699,040, Jan. 11, 1955; Dougherty, U.S. Pat. No. 2,748,567, June 5, 1956; Hayes, U.S. Pat. No. 2,768,497, Oct. 30, 1956; Tomlinson, U.S. Pat. No. 3,064,424, Nov. 20, 1962; and Hayes, U.S. Pat. No. 3,064,425, Nov. 20, 1962. It will be understood that these patents show combustion apparatus with plural liners, but this does not affect the basic structure of the liner or the principles of operation of the combustion apparatus. Attention may also be invited to Amann et al. U.S. Pat. No. 3,116,605, Jan. 7, 1964, and Collman et al. U.S. Pat. No. 3,267,674, Aug. 23, 1966, which structurally disclose regenerative gas turbine engines of the type illustrated schematically in FIG. 1, and also show combustion apparatus of the type referred to.

As will be apparent from what has been said above, my invention relates to the arrangement for conducting

the air from the compressor and heat exchanger to the combustion apparatus. This may be expressed concisely as follows: A portion of the output of compressor 2 is directed through the first compressed air conduit 6 into the forward end of the combustion case 10 so as to flow into the forward or combustion zone of the combustion liner. The remainder of the air is directed through the second conduit 8, heat exchanger 27, and conduit 28 to the downstream or dilution end of the case 10 so as to flow primarily through the dilution ports 44. The unheated compressed air thus enters the combustion apparatus at the space 46 and flows rearwardly and through the ports 42 and 43, while the heated compressed air enters the combustion apparatus at the space 47 and flows forwardly along the liner and into the ports 44. It would, of course, be possible to provide a complete or partial barrier between the outer surface of the liner 11 and the inner surface of the case 10 to block or impede flow between the spaces 47 and 46 along the outside of the combustion liner. However, I do not believe that such structure is needed, and prefer to omit it.

There does need to be some arrangement for determining the relative portions of the compressor discharge which enters case 10 through the conduits 6 and 28. Since there is a slight pressure drop in the regenerator, there needs to be some resistance to flow through the conduit 6, either by the support of the conduit or otherwise.

In practicing my invention, I deem it highly desirable to provide for variably dividing the air between the conduits 6 and 8 in accordance with engine operating conditions and, for this reason, I have indicated the valve 4 which acts as a flow splitter to control the relative flow through the regenerator and by-passing the regenerator.

The structure of such a valve is merely a matter of mechanics of construction, and the details are quite immaterial to my invention. However, to clarify what is intended, a suitable valve structure is illustrated somewhat schematically in FIGS. 2 and 3. As illustrated in these figures, the valve 4 includes a body bounded by a flat upper wall 54 and lower wall 55, with side walls 56 defining with upper and lower walls an entrance from the conduit 3 and the outlet to the conduits 6 and 8, generally as illustrated. A flow splitting vane 58 is integral with a shaft 59 rotatably mounted in the walls 54 and 55 immediately adjacent the wall 56 between outlets 6 and 8. The upper end of shaft 59 projects through wall 54 and is splined at 60 to receive a control arm 62 retained by a cap screw 63 and a washer. The outer end of arm 62 has a drilled hole 64 for connection of a suitable control linkage. The control linkage, which may be of any desired nature and may incorporate servos if desired, is indicated in FIG. 1 by the broken line 66 connecting the power control lever 35, fuel control valve 31, and air control valve 4. In practice, there may be some cam arrangement or the equivalent to cause the position valve member 58 to vary in desired relation to the opening of the fuel valve which determines the amount of fuel flowing to nozzle 34. By varying the fraction of the engine air flow which proceeds through conduit 6, the efficiency of the engine under various conditions of operation may be improved over what it would be if the division of the air is fixed.

In a regenerative engine of the type described, I consider it to be best that approximately 10 percent of the

air flow through conduit 6 under idling conditions of engine operation. When fuel flow is increased to accelerate the engine and the ratio of fuel to air in the combustion zone would otherwise tend to diminish, it may be desirable to open the valve to pass approximately 30 percent of the air through conduit 6. Under normal high power operation of the regenerative engine, approximately 20 percent of the air may preferably be supplied through conduit 6, with the remaining 80 percent being heated in the heat exchanger 23.

The by-passing of the regenerator will result in some increase in fuel consumption. However, the substantial decrease in maximum temperature in the primary combustion zone will beneficially reduce the formation of nitrogen oxides in the engine.

The detailed description of preferred embodiments of the invention for the purpose of explaining the principles thereof is not to be considered as limiting or restricting the invention, since many modifications may be made by the exercise of skill in the art without departing from the scope of the invention.

I claim:

1. A regenerative gas turbine engine comprising, in combination, air compressor means, a combustion apparatus supplied from the compressor means, the combustion apparatus including a combustion products generator having a combustion zone and a dilution zone, turbine means energized from the combustion apparatus connected to drive the compressor means, a heat exchanger, and a turbine exhaust duct connected through one pass of the heat exchanger; the heat exchanger having a second pass in heat exchange relation to the first pass; a first compressed air conduit leading from the compressor means to the combustion zone by-passing the heat exchanger; a second compressed air conduit leading from the compressor means through the second pass of the heat exchanger to the dilution zone, and flow splitter valve means between the compressor and the said conduits reversely throttling the flow into the conduits for dividing the compressor output between the said conduits variably as a function of engine power level so as to direct air unheated by the regenerator primarily to the combustion zone and air heated by the regenerator primarily to the dilution zone so as to minimize the temperature of the air entering the combustion zone to reduce combustion temperature and thereby generation of oxides of nitrogen.

2. A regenerative gas turbine engine comprising, in combination, air compressor means, a combustion apparatus supplied from the compressor means, the com-

bustion apparatus including a combustion products generator having a combustion zone and a dilution zone, turbine means energized from the combustion apparatus connected to drive the compressor means, a heat exchanger, and a turbine exhaust duct connected through one pass of the heat exchanger; the heat exchanger having a second pass in heat exchange relation to the first pass; a first compressed air conduit leading from the compressor means to the combustion zone by-passing the heat exchanger; a second compressed air conduit leading from the compressor means through the second pass of the heat exchanger to the dilution zone, means for dividing the compressor output between the said conduits so as to direct air unheated by the regenerator primarily to the combustion zone and air heated by the regenerator primarily to the dilution zone; and flow splitter valve means between the compressor and the said conduits reversely throttling the flow into the conduits for varying the division of air between the said conduits in accordance with a condition of engine operation so as to minimize the temperature of the air entering the combustion zone to reduce combustion temperature and thereby generation of oxides of nitrogen.

3. A regenerative gas turbine engine comprising, in combination, in flow sequence as recited, air compressor means, a first compressed air conduit leading from the compressor means to the combustion zone of a combustion apparatus, the combustion zone of the combustion apparatus, the dilution zone of the combustion apparatus, turbine means including means driving the compressor means, and a turbine exhaust duct including one pass of a heat exchanger; the heat exchanger having a second pass in heat exchange relation to the first pass; a second compressed air conduit leading from the compressor means through the second pass of the heat exchanger to the dilution zone of the combustion apparatus, flow splitter valve means between the compressor and the said conduits reversely throttling the flow into the conduits for variably dividing compressor output between the said conduits so as to direct air unheated by the regenerator primarily to the combustion zone and air heated by the regenerator primarily to the dilution zone, and means for variably setting the flow splitter valve means as a function of fuel-air ratio in the combustion apparatus so as to minimize the temperature of the air entering the combustion zone to reduce combustion temperature and thereby generation of oxides of nitrogen.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,742,702 Dated July 3, 1973

Inventor(s) Ronald E. Quinn

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 16, delete "which" and substitute -- what --.

Column 3, line 22, delete "comressed" and substitute
-- compressed --.

Column 4, line 59, after "position" insert -- of --.

Column 5, line 37, delete "echanger" and substitute
-- exchanger --.

Signed and sealed this 20th day of August 1974.

(SEAL)
Attest:

McCOY M. GIBSON, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents