



(12)

EUROPEAN PATENT APPLICATION

(43)

Date of publication:
11.12.2019 Bulletin 2019/50

(51)

Int Cl.:
F01D 17/08 (2006.01)
F01D 21/00 (2006.01)

(21)

Application number: 18176673.4

(22)

Date of filing: 08.06.2018

(84) Designated Contracting States: AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR Designated Extension States: BA ME Designated Validation States: KH MA MD TN	(72) Inventors: • BERNERO, Stefano 5401 Baden (CH) • GASSNER, Martin 5401 Baden (CH) (74) Representative: Freigutpartners IP Law Firm Hahnrainweg 4 5400 Baden (CH)
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(54)

METHOD FOR DETERMINING AN OUTLET TEMPERATURE OF AN UPSTREAM COMBUSTION STAGE IN A GAS TURBINE ENGINE HAVING AT LEAST TWO SERIALLY ARRANGED COMBUSTION STAGES

(57) Method for determining an outlet temperature (T_2) of an upstream combustion stage (21) in a gas turbine engine having at least two serially arranged combustion stages (21, 22), a compressor (10) fluidly communicated with and upstream a most upstream combustion stage (21), and a last expansion turbine (30) fluidly communicated with and downstream a most downstream combustion stage (22). The method comprises obtaining at least one first parameter representative of the inlet temperature (T_3) of the most downstream combustion stage (22), obtaining at least one second parameter representative of the outlet temperature (T_1) of the compressor (10), and obtaining the fuel massflows ($\dot{m}_{Fuel,1}$, $\dot{m}_{Fuel,2}$) and/or a fuel massflow ratio between the combustion stages (21,22). An outlet temperature (T_2) of an upstream combustion stage (21) is obtained based upon said first and second parameters and the fuel massflows and/or the fuel

massflow ratio.

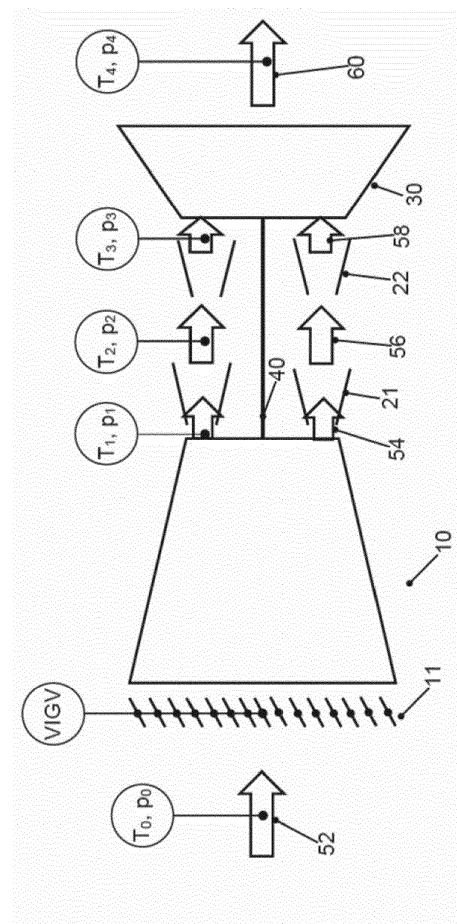


Fig. 1

Description

TECHNICAL FIELD

[0001] The present disclosure relates to a method as set forth in the claims.

BACKGROUND OF THE DISCLOSURE

[0002] From EP 718 470 a gas turbine engine is known in which two combustion chambers are provided in a fluidly serial arrangement, such that a second of said combustion chambers receives exhaust gases from the first one of said combustion chambers, with an intermediate expansion turbine being fluidly interposed between the two combustion chambers. Generally, the inlet temperature of the intermediate expansion turbine is an important process parameter for the operation of the gas turbine engine. A direct measurement of these temperatures under field conditions is not viable in an industrial use environment. It is known from expansion turbines to measure a temperature at the outlet of the expansion turbine, and derive the inlet temperature to the expansion turbine based upon the outlet temperature and a pressure ratio or pressure drop over the expansion turbine, whereas the calculation of the inlet temperature further takes into account characteristics of the specific expansion turbine.

[0003] In gas turbine engines of the type known from EP 718 470, the temperature downstream the intermediate expansion turbine, or upstream the second combustor, respectively, is measured, and the inlet temperature of the intermediate expansion turbine is calculated based upon said outlet temperature and pressure ratio with further consideration of the thermodynamic behaviour of the specific expansion turbine. The person having ordinary skill in the art is perfectly familiar with the calculation of the expansion turbine inlet temperature based upon the expansion turbine outlet temperature and the pressure ratio over the expansion turbine.

[0004] However, in gas turbine engines of the type known from EP 718 470, the temperature downstream or at the outlet of the intermediate expansion turbine is still at a level significantly above that at the outlet of a last or most downstream expansion turbine in which the expansion to the final pressure of the gas turbine process takes place. In particular, the temperature downstream the intermediate expansion turbine reaches values sufficiently high to enable a spontaneous ignition of fuel introduced into the second combustion chamber. Thus, for instance thermocouples used for determination of the outlet temperature of the intermediate expansion turbine need to operate under a harsh environment. Further, the pressure is still significantly elevated, such that extreme care must be taken of tightness of the feedthrough of instrumentation. The temperature measurement instrumentation requires careful maintenance.

[0005] An analogous issue is encountered when an

engine operates with a staged combustion with no intermediate expansion turbine fluidly interposed between two fluidly serially arranged combustion stages, and a determination of the outlet temperature of an upstream one of said combustion stages, or the inlet temperature of a downstream one of said combustion stages, is required. High temperatures and pressures of the fluid result in a challenging environment for temperature measurement instrumentation.

OUTLINE OF THE SUBJECT MATTER OF THE PRESENT DISCLOSURE

[0006] The present disclosure relates to a method of the type initially mentioned. It is an objective of the herein disclosed subject matter to provide a method which enables the determination of a temperature at the outlet of an upstream combustion stage in a gas turbine having at least two serially arranged combustion stages. An upstream combustion stage shall be understood as a combustion stage upstream of a last, most downstream combustion stage. In a more specific aspect, a method shall be provided which allows the required temperature determination without the need to place temperature sensors inside fluids which have temperatures and/or pressures beyond a certain threshold value. In this respect it may prove advantageous to have temperature sensors positioned in the working fluid no more than upstream of the most upstream combustion stage and downstream of the most downstream turbine.

[0007] This is achieved by the subject matter described in claim 1.

[0008] Further effects and advantages of the disclosed subject matter, whether explicitly mentioned or not, will become apparent in view of the disclosure provided below.

[0009] Accordingly, disclosed is a method for determining an outlet temperature of an upstream combustion stage in a gas turbine engine, the gas turbine engine having at least two serially arranged combustion stages. It shall be noted that the temperatures referred to are working fluid temperatures. A compressor is provided in fluid communication with and upstream a first, most upstream, of said combustion stages. A last, most downstream, expansion turbine is provided in fluid communication with and downstream a last, most downstream, of said combustion stages. There may or may not be other expansion turbines present in the gas turbine engine. It is understood that the last expansion turbine is the turbine in which the working fluid of the gas turbine engine is expanded to a terminal, final pressure of the thermodynamic process of the gas turbine engine. Said pressure, most commonly, is at least essentially equal to the pressure upstream the compressor, or, for air breathing gas turbine engines, the ambient pressure. However, as the skilled person will readily appreciate, the pressure after the last expansion turbine might be slightly higher than the pressure at the compressor inlet or the ambient pres-

sure, due to potential pressure losses for instance in an exhaust duct, a heat recovery steam generator, silencers, a scrubber, and other devices restricting an exhaust duct. The last expansion turbine may in certain embodiments be the one and only expansion turbine of the gas turbine engine, while in other embodiments intermediate expansion turbines may be present and fluidly interposed between combustion stages. The method comprises obtaining at least one first parameter representative of the inlet temperature of the last, most downstream, expansion turbine and/or the outlet temperature of the last, most downstream, of said combustion stages, obtaining at least one second parameter representative of the outlet temperature of the compressor and/or the inlet temperature of the first, most upstream, of said combustion stages, and obtaining the fuel massflows to each combustion stage and/or a fuel massflow ratio between the combustion stages. An outlet temperature of an upstream combustion stage different from the most downstream combustion stage is then obtained, in particular calculated or computed, based upon said first and second parameters and the fuel massflows to the combustion stages and/or the fuel massflow ratios.

[0010] Upstream and downstream refer to the flow direction of the working fluid through the gas turbine engine.

[0011] "Obtaining" a parameter or value is to be understood in a broad sense, and may comprise, while not being limited to, measuring a value or parameter directly or deriving a value or parameter from other values or parameters. It is in this respect understood that obtaining any of the at least one parameter representative of the inlet temperature of the last expansion turbine and/or the outlet temperature of the last of said combustion stages and the at least one second parameter representative of the outlet temperature of the compressor and/or the inlet temperature of the first of said combustion stages may in instances comprise a direct measurement of said at least one parameter. For instance, a compressor outlet temperature may typically be obtained through a direct measurement. However, a compressor outlet temperature may be represented by a combination of other values, such as for instance, for a compressor with a known thermodynamic characteristic, by a combination of conditions at the compressor inlet and/or ambient conditions in case of an air breathing engine and/or a compressor pressure ratio and/or a variable inlet guide vane position. It may be necessary to consider other parameters, such as for instance a mass flow of liquid agent injected into the compressor. The skilled person is perfectly familiar with obtaining a compressor outlet temperature for a given compressor from such a set of parameters. Likewise, the temperature at the inlet of the last expansion turbine may for a given expansion turbine typically be determined based upon measurements of the exhaust temperature downstream the last expansion turbine and a pressure ratio over the expansion turbine in further consideration of the expansion turbine thermodynamic characteristics.

The skilled person is also perfectly familiar with these calculations. The above examples are in no way to be considered as exhaustive, and the skilled person will readily be aware of or come up with an abundance of ways how to represent these temperatures.

[0012] Moreover, it is not necessary that these temperatures are explicitly used in a calculation of the outlet temperature of the upstream combustion stage, or a formula and/or computer program used for calculation or computation, but it may well be sufficient of the parameters representative of the temperatures to appear in a suitable combination.

[0013] A "parameter representative of a temperature may be broadly understood as a parameter having an influence on or being correlated with the said temperature, such that the parameter alone or in combination with other parameters may be used to calculate and/or to represent said temperature. This parameter may thus be said to represent the temperature, and in particular changes of said parameter cause changes of the temperature.

[0014] The fuel massflow ratio is representative of the relative fuel massflows to the different combustion stages. It may be represented as the ratio of the partial fuel massflows to the different combustion stages to each other, but also as partial fuel mass flows related to the total fuel mass flow to all combustion stages, and other parameters the skilled person may deem appropriate. The fuel massflow ratio may be obtained from measured mass flows, but may in certain embodiments be obtained from control signals and/or control valve positions and/or measured fuel pressures.

[0015] It is noted that the pressures and temperatures at the inlet and outlet of certain components of a gas turbine engine referred to are working fluid temperatures and pressures. Further, the pressures and temperatures referred to in the context of this application generally mean total pressures and temperatures, that is, the pressure and temperature of the fluid when it has isentropically been decelerated to a standstill, including the dynamic pressure head of a fluid flow and the temperature which corresponds to the kinetic energy of a fluid flow.

[0016] It is noted that within the framework of the present disclosure the use of the indefinite article "a" or "an" does in no way stipulate a singularity nor does it exclude the presence of a multitude of the named member or feature. It is thus to be read in the sense of "at least one" or "one or a multitude of".

[0017] In certain types of gas turbine engines, an intermediate expansion turbine may be provided and fluidly interposed between two combustion stages. It is readily appreciated that in such instances the outlet temperature of a combustion stage immediately upstream an intermediate expansion turbine equals or is an equivalent to the inlet temperature of that intermediate expansion turbine. Thus, in embodiments of the method, wherein at least one intermediate expansion turbine is provided and fluidly interposed between at least two serial combustion

stages, the method comprises obtaining a pressure ratio over at least one intermediate expansion turbine, and obtaining, in particular calculating or computing, an inlet temperature of said intermediate expansion turbine, or the outlet temperature of a combustion stage arranged immediately upstream said intermediate expansion turbine, wherein obtaining the outlet temperature of the upstream combustion stage comprises further considering the pressure ratio over the intermediate expansion turbine. In still more specific embodiments the method comprises obtaining a pressure ratio over each intermediate expansion turbine and obtaining, in particular calculating or computing, an inlet temperature of an intermediate expansion turbine, or the outlet temperature of a combustion stage arranged immediately upstream an intermediate expansion turbine, respectively, wherein obtaining the outlet temperature of the upstream combustion stage comprises further considering the pressure ratios over all intermediate expansion turbines.

[0018] In a general context the calculation of the outlet temperature of upstream combustion stages is based upon calculating a balance of the enthalpies from the entry into a first, most upstream, combustion stage to the outlet of a last, most downstream, expansion turbine. With knowledge of the pressure ratio over an expansion turbine and the outlet temperature of the expansion turbine, for a given expansion turbine, the enthalpy drop over the expansion turbine can be derived with knowledge of certain thermodynamic characteristics of the specific expansion turbine, and from there the inlet temperature of the expansion turbine can be calculated. This can be done for each expansion turbine in the gas turbine engine. However, as outlined above, a measurement of the exhaust temperatures of intermediate expansion turbines has shown to be subject to certain limitations. The same applies to a measurement of temperatures between two immediately subsequent combustion stages. In calculating the balance of enthalpies from the entry into the first, most upstream combustor until the exit from the last, most downstream expansion turbine, the enthalpy added along said flowpath due to combustion can be derived. The fuel massflow to each combustion stage or fuel massflow ratio enables to determine the enthalpy added in each combustion stage. The inventors have discovered that this balance enables the calculation of the temperatures upstream and downstream each combustion stage and furthermore upstream and downstream each intermediate expansion turbine, if present. Information indicative of the temperature downstream the last, most downstream expansion turbine and upstream the first, most upstream combustion stage is sufficient, wherein, as mentioned above, in particular the temperature upstream the first combustion stage may be derived from other values.

[0019] Embodiments of the herein disclosed method further comprise considering a parameter representative of at least one coolant mass flow in intermediate expansion turbines and/ or the combustion stages and/or be-

tween two subsequent combustion stages for the determination of the outlet temperature of the upstream combustion stage. For instance, said parameter may be provided as a constant or coefficient in an equation used for calculating said outlet temperature. It should be understood that an intermediate turbine may or may not be provided between the two aforementioned combustion stages. More specifically, also the temperatures of the coolant mass flows may be considered in obtaining, more specifically in calculating or computing, said outlet temperature.

[0020] In aspects, the method may further comprise considering at least one parameter representative of a at least one inert fluid mass flow and temperature of an inert fluid injected into the working fluid mass flow of the gas turbine engine in obtaining an outlet temperature of an upstream combustion stage. Said parameter may be measured mass flows and temperatures, but the mass flow may for other, non-limiting instances be provided as control valve positions.

[0021] In still further aspects, the herein disclosed method may comprise considering combustor pressure drops in obtaining the outlet temperature of the upstream combustion stage.

[0022] In still further aspects the method may comprise further considering the fuel temperature in obtaining, in particular calculating or computing, the outlet temperature of the upstream combustion stage.

[0023] In certain specific embodiments of the herein disclosed method obtaining the at least one first parameter representative of the inlet temperature of the last expansion turbine and/or the outlet temperature of the last of said combustion stages comprises obtaining an outlet temperature of the last expansion turbine, obtaining a pressure ratio over the last expansion turbine, and at least one parameter representative of the thermodynamic behavior of the last expansion turbine. This, per se, is a method well-known to the skilled person and may comprise the so called "TIT formula", which in instances is a polynomial with the outlet temperature of the last expansion turbine and the pressure ratio over the last expansion turbine as variables, and the coefficients representing the thermodynamic characteristics of the last expansion turbine. Also, conditions of the air at the inlet to the compressor may be considered, such as the relative humidity of ambient air. At the exit of the last expansion turbine the pressure, as outlined above, may at least essentially equal the pressure at the compressor inlet of the gas turbine engine, and may more specifically essentially equal the ambient or atmospheric pressure, with the deviations as outlined above due to pressure losses in an exhaust duct. The skilled person will readily appreciate that "essentially equals" is used due to the fact that in view of pressure losses in a fluid passage to the compressor inlet and in an exhaust flow path of the gas turbine engine those values may slightly differ from each other and/or from the ambient pressure. Thus, the statement still provides a clear teaching to the person having skill

in the art. The temperature of the working fluid at the outlet of the last expansion turbine is in most instances reduced to a temperature range, dependent upon the gas turbine type and operating regime, of at most 500°C - 700°C. The pressure and temperature conditions at the outlet of the last expansion turbine allow an unproblematic application of temperature sensors such as for instance thermocouples in the exhaust fluid flow emanating from the last expansion turbine. In other embodiments the at least one first parameter representative of the outlet temperature of the most downstream combustion stage and/or inlet temperature of the most downstream expansion turbine may be obtained by other methods known to or conceivable by a skilled person.

[0024] Obtaining the at least one second parameter representative of the outlet temperature of the compressor and/or the inlet temperature of the first of the combustion stages may comprise measuring the outlet temperature of the compressor and/or the inlet temperature of the first of the combustion stages as a second parameter. However, in other embodiments obtaining the at least one second parameter representative of the outlet temperature of the compressor and/or the inlet temperature of the first of the combustion stages comprises measuring a temperature and a pressure upstream of the compressor and a pressure at the outlet of the compressor as second parameters. The pressure and temperature upstream the compressor may be an ambient temperature and ambient pressure. Said ambient measurements may also comprise measurements of the ambient humidity and using the ambient humidity as a further second parameter. The method in said instances may further comprise obtaining the position of the vanes in a variable inlet guide vane row as a further second parameter. This method of deducing the outlet temperature of the compressor or the inlet temperature of the first, most upstream combustion stage from certain other parameters for a given compressor is well-known to the person having skill in the art. In other embodiments the at least one second parameter representative of the outlet temperature of the compressor and/or inlet temperature of the most downstream combustion stage may be obtained by other methods known to or conceivable by a skilled person.

[0025] Further, a mass flow of a liquid agent may be injected into a mass flow through the compressor upstream of or inside the compressor. Said mass flow of liquid agent may be a further second parameter.

[0026] It is understood that the features and embodiments disclosed above may be combined with each other. It will further be appreciated that further embodiments are conceivable within the scope of the present disclosure and the claimed subject matter which are obvious and apparent to the skilled person.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] The subject matter of the present disclosure is

now to be explained in more detail by means of selected exemplary embodiments shown in the accompanying drawings. The figures show

- 5 Fig. 1 a first exemplary embodiment of a gas turbine engine with two serially arranged combustion stages, and
- Fig. 2 a second exemplary embodiment of a gas turbine engine with two serially arranged combustion stages, wherein an intermediate expansion turbine is fluidly interposed between the two combustion stages.

[0028] It is understood that the drawings are highly schematic, and details not required for instruction purposes may have been omitted for the ease of understanding and depiction. It is further understood that the drawings show only selected, illustrative embodiments, and embodiments not shown may still be well within the scope of the herein disclosed and/or claimed subject matter.

EXEMPLARY MODES OF CARRYING OUT THE TEACHING OF THE PRESENT DISCLOSURE

[0029] Figure 1 shows a first exemplary embodiment of an air-breathing gas turbine engine having two serially arranged combustion stages. The gas turbine engine comprises compressor 10, first or upstream combustion stage 21 and second or downstream combustion stage 22, and expansion turbine 30. Expansion turbine 30 is coupled to compressor 10 by shaft 40 to drive the compressor and further a load, such as for instance a generator, which is not shown in the depiction, but familiar to the person having skill in the art. Each of combustion stages 21 and 22 may independently from each other be supplied with a respective fuel mass flow $\dot{m}_{\text{Fuel},1}$ to the first, upstream combustion stage 21 and $\dot{m}_{\text{Fuel},2}$ to the second, downstream combustion stage 22. Compressor 10 is equipped with a row of variable inlet guide vanes 11 which allow control of the inlet volume flow to compressor 10 and thus of the working fluid mass flow of the gas turbine engine. The position of the variable inlet guide vanes is denoted by VIGV. During operation, compressor 10 receives a flow of inlet air 52 at temperature T_0 and pressure p_0 . Pressure p_0 may in common, while non-limiting, instances be at least essentially equal an ambient pressure, apart from potential pressure losses in air filters, silencers and/or other installations in an inlet duct. Compressor 10 compresses the flow of inlet air to a pressure p_1 , which depends on the working fluid mass flow, flow characteristics of expansion turbine 30, the inlet temperature to the turbine and potential further influencing parameters. Due to the compression in compressor 10 the temperature of the fluid flowing through the compressor is raised to T_1 . The air flow is discharged from the compressor into combustion stage 21, where first combustion stage fuel mass flow $\dot{m}_{\text{Fuel},1}$ is combusted in the compressed air. Thereby, the temperature of flue gas

flow 56 discharged from the first combustion stage 21 is raised to T_2 , while the pressure due to inevitable losses of total pressure has dropped to p_2 . Flue gas flow 56 is discharged from upstream combustion stage 21 into downstream combustion stage 22, where a second combustion stage fuel mass flow $\dot{m}_{\text{Fuel},2}$ is combusted in the still oxygen-rich flue gas. Splitting the total fuel mass flow into two partial mass flows and combusting the two partial fuel mass flows in the dedicated combustion stages which are fluidly arranged in series may yield advantages for instance with respect to the formation of pollutants in the flue gas. In the second, downstream combustion stage 22 the temperature of the flue gas is raised to T_3 , while the pressure drops to p_3 . A mass flow of flue gas 58 at temperature T_3 and pressure p_3 is discharged from the second, downstream combustion stage 22 into expansion turbine 30. In expansion turbine 30 the flue gas mass flow 58 discharged from second combustion stage 22 is expanded to a pressure p_4 , thereby generating useful power to drive compressor 10 and an external load. Due to the expansion in the expansion turbine the temperature of the exhaust flow 60 has decreases to T_4 . The pressure p_4 downstream expansion turbine 30 may in non-nonlimiting instances be at least essentially equal to ambient pressure, apart from pressure losses in installations downstream in an exhaust duct, such as tubing of a heat recovery steam generator, scrubbers and so forth. Likewise, as the skilled person will readily appreciate, expansion turbine outlet pressure p_4 may at least essentially equal the compressor inlet pressure p_0 , apart from pressure losses in the exhaust duct and in the air intake. Generally speaking, while in the embodiment shown in figure 1 expansion turbine 30 is the only expansion turbine of the gas turbine engine, it is at the same time a last, most downstream expansion turbine. Likewise, second, downstream combustion stage 22 may be referred to as most downstream or last combustion stage.

[0030] Pressures p_0 , p_1 and p_4 may be readily measured. Pressures p_2 and p_3 may also be obtained through direct measurement, or otherwise be accounted for through known pressure loss characteristics of the combustion stages. However, while temperatures T_0 at the compressor inlet, T_1 at the compressor outlet and T_4 at the outlet of last expansion turbine 30 may be obtained through direct measurement, a reliable measurement of temperatures T_2 and T_3 at the outlets of the combustion stages turns out at least fairly difficult, if not unfeasible in field applications. Methods for obtaining temperature T_3 at the outlet of the last, most downstream combustion stage 22 based upon the pressure ratio p_3/p_4 over the last, most downstream expansion turbine 30 and the temperature T_4 at the outlet of the last, most downstream expansion turbine 30 are well-known to the person having skill in the art. The ratio of the temperatures T_3 and T_4 at the inlet and outlet of expansion turbine 30 is coupled to the ratio of the pressures at the inlet and outlet of expansion turbine 30 by thermodynamic laws, i.e. $T_3/T_4 = f(p_3/p_4)$. That is, with further knowledge of the

thermodynamic behavior of expansion turbine 30 and the certain constants of the fluid, such as the specific heat or specific heats and/or the gas constant, the temperature T_3 at the inlet of expansion turbine 30 can be calculated as a function of the temperature T_4 at the outlet of expansion turbine 30 and the pressure ratio p_3/p_4 over the expansion turbine. In order to control combustion kinetics and pollutant formation in combustion stages 21 and 22 it may prove highly desirable to obtain reliable information about temperature T_2 at the outlet of first combustion stage 21, or at the inlet of second combustion stage 22, respectively. According to the herein disclosed method, temperature T_2 at the outlet of the first combustion stage 21, or at the inlet of the second combustion stage 22, respectively, is determined and obtained based upon a heat balance between the outlet of compressor 10 and the inlet of expansion turbine 30. Based upon the fuel mass flows $\dot{m}_{\text{Fuel},1}$ and $\dot{m}_{\text{Fuel},2}$ to the combustion stages 21 and 22, respectively, and in further consideration of cooling air mass flows and pressure losses in the combustion stages, temperature T_2 can be calculated based upon a set of measured values and a thermodynamic model of the gas turbine engine, and/or the components thereof, respectively, by an enthalpy balance between the outlet of compressor 10 and the inlet of expansion turbine 30, and over the first and second combustion stages. The fuel mass flows may be considered in the calculations, or computations, respectively, by a fuel massflow ratio, which may, non-limiting, be defined as $\dot{m}_{\text{Fuel},1}/\dot{m}_{\text{Fuel},2}$. The skilled person will be readily aware of which other influencing parameters, like coolant mass flows and temperatures and thermodynamic behavior of components, must be additionally considered in obtaining the desired temperatures.

[0031] The embodiment shown in figure 2 differs from the embodiment discussed above in that an intermediate expansion turbine 31 is fluidly interposed between first combustion stage 21 and second combustion stage 22. Expansion turbine 31 is through shaft 40 mechanically coupled to expansion turbine 30 and compressor 10. A fuel gas mass flow 56 is discharged from the first combustion stage 21 into intermediate expansion turbine 31. The temperature at the outlet of the first combustion stage, or at the inlet of intermediate expansion turbine 31, respectively, is T_{21} , the pressure is p_{21} . In the intermediate expansion turbine 31 the working fluid is expanded from pressure p_{21} to pressure p_{22} , whereby the temperature decreases from T_{21} to T_{22} . Temperature T_{22} and pressure p_{22} are the temperature and pressure at the outlet of intermediate expansion turbine 31 and at the inlet of second combustion stage 22. The ratio of the temperatures at the inlet and outlet of intermediate expansion turbine 31 is coupled to the ratio of the pressures at the inlet and outlet of the intermediate expansion turbine by thermodynamic laws, i.e. $T_{21}/T_{22} = f(p_{21}/p_{22})$. That is, with further knowledge of the thermodynamic behavior of intermediate expansion turbine 31 one of the temperatures at the inlet or outlet of intermediate expansion

sion turbine 31 can be calculated as a function of the other one of said temperatures and the pressure ratio p_{21}/p_{22} over the intermediate expansion turbine. With knowledge of certain parameters representative of temperature T_1 at the outlet of compressor 10 or at the inlet of first combustion stage 21, respectively, and temperature T_3 at the outlet of the last, most downstream combustion stage 22 or at the inlet of the last, most downstream expansion turbine 30, an enthalpy balance can be calculated. That is, the difference of the enthalpies between compressed air mass flow 54 and flue gas mass flow 58 must be equal to the enthalpies added in the combustion stages minus the useful work extracted in intermediate expansion turbine 31. Said useful work in turn is a function of the difference between temperatures $T_{21} - T_{22}$. That is, with knowledge of the fuel mass flows to the combustion stages, or a ratio thereof, respectively, and further the pressure ratio over intermediate expansion turbine 31, temperatures T_{21} at the outlet of the first, upstream combustion stage or the inlet of the intermediate expansion turbine, respectively, and T_{22} at the outlet of the intermediate expansion turbine or the inlet of the second, downstream combustion stage can be calculated. The calculation may require recursions. The skilled person will be readily aware of which other influencing parameters, like coolant mass flows and temperatures and thermodynamic behavior of components, must be additionally considered in obtaining the desired temperatures.

[0032] As is shown by virtue of these exemplary embodiments, in a gas turbine engine having a multitude of serially arranged combustion stages the thermodynamic state of the working fluid can be obtained at the outlet of each combustion stage without the need to place temperature measurement instrumentation in the thermally highly loaded section of the gas turbine engine between the first, most upstream combustion stage and the outlet of the last, most downstream expansion turbine. In certain embodiments, such instrumentation which, in view of the high pressures and temperatures, is potentially subject to high maintenance requirements, can be omitted throughout the entire working fluid flow path from the inlet to the compressor to the outlet of the last, most downstream expansion turbine. Thereby, potentially unreliable measurements can be avoided to have an impact on engine control, while omitting the instrumentation and the potentially required high maintenance effort reduces cost. As further shown by virtue of the above exemplary embodiments the method may be applied in serial combustion gas turbine engines with as well as without an intermediate expansion turbine being fluidly interposed between two combustion stages.

[0033] While the subject matter of the disclosure has been explained by means of exemplary embodiments, it is understood that these are in no way intended to limit the scope of the claimed invention. It will be appreciated that the claims cover embodiments not explicitly shown or disclosed herein, and embodiments deviating from

those disclosed in the exemplary modes of carrying out the teaching of the present disclosure will still be covered by the claims.

Claims

1. A method for determining an outlet temperature (T_2 , T_{21}) of an upstream combustion stage (21) in a gas turbine engine, the gas turbine engine having at least two serially arranged combustion stages (21, 22), wherein a compressor (10) is provided in fluid communication with and upstream a first, most upstream, of said combustion stages (21), and a last expansion turbine (30) is provided in fluid communication with and downstream a last, most downstream, of said combustion stages (22), **characterized in** obtaining at least one first parameter representative of the inlet temperature (T_3) of the last, most downstream, expansion turbine (30) and/or the outlet temperature (T_3) of the last, most downstream, of said combustion stages (22), obtaining at least one second parameter representative of the outlet temperature (T_1) of the compressor (10) and/or the inlet temperature (T_1) of the first, most upstream, of said combustion stages (21), obtaining the fuel massflows ($\dot{m}_{\text{Fuel},1}$, $\dot{m}_{\text{Fuel},2}$) to and/or a fuel massflow ratio between the combustion stages (21,22), and obtaining an outlet temperature (T_2 , T_{21}) of an upstream combustion stage (21) different from the most downstream combustion stage (22) based upon said first and second parameters and the fuel massflows and/or the fuel massflow ratio.
2. The method according to the preceding claim, wherein at least one intermediate expansion turbine (31) is provided and fluidly interposed between at least two serial combustion stages (21, 22), wherein the method is **characterized in** obtaining a pressure ratio (p_{21}/p_{22}) over at least one intermediate expansion turbine (31), and obtaining an inlet temperature (T_{21}) of said intermediate expansion turbine, or the outlet temperature (T_{21}) of a combustion stage (21) arranged immediately upstream said intermediate expansion turbine, wherein obtaining the outlet temperature of the upstream combustion stage comprises further considering the pressure ratio over the intermediate expansion turbine.
3. The method according to the preceding claim, **characterized in** obtaining a pressure ratio (p_{21}/p_{22}) over each intermediate expansion turbine and obtaining an inlet temperature (T_{21}) of an intermediate expansion turbine, or the outlet temperature (T_{21}) of a combustion stage arranged immediately upstream an intermediate expansion turbine, respectively, wherein obtaining the outlet temperature of the upstream

combustion stage comprises further considering the pressure ratios over all intermediate expansion turbines.

4. The method according to any of the preceding claims, **characterized in** further comprising considering a parameter representative of at least one coolant mass flow in intermediate expansion turbines and/ or the combustion stages and/or between two subsequent combustion stages in determining the outlet temperature of the upstream combustion stage. 5
5. The method according to the preceding claim, **characterized in** further comprising considering a parameter representative of the temperature of the coolant mass flows in determining the outlet temperature of the upstream combustion stage. 10
6. The method according to any of the preceding claims, **characterized in** further comprising considering at least one parameter representative of a at least one inert fluid mass flow and temperature of an inert fluid injected into the working fluid mass flow of the gas turbine engine in determining an outlet temperature of an upstream combustion stage. 15
7. The method according to any preceding claim, **characterized in** further considering combustor pressure drops in obtaining the outlet temperature of the upstream combustion stage. 20
8. The method according to any preceding claim, **characterized in** further considering the fuel temperature in obtaining the outlet temperature of the upstream combustion stage. 25
9. The method according to any of the preceding claims, **characterized in that** obtaining the at least one first parameter representative of the inlet temperature (T_3) of the last expansion turbine (30) and/or the outlet temperature (T_3) of the last of said combustion stages (22) comprises obtaining an outlet temperature (T_4) of the last expansion turbine (30), obtaining a pressure ratio (p_3/p_4) over the last expansion turbine, and at least one parameter representative of the thermodynamic behavior of the last expansion turbine. 30
10. The method according to any of the preceding claims, **characterized in that** obtaining the at least one second parameter representative of the outlet temperature (T_1) of the compressor (10) and/or the inlet temperature (T_1) of the first of the combustion stages (21) comprises measuring the outlet temperature of the compressor and/or the inlet temperature of the first of the combustion stages as a second parameter. 35

11. The method according to any of the preceding claims, **characterized in that** obtaining the at least one second parameter representative of the outlet temperature (T_1) of the compressor (10) and/or the inlet temperature (T_1) of the first of the combustion stages (21) comprises measuring a temperature (T_o) and a pressure (p_o) upstream of the compressor and a pressure (p_i) at the outlet of the compressor as second parameters. 40
12. The method according to the preceding claim, **characterized in** obtaining the position (VIGV) of the vanes in a variable inlet guide vane row as a further second parameter. 45
13. The method according to the preceding claim, **characterized in** further injecting a mass flow of a liquid agent injected into a mass flow through the compressor upstream of or inside the compressor, and determining said mass flow as a further second parameter. 50

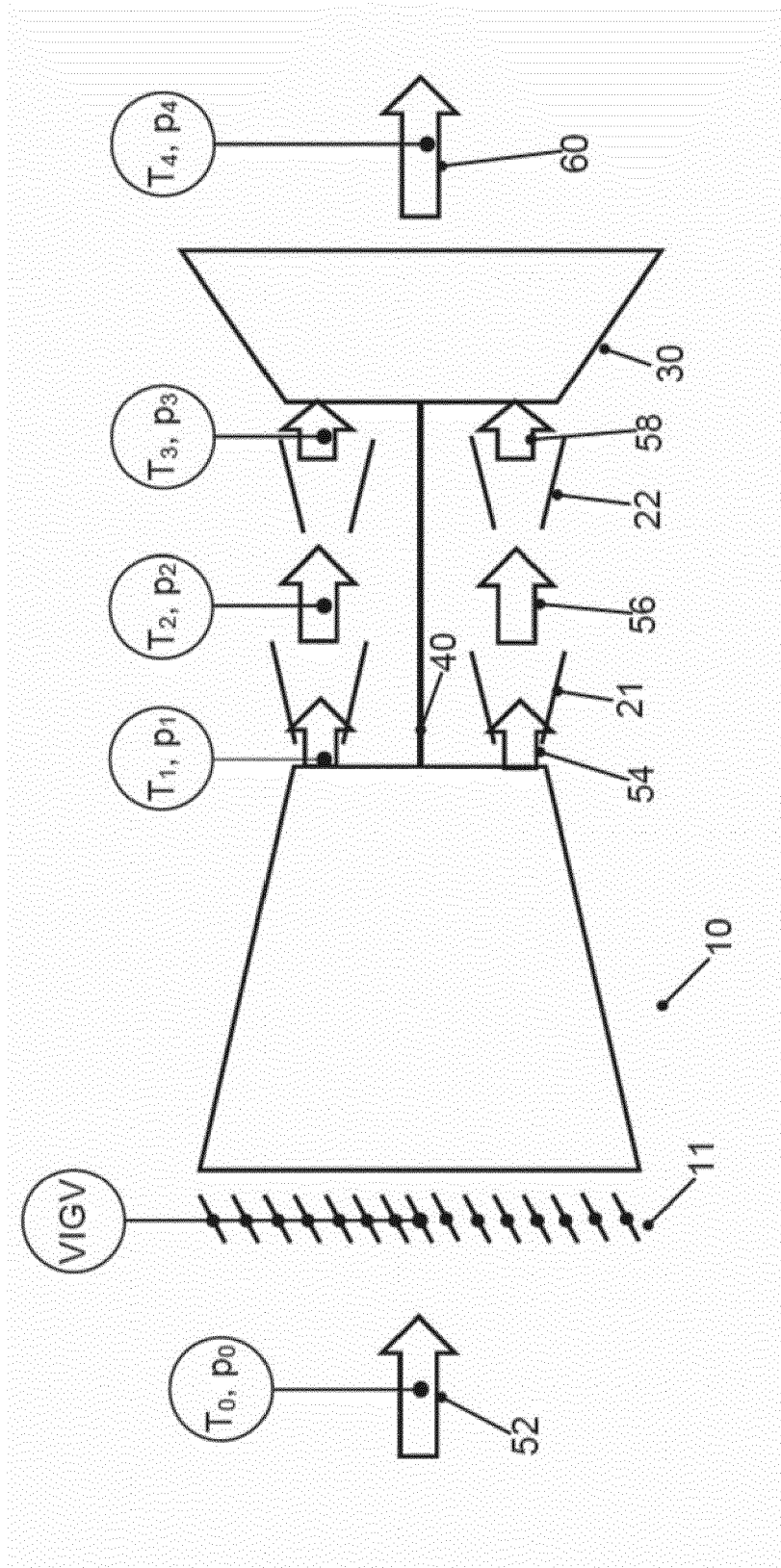


Fig. 1

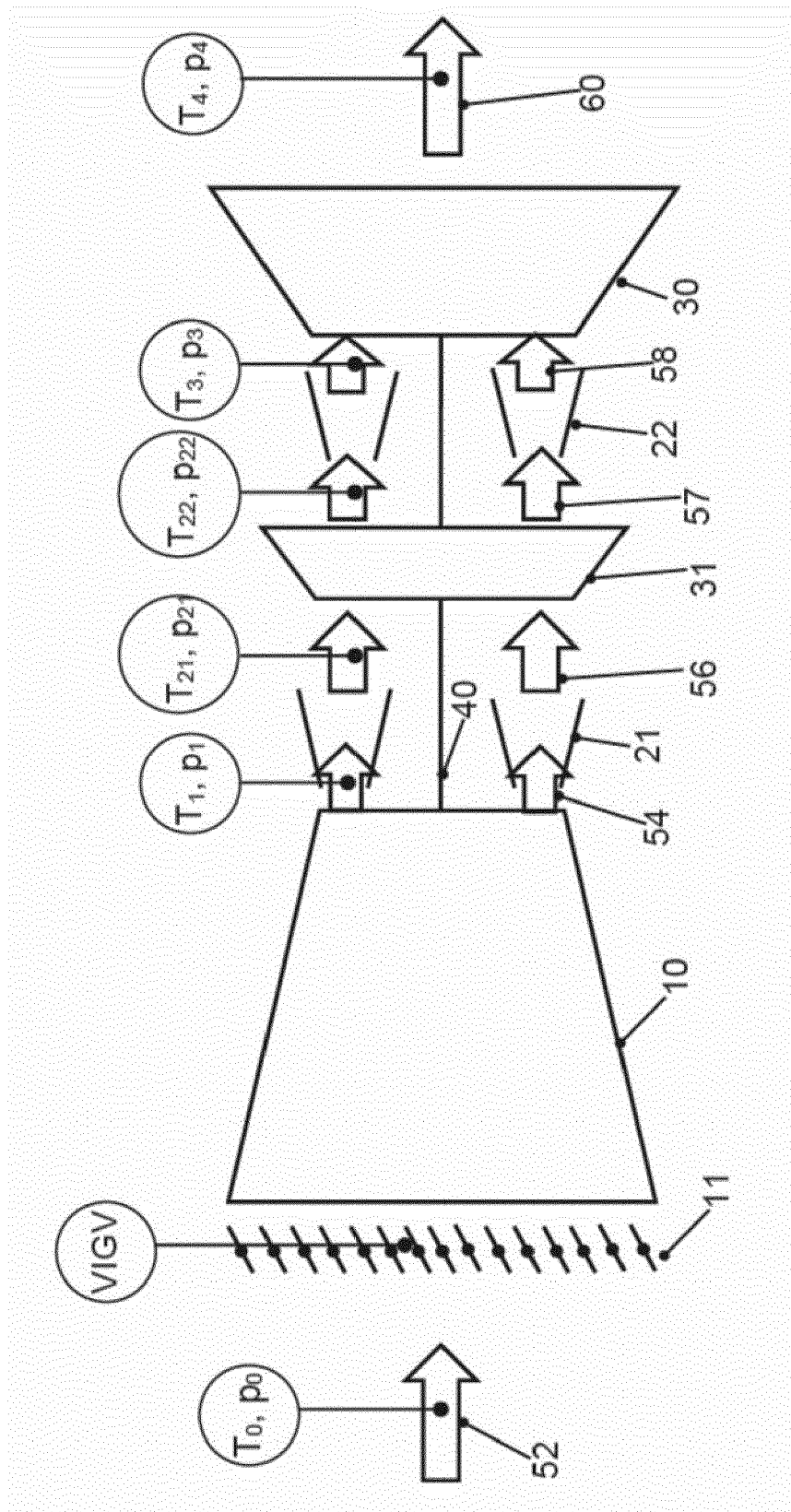


Fig. 2



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A	* claims 1, 4-6; figure 1 * * column 2, line 32 - column 3, line 22 *	2,3,6,9,11,13	
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