



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
15.03.2023 Bulletin 2023/11

(51) International Patent Classification (IPC):
F23R 3/50 ^(2006.01) **F23R 3/28** ^(2006.01)

(21) Application number: **21195837.6**

(52) Cooperative Patent Classification (CPC):
F23R 3/50; F23R 3/283; F05D 2260/964;
F23R 2900/00013; F23R 2900/00014;
F23R 2900/00016

(22) Date of filing: **09.09.2021**

(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:
• **SCARPATO, Alessandro**
5417 Untersiggenthal (CH)
• **BOTHIEN, Mirko Ruben**
8037 Zurich (CH)

(74) Representative: **Bernotti, Andrea et al**
Studio Torta S.p.A.
Via Viotti, 9
10121 Torino (IT)

(71) Applicant: **Ansaldo Energia Switzerland AG**
5400 Baden (CH)

(54) **GAS TURBINE ENGINE WITH ACOUSTIC MODE STABILIZATION, METHOD FOR CONTROLLING AND METHOD FOR RETROFITTING A GAS TURBINE ENGINE**

(57) A gas turbine engine includes a combustor (3) having a natural vibration frequency (f_0) and provided with a plurality of first burners (17) and a plurality of second burners (18). The first burners (17) are configured to produce first flames with a first time delay (τ_1) and the second burners (18) are configured to produce second flames with a second time delay (τ_2). A difference between the first time delay (τ_1) and the second time delay

(τ_2) is equal to a reciprocal of the natural vibration frequency (f_0):

$$\tau_1 - \tau_2 = 1/f_0$$

where τ_1 is the first time delay, τ_2 is the second time delay and f_0 is the natural vibration frequency of the combustor.

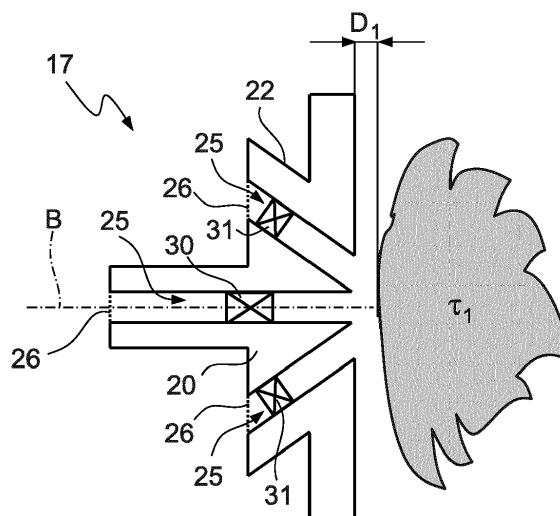


FIG. 3

Description

TECHNICAL FIELD

[0001] The present invention relates to a gas turbine engine with acoustic mode stabilization, method for controlling and method for retrofitting a gas turbine engine.

BACKGROUND

[0002] In the field of gas turbine engines, it is well known that combustion instabilities may arise in certain operating conditions. Such conditions may depend on the response of the complex structure and dynamics of fluids in the gas turbine engines and may widely vary according to the kind and the size of gas turbines.

[0003] Critical acoustic vibrating modes are known, because normally they become apparent during the steps of design and test. It is therefore possible to implement protective measures that avoid or reduce effects of critical acoustic vibrating modes. Known measures, that include acoustic dampers and controlling fuel supply to change operating conditions, are not completely satisfactory, however.

[0004] Acoustic dampers, such as Helmholtz dampers, occupy relatively large space and require mechanical and fluidic coupling to the flow path of the gas turbine engine. Moreover, damping action of the acoustic dampers may depend on the specific location where the dampers are connected and optimal positioning may not be achieved because of geometrical or mechanical constraints.

[0005] Controlling fuel supply to all or part of the burners often results in an effective protective action against critical acoustic vibrating modes, but the change of combustion conditions may lead to an inadmissible increase of pollutant emissions, especially carbon monoxide.

[0006] Therefore, there is a general interest in improving protection of gas turbines engines from critical operation conditions, in which dangerous acoustic vibration modes (pulsations) may arise.

SUMMARY OF THE INVENTION

[0007] It is an aim of the present invention to provide a gas turbine engine, a method for controlling and a method for retrofitting a gas turbine engine, which allow to overcome or to attenuate at least in part the limitations described.

[0008] According to the present invention, there is provided a gas turbine engine according to claim 1, a method for operating a gas turbine engine according to claim 9 and a method for retrofitting a gas turbine engine according to claim 13.

[0009] According to the invention, a combustor has first burners that generate first flames with a first time delay τ_1 and second burners that generate second flames with a second time delay τ_2 . The difference between the first

time delay τ_1 and the second time delay τ_2 is equal to the reciprocal of the natural vibration frequency, i.e.: $\tau_1 - \tau_2 = 1/f_0$, where τ_1 is the first time delay, τ_2 is the second time delay and f_0 is the natural vibration frequency of the combustor (i.e. the resonance frequency of the combustor).

[0010] When the first and second time delays meet the above condition, the acoustic vibration modes (i.e. pulsations) that usually are generated in a combustion chamber of a gas turbine during operation are attenuated and at least partly cancelled. In particular, by use of the above equation, attenuation and cancellation are made to occur at the natural vibration frequency f_0 , i.e. at the critical frequency where acoustic vibration modes may amplify and cause damage of the gas turbine engine.

[0011] The attenuation is achieved without use of additional components, such as acoustic dampers, which are bulky and need fluid coupling to the hot gas path from outside. Moreover, the overall fuel supply is not altered by throttling to either the first burners or to the second burners.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The present invention will now be described with reference to the accompanying drawings, which show some non-limitative embodiments thereof, in which:

- figure 1 is a simplified block diagram of a gas turbine engine;
- figure 2 is a schematic view of a combustor incorporated in the gas turbine engine of figure 1;
- figures 3 and 4 are schematic views of a first burner (figure 3) and of a second burner (figure 4) of the combustor of figure 2, made in accordance with a first embodiment of the present invention;
- figures 5 and 6 are schematic views of a first burner (figure 5) and of a second burner (figure 6) of the combustor of figure 2, made in accordance with a second embodiment of the present invention;
- figures 7 and 8 are schematic views of a first burner (figure 7) and of a second burner (figure 8) of the combustor of figure 2, made in accordance with a third embodiment of the present invention;
- figures 9 and 10 are schematic views of a first burner (figure 9) and of a second burner (figure 10) of the combustor of figure 2, made in accordance with a fourth embodiment of the present invention;
- figures 11 and 12 are schematic views of a first burner (figure 11) and of a second burner (figure 12) of the combustor of figure 2, made in accordance with a fifth embodiment of the present invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0013] Figure 1 shows a simplified view of a gas turbine

engine, designated as whole with numeral 1. The gas turbine engine 1 comprises a compressor 2, a first combustor 3, optionally a high-pressure turbine 5, a second combustor 7 (also referred to as sequential combustor) and a low-pressure turbine 8. The example of figure 1 is not limitative, as the invention may be advantageously exploited also in gas turbine engines having different structure, such as with a single combustor or with two combustors and no high-pressure turbine between the first combustor and the second combustor. A diluter, to introduce diluting air in the hot gas passing through the combustors, may also be provided between the first and the second combustors, in addition to or as an alternative to the high pressure turbine. The two combustors may also be directly coupled, i.e. without any components in-between.

[0014] The gas turbine engine further comprises a fuel supply system 9 and a controller 10.

[0015] The fuel supply system 9 delivers fuel flowrates for operation of the first combustor 3 and second combustor 7 and comprises a first supply system 11, coupled to the first combustor 3, and a second supply system 12, coupled to the second combustor 7. Both the first supply system 11 and the second supply system 12 are controlled by the controller 10.

[0016] The controller 10 receives state signals from system sensors 13 and operates the gas turbine through actuators to provide a controlled power output. The actuators include orientable inlet guide vanes 14 of the compressor 2 and valves of the first supply system 11 and second supply system 12.

[0017] A flow of compressed air supplied by the compressor 2 is added with fuel and the air/fuel mixture thus obtained is burnt in the first combustor 3. The exhaust gas of the first combustor 3 is partly expanded in the high-pressure turbine 5; then additional fuel is mixed and burnt in the second combustor 7. The exhaust gas is finally expanded in the low-pressure turbine 8 and discharged either to the outside or e.g. to a heat recovery steam generator. The amount of fuel delivered by the first supply system 11 and second supply system 12 is controlled by the controller 10.

[0018] The invention will be hereinafter described in detail with reference to the first combustor 3. It is however understood that the invention is also applicable to the second combustor 7 or a single combustor gas turbine engine without any substantial change.

[0019] The first combustor 3 is schematically shown in figure 2 and comprises an annular combustion chamber 15, extending about a longitudinal combustor axis A of the gas turbine engine 1, a plurality of first burners 17 and a plurality of second burners 18, circumferentially distributed around the combustor axis A at a common radial distance therefrom.

[0020] The first burners 17 and the second burners 18 may define a first asymmetric group of burners and a second asymmetric group of burners, respectively. In other words, although the first burners 17 and the second

burners 18 can be symmetrically distributed as a whole, the sole first burners 17 and the sole second burners 18 may be not. Such a configuration helps promoting cancellation of the vibrating modes that propagate in the combustion chamber and counteracting their amplification.

[0021] The first combustor 3 has a natural vibration frequency f_0 . The natural vibration frequency is the resonance frequency of the first combustor, such that acoustic vibration modes (i.e. pulsations) having that frequency do not attenuate when propagating through the first combustor, but are amplified. Therefore, pulsations having the natural vibration frequency need to be dampened to avoid structural damages and loss of efficiency.

[0022] The first burners 17 and the second burners 18 may be all operated with a same fuel flowrate by the controller 10.

[0023] The first burners 17 are configured to produce first flames with a first time delay τ_1 and the second burners 18 are configured to produce second flames with a second time delay τ_2 , where the second time delay τ_2 is different from the first time delay τ_1 .

[0024] The time delay is a characteristic time required for the fuel to be conveyed from a fuel injection point to the flame front.

[0025] The first burners 17 and the second burners 18 are structured so that a difference between the first time delay τ_1 and the second time delay τ_2 is equal to the reciprocal of the natural vibration frequency f_0 :

$$\tau_1 - \tau_2 = 1/f_0.$$

[0026] The first burners 17 and the second burners 18 may comprise respective first stages 20, 21 and respective second stages 22, 23. The first stages 20, 21 may be pilot stages (e.g. arranged for generating a diffusion flame) that extend along a burner axis B and the second stages 22, 23 may be main premix stages that extend around the respective first stages 20, 21.

[0027] The time delay of the first burner preferably refers to the time delay of the second (main) stage 22 and likewise the time delay of the second burner preferably refers to the time delay of the second (main) stage 23. Anyway, it is also possible that the time delay of the first burner 17 refers to an average of the time delay of the first and second stages 20, 22 and likewise the time delay of the second burner 18 refers to an average of the time delay of the first and second stages 21, 23; such a solution may be preferred in case a substantial amount of fuel, e.g. 10% or more, is fed via the first (pilot) stages 20, 21.

[0028] In one embodiment, the first burners 17 have first air passages 25 and the second burners 18 have second air passages 27. The second air passages 27 are different from the first air passages 25. Differences in air passages determine different air supply, that in turn results in different time delays.

[0029] For example, the first burners 17 may have first air passages 25 with respective air inlets and first inlet grids 26 at the air inlets. The second burners 18 may likewise have second air passages 27 with respective air inlets and second inlet grids 28 at the air inlets. The first inlet grids 26 and the second inlet grids 28 are different from one another and e.g. they are configured to differently affect inlet airflows and cause different first time delay τ_1 and second time delay τ_2 . Use of different inlet grids is a simple and cheap, yet effective solution to differentiate air supply and obtain different time delays.

[0030] As an alternative or additional measure, the first burners 17 may have swirlers 30, 31; the second burners 18 may have swirlers 32, 33, which are different from the swirlers 30, 31.

[0031] In another embodiment (not shown), air splitters may be arranged to differently divide airflows in the first air passages 25 of the first burners 17 and in the second air passages 27 of the second burners 18.

[0032] With reference to figures 5 and 6, where parts substantially identical to those already shown are identified by the same numerals, in another embodiment the first burners 17 have a first fuel split ratio between the respective first stage 20 and second stage 22 and the second burners 18 have a second fuel split ratio between the respective first stage 21 and second stage 23, whereby the second fuel split ratio is different from the first fuel split ratio.

[0033] For example, the first supply system 11 may comprise independent fuel valves 33, 35 for the first stage 20 and for the second stage 22 of the first burners 17, and further independent fuel valves 34, 36 for the first stage 21 and for the second stage 23 of the second burners 18. The fuel valves 33-36 are controlled by the controller 10 to supply fuel flowrates F_1 , F_2 to the first stage 20 and to second stage 22 respectively of the first burners 17 and fuel flowrates F_1' , F_2' to the first stage 21 and to second stage 23 respectively of the second burners 18.

[0034] The fuel flowrates F_1 , F_2 and the fuel flowrates F_1' , F_2' are selected such that a first fuel split ratio F_1/F_2 of the first burners 17 is different from a second fuel split ratio F_1'/F_2' of the second burners 18:

$$F_1/F_2 \neq F_1'/F_2'.$$

[0035] In one embodiment, however, each of the first burners 17 and second burners 18 receives the same total fuel flowrate F_T :

$$F_1 + F_2 = F_1' + F_2' = F_T.$$

[0036] The fuel split ratio between the first and second burners may be used to control flame characteristic (shape, location) and thus the time delay, without any structural modification of the first and second burners, as damping of the target frequencies may be obtained

through gas turbine engine control.

[0037] In one embodiment, shown in figures 7 and 8, the first burners 17 and the second burners 18 have respective different outlets. As for air inlets, also burner outlets may be exploited to differentiate the behavior of the first burners 17 and second burners 18. Differences may reside e.g. in shape, length and width of the outlets.

[0038] With reference to figures 7 and 8, the first burners 17 are provided with respective first outlets 40, which project in an axial direction and are defined by conical or generally convergent or cylindrical sections having a first length L_1 and a first width W_1 .

[0039] The second burners 18 are provided with respective second outlets 41, which project in an axial direction and are defined by conical or generally convergent or cylindrical sections having a second length L_2 , different from the first length L_1 , and/or a second width W_2 , different from the first width W_1 .

[0040] In other embodiments not shown, only the first burners 17 or the second burners 18 are provided with projecting outlets.

[0041] The first burners 17 may also be configured to cause respective first flame anchorage locations and the second burners 18 may be configured to cause respective second flame anchorage locations, the second flame anchorage locations being axially different from the first flame anchorage locations.

[0042] The effect may be achieved in a simple and cost effective manner e.g. by using lance injectors of different length at the first burners 17 and second burners 18. For example, the first burners 17 include respective first lance injectors 43 having a first length L_1' and the second burners 18 include respective first lance injectors 44 having a second length L_2' , where the second length L_2' is different from the first length L_1' (figures 9 and 10).

[0043] According to embodiment of the invention, shown in figures 11 and 12, another way to cause different flame axial anchoring locations and delay times in the first burners 17 and second burners 18 relies on burners with stabilizing actuators differently operated.

[0044] Specifically, the burners have a first flame stabilizer 45, configured to trigger a first flame configuration and make the burners to operate as the first burners 17, and a second flame stabilizer 46, configured to trigger a second flame configuration and make the burners to operate as the second burners 18. The first flame stabilizers 45 and the second flame stabilizers 46 may be e.g. spark plugs or plasma generators. The first flame stabilizers 45 and the second flame stabilizers 46 are controlled by the controller 10.

[0045] The present invention also refers to method for operating a gas turbine engine.

[0046] According to the method, first burners 17 of a gas turbine engine combustor are operated to produce first flames with a first time delay τ_1 and second burners 18 of the gas turbine combustor are operated to produce second flames with a second time delay τ_2 .

[0047] The difference between the first time delay τ_1

and the second time delay τ_2 is equal to a reciprocal of the natural vibration frequency f_0 :

$$\tau_1 - \tau_2 = 1/f_0$$

where τ_1 is the first time delay, τ_2 is the second time delay and f_0 is the natural vibration frequency.

[0048] In a first example, the first flames have a first flame shape and the second flames have a second flame shape, different from the first flame shape.

[0049] In another example, the first flames are set at a first distance D_1 from the respective first burner assemblies 17 and the second flames are set at a second distance D_2 from the respective second burner assemblies 18, the second distance D_2 being different from the first distance D_1 .

[0050] In a further example, the first burners 17 have a first fuel split ratio F_1/F_2 between a first stage 20 and second stage 22 thereof and the second burners 18 have a second fuel split ratio F_1'/F_2' between a first stage 21 and second stage 23 thereof, the second fuel split ratio F_1'/F_2' being different from the first fuel split ratio F_1/F_2 .

[0051] The solutions exemplified above may also be combined together.

[0052] A gas turbine engine may also be retrofitted to achieve suppression of natural vibration frequency as described above. The gas turbine engine comprises a combustor having a natural vibration frequency f_0 . The combustor 3, 7 comprises a plurality of first burners 17. The first burners are configured to produce flames with a first time delay τ_1 .

[0053] The retrofitting method comprises replacing one or more components of at least one of the first burners 17 with a modified component to obtain a second burner 18. The second burners 18 are configured to generate flames with a second time delay τ_2 . The second time delay τ_2 is different from the first time delay τ_1 .

[0054] The difference between the first (native) time delay τ_1 and the second (modified) time delay τ_2 is equal to the reciprocal of the natural vibration frequency f_0 , as explained above.

[0055] The replacement component may be at least one of inlet grids (26, 28); swirlers (30, 31, 32, 33); air splitters; outlets (40, 41); lance injectors (43, 44); stabilizing actuators (45, 46); etc.

[0056] The controller 10 contains a computer program configured to control operation of the gas turbine engine 1. As herein understood, component replacement to achieve suppression of natural vibration frequency may also include replacing the controller 10 or replacing the computer program loaded in the controller 10 with a modified computer program or replacing or adding code portions to the computer program.

[0057] For example, the native computer program that controls the fuel split ratio F_1/F_2 of the first stage 20 and second stage 22 of one or more of the first burners 17 may be replaced with a modified computer program that

controls the fuel split ratio F_1'/F_2' .

[0058] Finally, it is evident that the described gas turbine engine and method may be subject to modifications and variations, without departing from the scope of the present invention, as defined in the appended claims.

[0059] For example, it is understood that the invention applies also to gas turbines with single combustors.

Claims

1. A gas turbine engine comprising a combustor (3; 7) having a natural vibration frequency (f_0); wherein:

the combustor (3; 7) comprises a plurality of first burners (17) and a plurality of second burners (18);

the first burners (17) are configured to produce first flames with a first time delay (τ_1) and the second burners (18) are configured to produce second flames with a second time delay (τ_2); and a difference between the first time delay (τ_1) and the second time delay (τ_2) is equal to a reciprocal of the natural vibration frequency (f_0):

$$\tau_1 - \tau_2 = 1/f_0$$

where τ_1 is the first time delay, τ_2 is the second time delay and f_0 is the natural vibration frequency of the combustor.

2. The gas turbine engine according to claim 1, wherein the first burners (17) have first air passages (25) and the second burners (18) have second air passages (27), the second air passages (27) being different from the first air passages (25).

3. The gas turbine engine according to claim 2, wherein the first air passages (25) comprise air inlets and first inlet grids (26) at the air inlets and wherein the second air passages (27) comprise air inlets and second inlet grids (28) at the air inlets, the second inlet grids (28) being different from the first inlet grids (26), and/or

the first burners (17) have first swirlers (30, 31) and the second burners (18) have second swirlers (32, 33), which are different from the first swirlers (30, 31), and/or

air splitters are provided for dividing the airflow between the first air passages (25) of the first burners (17) and second air passages (27) of the second burners (18), wherein the air splitters are configured for differently dividing airflows between the first air passages (25) of the first burners (17) and the second air passages (27)

of the second burners (18).

4. The gas turbine engine according to any one of the preceding claims, **characterized by** comprising

a fuel supply system (11) coupled to the first burners (17) and to the second burners (18), wherein the first burners (17) and the second burners (18) have at least a first stage (20, 21) and a second stage (22, 23), and a control system (10) configured to control fuel supply to the first stage (20, 21) and to the second stage (22, 23) to provide a first fuel split ratio (F_1/F_2) between the first stage (20) and the second stage (22) of the first burners (17) and to provide a second fuel split ratio (F_1'/F_2') between the first stage (21) and the second stage (23) of the second burners (18), wherein the first fuel split ratio (F_1/F_2) is different from a second fuel split ratio (F_1'/F_2').

5. The gas turbine engine according to any one of the preceding claims, wherein the first burners (17) have respective first outlets (40) and the second burners (18) have respective second outlets (41), the second outlets (41) being different from the first outlets (40).

6. The gas turbine engine according to any one of the preceding claims, wherein the first burners (17) are configured to cause respective first flame anchorage axial locations and the second burners (18) are configured to cause respective second flame anchorage axial locations, the second flame anchorage axial locations being different from the first flame anchorage axial locations.

7. The gas turbine engine according to the preceding claim, wherein

the first burners (17) include respective first lance injectors (43) having a first length L_1' and the second burners (18) include respective first lance injectors (44) having a second length L_2' , where the second length L_2' is different from the first length L_1' , and/or

the first burners (17) and the second burners (18) comprises a first flame stabilizer (45) configured to trigger a first flame with the first flame anchorage axial locations and a second flame stabilizer (46) configured to trigger a second flame with the second flame anchorage axial locations; wherein the first flame stabilizers (45) and the second flame stabilizers (46) are controlled so that all the first burners (17) have a first flame configuration and all the second burners (18) have a second flame configuration.

8. The gas turbine engine according to any one of the preceding claims, wherein:

the combustor (3; 7) comprises an annular combustion chamber (15) extending around a combustor axis (A);
the first burners (17) and the second burners (18) are circumferentially arranged around the combustor axis (A);
the first burners (17) and the second burners (18) define a first asymmetric group of burners and a second asymmetric group of burners, respectively.

9. A method for operating a gas turbine engine comprising a combustor (3; 7) having a natural vibration frequency (f_0), wherein:

the combustor (3; 7) comprises a plurality of first burners (17) and a plurality of second burners (18);
the first burners (17) are operated to produce first flames with a first time delay (τ_1) and the second burners (18) are operated to produce second flames with a second time delay (τ_2);
wherein a difference between the first time delay (τ_1) and the second time delay (τ_2) is equal to a reciprocal of the natural vibration frequency (f_0):

$$\tau_1 - \tau_2 = 1/f_0$$

where τ_1 is the first time delay, τ_2 is the second time delay and f_0 is the natural vibration frequency of the combustor.

10. The method according to claim 9, wherein the first flames have a first flame shape and the second flames have a second flame shape, different from the first flame shape.

11. The gas turbine engine according to any of claims 9-10, wherein the first flames are set at a first distance (D_1) from the respective first burner assemblies (17) and the second flames are set at a second distance (D_2) from the respective second burner assemblies (18), the second distance (D_2) being different from the first distance (D_1).

12. The gas turbine engine according to any of claims 9-11, wherein the first burners (17) have a first fuel split ratio (F_1/F_2) between a first stage (20) and second stage (22) thereof and the second burners (18) have a second fuel split ratio (F_1'/F_2') between a first stage (21) and second stage (23) thereof, the second fuel split ratio (F_1'/F_2') being different from the first fuel split ratio (F_1/F_2).

13. A method of retrofitting a gas turbine engine comprising a combustor (3; 7) having a natural vibration frequency (f_0), wherein:

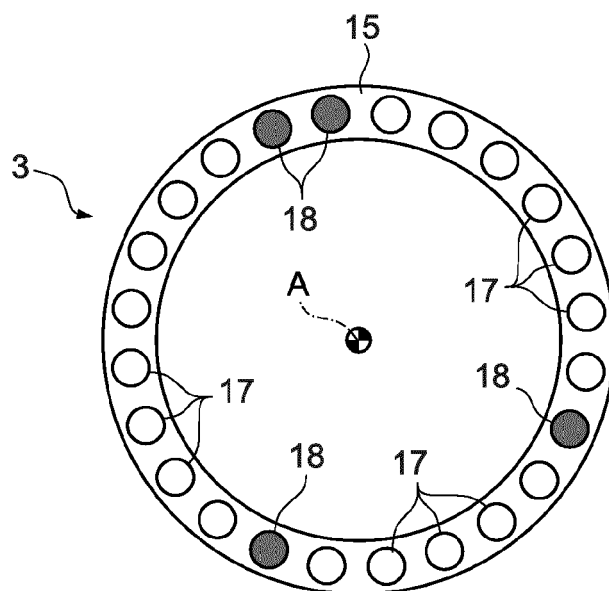
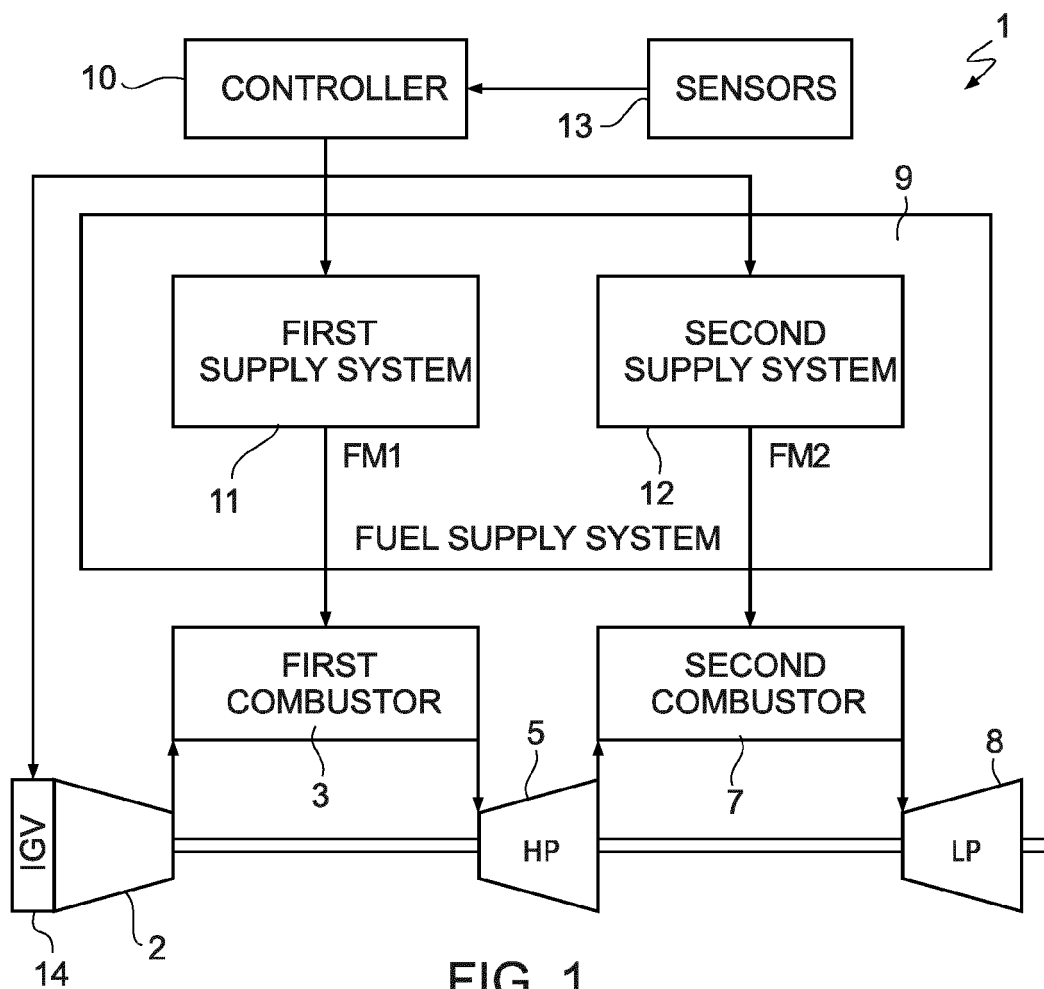
the combustor (3; 7) comprises a plurality of first burners (17) configured to produce flames with a time delay (τ_1),
the method comprising:

replacing a component (26, 28; 30, 31; 10; 40, 41; 43, 44) of at least one of the first burners (17) with a modified component (26, 28; 30, 31; 10; 40, 41; 43, 44) to obtain a second burner (18), whereby the at least one second burner (18) is configured to produce flames with a second time delay (τ_2), different from the first time delay (τ_1); and selecting the modified component (26, 28; 30, 31; 10; 40, 41; 43, 44) such that a difference between the first time delay (τ_1) and the second time delay (τ_2) is equal to a reciprocal of the natural vibration frequency (f_0):

$$\tau_1 - \tau_2 = 1/f_0$$

where τ_1 is the first time delay, τ_2 is the second time delay and f_0 is the natural vibration frequency of the combustor.

14. The method according to claim 13, wherein replacing the component (26, 28; 30, 31; 40, 41; 43, 44) comprises replacing at least one of: inlet grids (26, 28), swirlers (30, 31, 32, 33), air splitters; outlets (40, 41), lance injectors (43, 44), stabilizing actuators.
15. The method according to claim 13 or 14, wherein the gas turbine engine (1) comprises a controller (10) with a computer program configured to control operation of the gas turbine engine (1), and wherein replacing the component (10) comprises replacing the computer program loaded in the controller (10) with a modified computer program or replacing or adding code portions to the computer program.



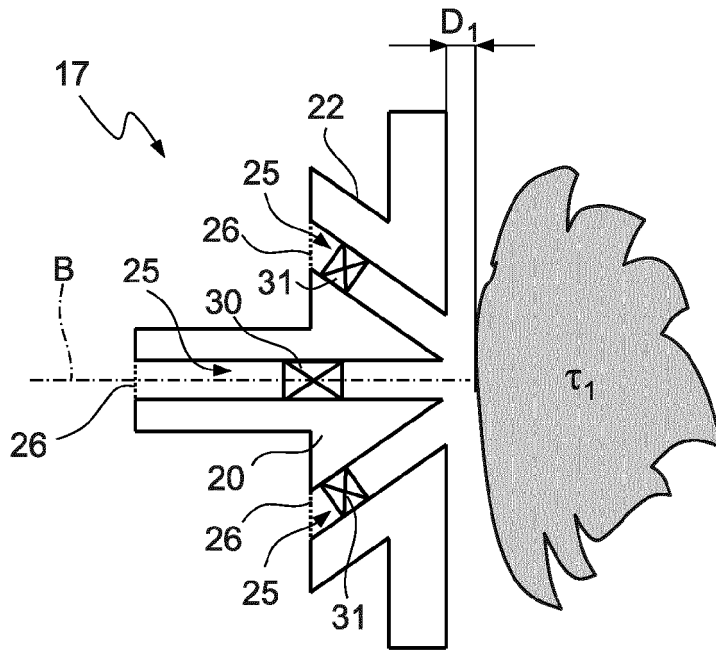


FIG. 3

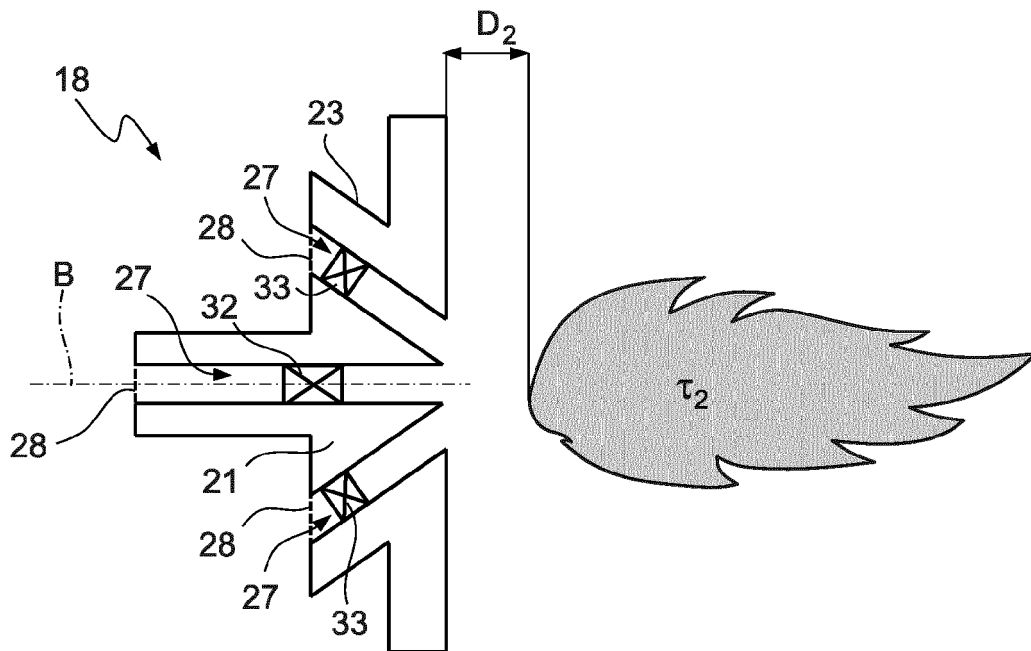


FIG. 4

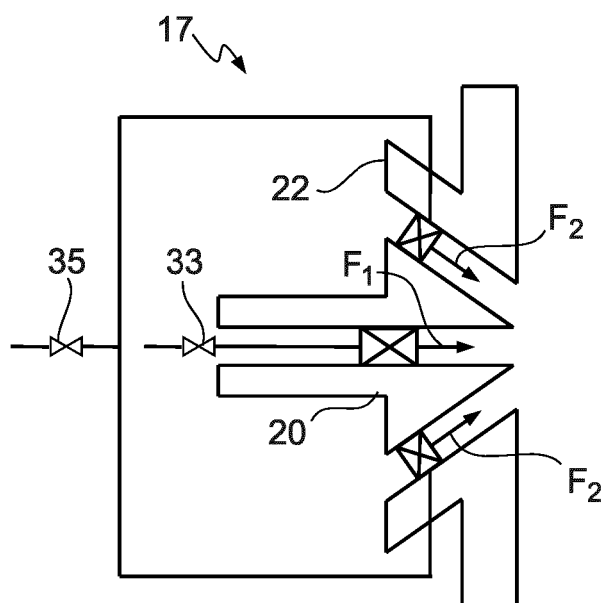


FIG. 5

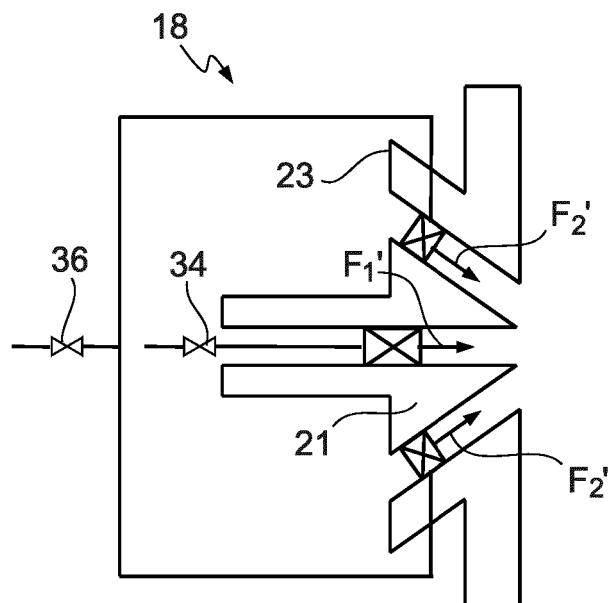


FIG. 6

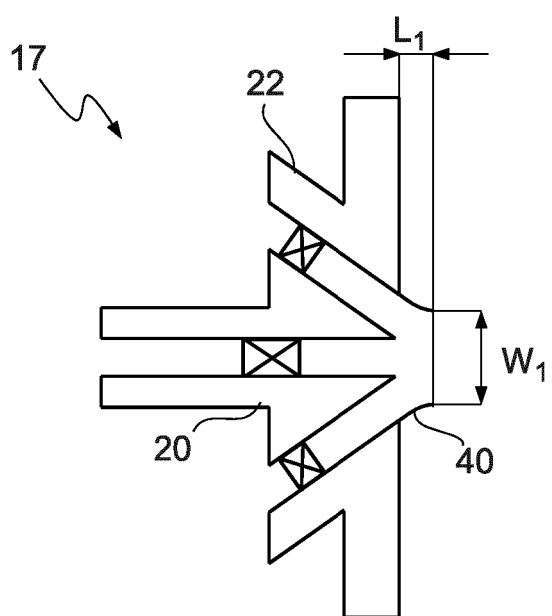


FIG. 7

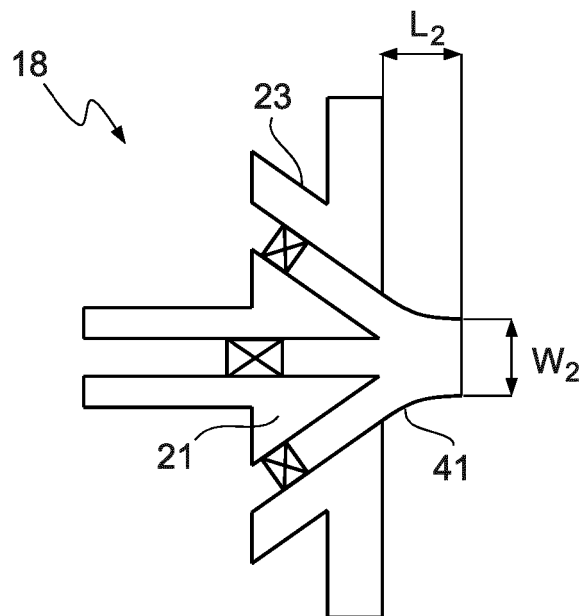


FIG. 8

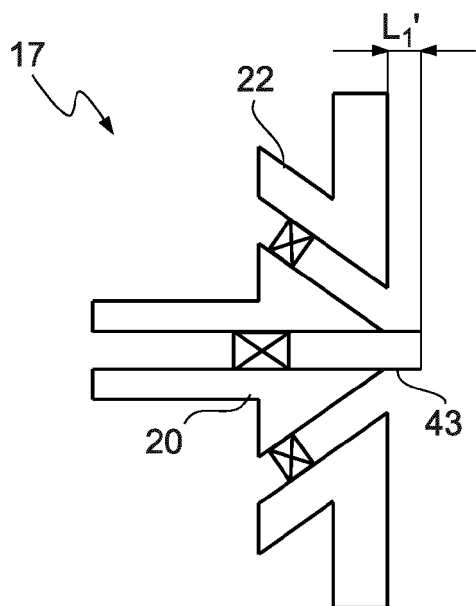


FIG. 9

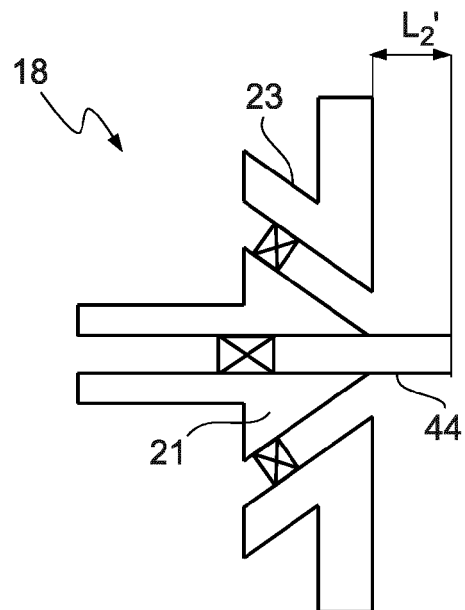


FIG. 10

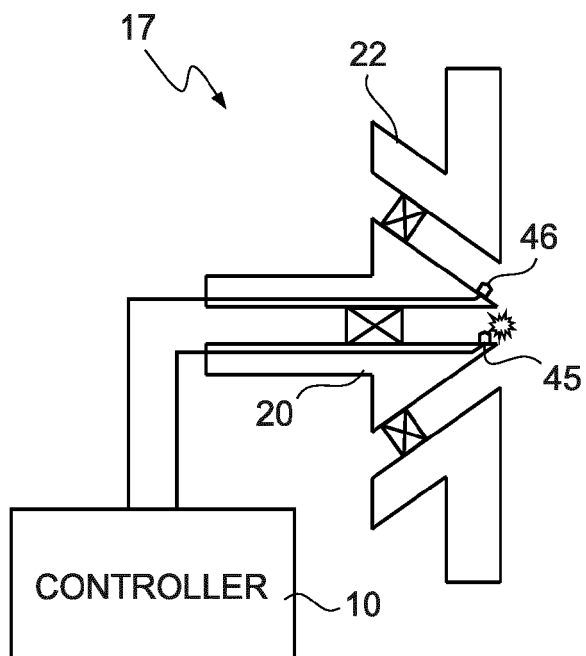


FIG. 11

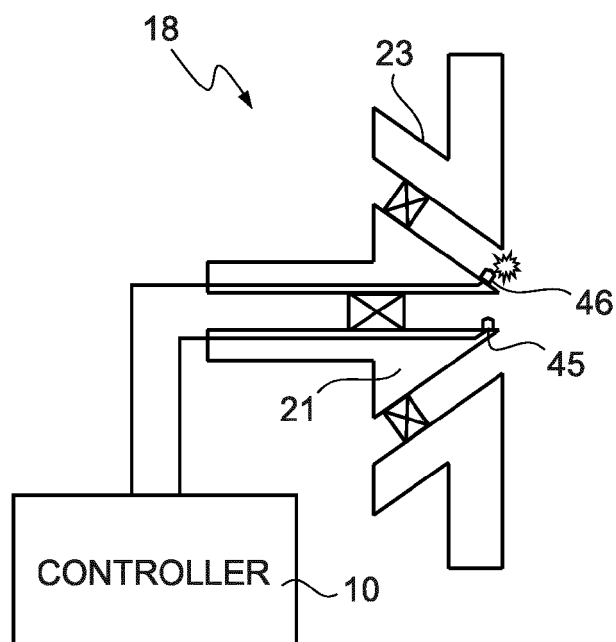


FIG. 12



EUROPEAN SEARCH REPORT

Application Number

EP 21 19 5837

5

10

15

20

25

30

35

40

45

50

55

EPO FORM 1503 03/82 (P04C01)

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2004/093851 A1 (DAWSON ROBERT W [US]) 20 May 2004 (2004-05-20)	1-7, 9-12	INV.
Y	* paragraph [0013]; figures *	13-15	F23R3/50
	-----		F23R3/28
Y	EP 2 848 865 A1 (ALSTOM TECHNOLOGY LTD [CH]) 18 March 2015 (2015-03-18) * paragraphs [0013], [0030] - paragraph [0034]; figures 5-7 *	13-15	

X	DE 10 2004 015186 A1 (ALSTOM TECHNOLOGY LTD BADEN [CH]) 20 October 2005 (2005-10-20) * paragraphs [0019], [0024] - paragraph [0026]; figures *	1-5, 8-10, 12	

X	US 2001/018172 A1 (LOVETT JEFFERY ALLAN [US] ET AL) 30 August 2001 (2001-08-30) * paragraphs [0004], [0005], [0019] - paragraph [0031]; figures 2-5 *	1-3, 6, 9-11	

X	US 2008/053097 A1 (HAN FEI [US] ET AL) 6 March 2008 (2008-03-06) * paragraph [0038] - paragraph [0042]; figure 4 *	1, 5-7, 9, 10	TECHNICAL FIELDS SEARCHED (IPC)
	-----		F23R
X	US 2015/219337 A1 (CROTHERS SARAH LORI [US] ET AL) 6 August 2015 (2015-08-06) * paragraphs [0021], [0022], [0033] - paragraphs [0039], [0050]; figures 3-5 *	1, 4, 8, 13-15	

X	US 2003/041588 A1 (JOOS FRANZ [DE] ET AL) 6 March 2003 (2003-03-06) * paragraph [0018] - paragraph [0021] * * paragraph [0026] - paragraph [0035]; figures *	1-4, 6, 7, 9-12	

1 The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 11 February 2022	Examiner Mootz, Frank
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 21 19 5837

5

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

11-02-2022

10

15

20

25

30

35

40

45

50

55

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2004093851 A1	20-05-2004	EP 1426689 A1 US 2004093851 A1	09-06-2004 20-05-2004
EP 2848865 A1	18-03-2015	NONE	
DE 102004015186 A1	20-10-2005	DE 102004015186 A1 WO 2005093326 A2	20-10-2005 06-10-2005
US 2001018172 A1	30-08-2001	US 6269646 B1 US 2001018172 A1	07-08-2001 30-08-2001
US 2008053097 A1	06-03-2008	DE 102007042059 A1 JP 5010402 B2 JP 2008064449 A KR 20080022054 A US 2008053097 A1	06-03-2008 29-08-2012 21-03-2008 10-03-2008 06-03-2008
US 2015219337 A1	06-08-2015	NONE	
US 2003041588 A1	06-03-2003	DE 19939235 A1 GB 2355517 A JP 2001090951 A US 6449951 B1 US 2003041588 A1	22-02-2001 25-04-2001 03-04-2001 17-09-2002 06-03-2003