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- (71) Applicant (for all designated States except US): **AL-STOM TECHNOLOGY LTD.** [CH/CH]; Brown Boveri Strasse 7, CH-5400 Baden (CH).
- (72) Inventors; and
- (71) Applicants (for US only): **STUTTAFORD, Peter, John** [ZA/US]; 12075 159th Court North, Jupiter, FL 33478 (US). **JORGENSEN, Stephen** [US/US]; 10725 SW Greenridge Lane, Palm City, FL 34990 (US). **CHEN, Yan** [CN/US]; 18646 157th Place NE, Woodinville, WA 98072 (US). **RIZKALLA, Hany** [CA/US]; 1553 SE Conference

Circle, Stuart, FL 34997 (US). **OUMEJJJOD, Khalid** [US/US]; 2025 Bonisle Circle, Palm Beach Gardens, FL 33418 (US). **METTERNICH, Jeremy** [US/US]; 8365 Belize Place, Wellington, FL 33414 (US).

(74) Agents: **MACK, Brian, R.** et al.; SHOOK, HARDY & BACON LLP, 2555 Grand Boulevard, Kansas City, MO 64108 (US).

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(54) Title: COMBUSTOR WITH RADially STAGED PREMIXED PILOT FOR IMPROVED OPERABILITY

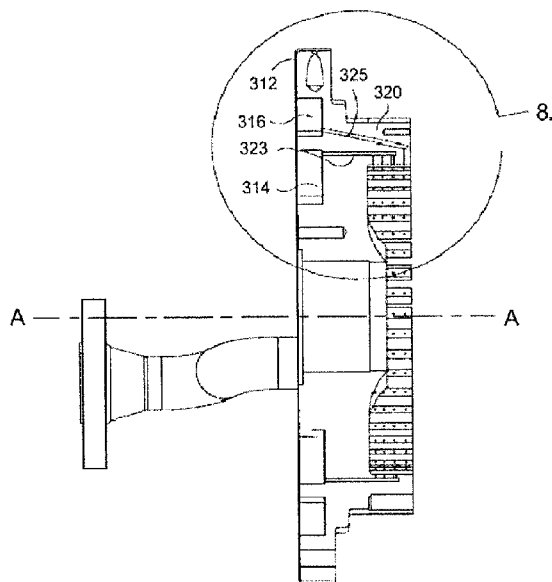


FIG. 7.

(57) Abstract: The present invention discloses a novel apparatus and method for a mixing fuel and air in a gas turbine combustion system. The mixer helps to mix fuel and air while being able to selectively increase the fuel flow to a shear to a shear layer of a pilot flame in order to reduce polluting emissions. The mixer directs a flow of air radially inward into the combustion system and includes two sets of fuel injectors within each radially-oriented vane. A first plurality of fuel injectors operate independent of a second plurality of fuel injectors and the second plurality of fuel injectors are positioned to selectively modulate the fuel flow to the shear layer of the resulting pilot flame.



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COMBUSTOR WITH RADIALY STAGED PREMIXED PILOT FOR IMPROVED OPERABILITY

FIELD OF THE INVENTION

The present invention generally relates to a system and method for improving
5 combustion stability and reducing emissions in a gas turbine combustor. More specifically, improvements in a combustor premixer and fuel injection location are provided.

BACKGROUND OF THE INVENTION

In an effort to reduce the amount of pollution emissions from gas-powered
turbines, governmental agencies have enacted numerous regulations requiring reductions in
10 the amount of oxides of nitrogen (NO_x) and carbon monoxide (CO). Lower combustion emissions can often be attributed to a more efficient combustion process, with specific regard to fuel injector location and mixing effectiveness.

Early combustion systems utilized diffusion type nozzles, where fuel is mixed
with air external to the fuel nozzle by diffusion, proximate the flame zone. Diffusion type
15 nozzles produce high emissions due to the fact that the fuel and air burn stoichiometrically at high temperature to maintain adequate combustor stability and low combustion dynamics.

An enhancement in combustion technology is the utilization of premixing,
such that the fuel and air mix prior to combustion to form a homogeneous mixture that burns
at a lower temperature than a diffusion type flame and produces lower NO_x emissions.
20 Premixing can occur either internal to the fuel nozzle or external thereto, as long as it is upstream of the combustion zone. An example of a premixing combustor of the prior art is shown in FIG. 1. A combustor 8 has a plurality of fuel nozzles 18, each injecting fuel into a premix cavity 19 where fuel mixes with compressed air 6 from plenum 10 before entering combustion chamber 20. Premixing fuel and air together before combustion allows for the
25 fuel and air to form a more homogeneous mixture, which will burn more completely, resulting in lower emissions. However, in this configuration the fuel is injected in relatively the same plane of the combustor, and prevents any possibility of improvement through altering the mixing length.

An alternate means of premixing and lower emissions can be achieved through
30 multiple combustion stages, which allows for enhanced premixing as load increases.

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Referring now to FIG. 2, an example of a prior art multi-stage combustor is shown. A combustor 30 has a first combustion chamber 31 and a second combustion chamber 32 separated by a venturi 33, which has a narrow throat region 34. While combustion can occur in either first or second combustion chambers or both chambers, depending on load conditions, the lowest emissions levels occur when fuel, which is injected through nozzle regions 35, is completely mixed with compressed air in first combustion chamber 31 prior to combusting in the second combustion chamber 32. Therefore, this multi-stage combustor with a venturi is more effective at higher load conditions.

Gas turbine engines are required to operate at a variety of power settings. Where a gas turbine engine is coupled to drive a generator, required output of the engine is often measured according to the amount of load on the generator, or power that must be produced by the generator. A full load condition is the point where maximum generating capacity is being drawn from the generator. This is the most common operating point for land-based gas turbines used for generating electricity. However, often times electricity demands do not require the full capacity of the generator, and the operator desires to operate the engine at a lower load setting, such that only the load demanded is being produced, thereby saving fuel and lowering operating costs. Combustion systems of the prior art have been known to become unstable at lower load settings, especially below 50% load, while also producing unacceptable levels of NO_x and CO emissions. This is primarily due to the fact that most combustion systems are staged for most efficient operation at high load settings. The combination of potentially unstable combustion and higher emissions often times prevents engine operators from running engines at lower load settings, forcing the engines to either run at higher settings, thereby burning additional fuel, or shutting down, and thereby losing valuable revenue that could be generated from the part-load demand.

A further problem with shutting down the engine is the additional cycles that are incurred by the engine hardware. A cycle is commonly defined as the engine passing through the normal operating envelope. Engine manufacturers typically rate hardware life in terms of operating hours or equivalent operating cycles. Therefore, incurring additional cycles can reduce hardware life requiring premature repair or replacement at the expense of the engine operator. What is needed is a system that can provide flame stability and low emissions benefits at a part load condition, as well as at a full load condition, such that engines can be efficiently operated at lower load conditions, thereby eliminating the wasted

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fuel when high load operation is not demanded or incurring the additional cycles on the engine hardware when shutting down.

SUMMARY OF THE INVENTION

The present invention discloses a mixer for premixing fuel and air prior to
5 combustion in combination with precise staging of fuel flow to the combustor to achieve reduced emissions at multiple operating load conditions. The mixer operates so as to selectively increase the fuel flow to a boundary layer of a pilot flame, thereby increasing the stability of the pilot flame for use in ignition of other fuel injected into the combustor. More specifically, in an embodiment of the present invention, a premixer for a gas turbine
10 combustor is disclosed. The premixer comprises an end cover having multiple fuel plenums contained therein and a radial inflow swirler. The radial inflow swirler comprises a plurality of vanes oriented at least partially perpendicular, relative to the longitudinal axis of the combustor. The plurality of vanes each have a plurality of fuel injectors in fluid communication with the multiple fuel plenums of the end cover. The premixer further
15 comprises an inner wall and outer wall, both of which extend from a direction generally perpendicular to the longitudinal axis and transition to a direction generally parallel with the longitudinal axis.

In an alternate embodiment of the present invention, a method of tuning a pilot flame in a gas turbine combustor is disclosed. The method comprises providing a cover for
20 the combustor having multiple fuel plenums and passageways for flowing fuel from the plenums. The method also provides a radially inflowing swirler coupled to the cover and having a plurality of vanes oriented in a generally radial direction relative to a combustor axis where each vane has a plurality of fuel injectors with the fuel injectors in fluid communication with a first fuel plenum and a second fuel plenum where the fuel from the
25 second fuel plenum is controlled independent of the fuel from the first fuel plenum so as to provide a radial staging of fuel to the fuel injectors within each of the vanes.

In yet another embodiment of the present invention, a method of operating a combustion system to improve ignition of the combustor main fuel injectors is provided. The method provides for a way of increasing the fuel/air ratio to a shear layer of the pilot flame
30 through fuel injection through a second set of fuel injectors such that a main combustion flame can be more easily lit upon injection of fuel from the main set of fuel injectors.

The premixer of the present invention is positioned within a combustor casing, where the combustor has a longitudinal axis, and the casing is in fluid communication with the engine compressor. In an embodiment of the invention, the premixer includes a radial inflow swirler having a plurality of fuel injectors with staged fuel injection so as to modulate the fuel/air mixture in a shear layer for igniting fuel injected by a main set of fuel injectors.

Additional advantages and features of the present invention will be set forth in part in a description which follows, and in part will become apparent to those skilled in the art upon examination of the following, or may be learned from practice of the invention. The instant invention will now be described with particular reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

The present invention is described in detail below with reference to the attached drawing figures, wherein:

FIG. 1 is a cross section view of a gas turbine combustion system of the prior art.

FIG. 2 is a cross section view of an alternate gas turbine combustion system of the prior art.

FIG. 3 is a cross section view of a combustion system in accordance with an embodiment of the present invention.

FIG. 4 is a perspective view of a portion of the combustion system in accordance with an embodiment of the present invention.

FIG. 5 is a cross section view of the portion of the combustion system of FIG. 4 in accordance with an embodiment of the present invention.

FIG. 6 is an end view of the portion of the combustion system of FIG. 4 in accordance with an embodiment of the present invention.

FIG. 7 is a cross section view of an end cover and swirler portion of the combustion system of FIG. 3 in accordance with an embodiment of the present invention.

FIG. 8 is a detailed cross section view of a portion of the end cover and swirler depicted in FIG. 7 in accordance with an embodiment of the present invention.

FIG. 9 depicts the process of operating a combustion system in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

By way of reference, this application incorporates the subject matter of U.S. Patent Nos. 6,935,116, 6,986,254, 7,137,256, 7,237,384, 7,308,793, 7,513,115, and 7,677,025.

5 The preferred embodiment of the present invention will now be described in detail with specific reference to FIGS. 3-9. Referring now to FIG. 3, a gas turbine combustion system 300 in accordance with an embodiment of the present invention is shown. Combustion system 300 is mounted to a casing (not shown), which is coupled to a compressor plenum of an engine for receiving compressed air from a compressor.

10 The combustion system 300 extends about a longitudinal axis A-A and includes a flow sleeve 302 for directing a predetermined amount of compressor air along an outer surface of combustion liner 304. Main fuel injectors 306 are positioned radially outward of the combustion liner 304 and are designed to provide a fuel supply to mix with compressed air along a portion of the outer surface of the combustion liner 304, prior to
15 entering the combustion liner 304.

 Extending generally along the longitudinal axis A-A is a pilot fuel nozzle 308 for providing and maintaining a pilot flame for the combustion system. The pilot flame is used to ignite, support and maintain multiple stages of fuel injectors of combustion system 300.

20 Referring now to FIGS. 3-5, the combustion system 300 also includes a radially staged premixer 310. FIG. 4 shows a perspective view of the radial premixer 310 while FIG. 5 shows a cross section of the radial premixer 310. The premixer 310 comprises an end cover 312 having a first fuel plenum 314 extending about the longitudinal axis A-A of the combustion system 300 and a second fuel plenum 316 positioned radially outward of the
25 first fuel plenum 314 and concentric with the first fuel plenum 314.

 The radially staged premixer 310 also comprises a radial inflow swirler 318 comprising a plurality of vane 320 that are oriented in a direction that has at least a partial radial component thereto relative to the longitudinal axis A-A of the combustion system 300. The radial orientation serves to direct airflow from the outer portions of the combustion
30 system 300 inward into the combustor and towards the longitudinal axis A-A. The vanes 320 may also have a circumferential angle to them as shown by the swirler 318 of FIG. 6. The circumferential angle of the vanes 320 serves to help impart an angular momentum to the

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radially inward flow in order to enhance mixing of fuel and air. The vanes 320, as depicted in FIGS. 4 and 6-8 have a generally rectangular cross section. However, the vanes 320 can have different cross sections such as an airfoil-shaped cross section, depending on the geometry of the radially staged premixer, fuel passageways, and manufacturing techniques.

5 Referring now to FIGS. 7 and 8, the plurality of vanes 320 of swirler 318 each have a first plurality of fuel injectors 322 and a second plurality of fuel injectors 324. That is, for the embodiment of the present invention depicted in FIGS. 7 and 8, each vane 320 has three fuel injectors 322 and a second fuel injector 324. First plurality of fuel injectors 322 are in fluid communication with the first fuel plenum 314 in end cover 312 by way of a first
10 passage 323 while the second plurality of fuel injectors 324 are in fluid communication with the second fuel plenum 316 by way of a second passage 325. As such, the amount of fuel being injected by respective vanes 320 can be independently controlled through the first injectors 322 and second injectors 324.

In the embodiment of the invention disclosed in FIGS. 7 and 8, the first
15 passage 323 is generally parallel to the longitudinal axis A-A, while the second passage 325 is oriented at an angle relative to the longitudinal axis A-A. The exact orientation of the first passage 323 and second passage 325 can vary depending on the size and shape of the end cover 312 and radial inflow swirler 318.

The exact size and spacing of the first plurality of fuel injectors 322 and
20 second plurality of fuel injectors 324 can vary depending on the amount of fuel to be injected. For the embodiment shown in FIG. 8, the injector holes are generally perpendicular to the exit plane of the vanes 320. The diameter of injector holes 322 and 324 can vary, but are generally in the range of approximately 0.030 inches – 0.200 inches.

The radial inflow swirler 318 further comprises a pair of walls extending from
25 adjacent the plurality of vanes 320 in a direction which is initially generally perpendicular to the longitudinal axis A-A, thereby forming a premix passage 330. The pair of walls comprise an inner wall 332 and an outer wall 334, with the outer wall 334 spaced a distance from the inner wall 332 approximately equal to the axial length of the vane 320. The inner wall 332 and outer wall 334 transition towards a direction that is generally parallel to the longitudinal
30 axis A-A. For the embodiment depicted in FIG. 5, the premix passage 330 formed by the inner wall 332 and outer wall 334 maintains a generally constant cross section and provides a region in which fuel from the plurality of vanes 320 can mix with surrounding airflow. The inner wall 332 is essentially formed by a portion of the end cover 312 and the pilot nozzle

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while the outer wall 334 is fabricated from a formed sheet metal. However, it is envisioned that the inner wall 332 and outer wall 334 could each be separate from the end cover 312 and the geometry of the premix passage 330 can also vary, as may be required to provide the necessary fuel/air mixture to the combustion system 300.

5 The present invention provides a combustion system operable in a manner so as to improve ignition of the main injectors for the combustion system. Referring to FIG. 9, a method 900 of operating the combustion system to improve ignition of a main set of injectors is provided.

10 In a step 902, a flow of fuel is provided from the first fuel plenum and through a first set of fuel injectors of a radial inflow swirler in order to mix with a passing airflow. The fuel/air mixture travels through the premix passage and discharges into the combustion chamber, where in a step 904, a pilot flame is established along the longitudinal axis of the combustor. The pilot flame is supported with fuel from the radial inflow swirler.

15 As one skilled in the art understands, a flame inherently contains a shear layer. Generally speaking, a shear layer, or boundary layer is a region of flow in which there can be significant velocity gradient. The shear layer of a flame is the shared region between the outermost edge of the flame and the non-flammable surroundings or an adjacent flame.

20 In a step 906, fuel from the second plenum is directed through a second set of fuel injectors of the radial inflow swirler. By directing a supply of fuel to the second injectors in each of the vanes of the swirler, additional fuel is directed to the radially outward most region of the premix passage, adjacent the passage outer wall, and therefore increases the amount of fuel along the shear layer so that fuel/air ratio is locally increased. In operation, when fuel is supplied to the second injectors, this represents a fuel flow increase of approximately 5%-50% over the amount of fuel flowing through only the first set of fuel
25 injectors of the radial inflow swirler.

30 In a step 908, fuel is provided to a main set of fuel injectors. For the embodiment of the present invention depicted in FIG. 3, the main set of fuel injectors comprises a set of annular fuel injectors positioned about the combustion liner 304 so as to inject a flow of fuel upstream and into a passing air stream. The fuel from the main injectors ignites as a result of the pilot flame, enhances the shear layer, and establishes a main combustion flame in a step 910.

As a result of the present invention, ignition of fuel from a main set of fuel injectors can occur more easily and reliably due to the ability to control the fuel/air ratio of

the shear layer of the pilot flame. More specifically, by locally increasing the supply of fuel at an outermost radial location in the premix passage, the concentration of fuel in the shear layer of the resulting pilot flame is increased. As a result, the richened shear layer allows the main injectors to more easily and reliably ignite without the need for a lot of energy, which
5 then results in lower pulsation levels during ignition of the main fuel injectors.

An additional benefit of being able to locally richen the fuel flow to the shear layer is the ability to maintain a stable process of igniting the fuel being injected by the main injectors. That is, in a premixed combustion system, fuel flow levels are traditionally kept as lean as possible in order to reduce emissions. By locally adding fuel to the shear layer during
10 a selective time period, a more fuel-rich mixture is established, thereby increasing the fuel/air ratio in the shear layer region. A more fuel-rich mixture provides more favorable conditions for ignition to occur and increases the stability of the flame. Once the flame is ignited, then the level of fuel richness can be reduced to a leaner mixture without jeopardizing the stability of the flame.

Yet another benefit recognized through the radially fuel staging of the present invention is with respect to combustion noise. Combustion noise is a by-product of the combustion process. More specifically, fluctuations in the combustion process create unsteadiness in the heat release rate which generate sound. Combustion noise is also
15 generated by non-uniformities in temperature due to unsteady combustion. Typically, leaner flames, or flames resulting from leaner fuel-air mixtures have generally more tendency for fluctuations and instabilities due to their lower levels of fuel. The shear layer region of a flame is typically sensitive to fuel/air mixture modulation. By modulating the fuel flow to the shear layer, the fuel/air mixture in the shear layer is more fuel-rich or fuel-lean, which can be an effective measure for reducing combustion instabilities.
20

For example, for an embodiment of the present invention, noise levels associated with the combustion process disclosed herein without additional fuel provided to the shear layer of the pilot flame can result in generally high sound pressure levels at certain transient operating conditions. However, with the additional fuel provided to the shear layer, tests have shown combustion noise levels reduced to approximately 33% during the same
25
30 transient operating conditions.

While the invention has been described in what is known as presently the preferred embodiment, it is to be understood that the invention is not to be limited to the disclosed embodiment but, on the contrary, is intended to cover various modifications and

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equivalent arrangements within the scope of the following claims. The present invention has been described in relation to particular embodiments, which are intended in all respects to be illustrative rather than restrictive. Alternative embodiments and required operations, such as machining of shroud faces other than the hardface surfaces and operation-induced wear of the
5 hardfaces, will become apparent to those of ordinary skill in the art to which the present invention pertains without departing from its scope.

From the foregoing, it will be seen that this invention is one well adapted to attain all the ends and objects set forth above, together with other advantages which are obvious and inherent to the system and method. It will be understood that certain features
10 and sub-combinations are of utility and may be employed without reference to other features and sub-combinations. This is contemplated by and within the scope of the claims.

CLAIMS

What is claimed is:

1. A radially-staged premixer for a gas turbine combustor comprising: an end cover having a first fuel plenum extending about a longitudinal axis of the combustor and
5 a second fuel plenum positioned radially outward of the first fuel plenum; and a radial inflow swirler comprising: a plurality of vanes oriented so as to have at least a partial radial component, the plurality of vanes directing a fuel-air mixture radially inward into the combustor, the plurality of vanes having a first plurality of fuel injectors in fluid communication with the first fuel plenum and a second plurality of fuel injectors in fluid
10 communication with the second fuel plenum; an inner wall extending from adjacent the plurality of vanes in a direction generally perpendicular to the longitudinal axis and transitioning towards a direction generally parallel to the longitudinal axis; and an outer wall spaced a distance from the inner wall and also extending from adjacent the plurality of vanes in a direction generally perpendicular to the longitudinal axis and transitioning towards a
15 direction generally parallel to the longitudinal axis, such that the outer wall is generally offset from the inner wall, thereby forming a premix passage between the inner wall and outer wall.
2. The premixer of claim 1, wherein the second fuel plenum is concentric with the first fuel plenum.
3. The premixer of claim 1, wherein the plurality of vanes each have a
20 generally rectangular cross section.
4. The premixer of claim 1, wherein the plurality of vanes are also oriented tangentially relative to the longitudinal axis.
5. The premixer of claim 1, wherein the first plurality of fuel injectors provide fuel for establishing a pilot flame generally along the longitudinal axis.
- 25 6. The premixer of claim 5, wherein the second plurality of fuel injectors provides fuel to a shear layer positioned radially outward from the longitudinal axis for establishing a main combustor flame.

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7. The premixer of claim 1, wherein approximately 5% - 50% of fuel from the end cover passes through the second plurality of fuel injectors.

8. The premixer of claim 1, wherein the first plurality of fuel injectors and second plurality of fuel injectors are approximately 0.030 – 0.200 inches in diameter.

5 9. The premixer of claim 1, wherein the plurality of vanes have an airfoil-shaped cross section.

10. A method of tuning a pilot flame in a gas turbine combustor comprising: providing a cover for the gas turbine combustor having a first fuel plenum, a second fuel plenum radially outward of the first fuel plenum, and passageways for flowing
10 fuel from the first fuel plenum and the second fuel plenum; providing a radially inflowing swirler coupled to the cover, the swirler having: a plurality of vanes oriented in a general radial direction relative to a longitudinal axis of the combustor where each vane has a plurality of fuel injectors in fluid communication with the first fuel plenum and second fuel plenum; and an inner wall extending from proximate the plurality of vanes initially in a
15 direction generally perpendicular to the longitudinal axis and transitioning to extend in a direction generally parallel to the longitudinal axis; and an outer wall spaced a distance from the inner wall and also initially extending from proximate the plurality of vanes in a direction generally perpendicular to the longitudinal axis and transitioning to extend in a direction generally parallel to the longitudinal axis, such that the outer wall is offset from the inner
20 wall, thereby forming a premix passage therebetween; wherein the fuel from the second fuel plenum is controlled independent of the fuel from the first fuel plenum so as to provide a radial staging of fuel to the fuel injectors for regulating fuel flow to a shear layer about the longitudinal axis of the combustor.

11. The method of claim 10, wherein the first fuel plenum and the second
25 fuel plenum each supply an independently regulated flow of gaseous fuel into the plurality of swirlers.

12. The method of claim 10, wherein the second fuel plenum is concentric with the first fuel plenum.

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13. The method of claim 10, wherein the plurality of vanes impart a swirl to a passing airflow.

14. The method of claim 10, wherein each vane has a plurality of fuel injectors for injecting fuel from the first fuel plenum and a single fuel injector for injecting
5 fuel from the second fuel plenum.

15. A method of operating a combustion system to improve ignition of a combustor main fuel injectors comprising: providing a flow of fuel from a first fuel plenum and through a first set of fuel injectors of a radial inflow swirler to mix with a passing airflow; establishing a pilot flame in a combustor, the pilot flame supplied with fuel from the
10 radial inflow swirler and a shear layer adjacent the pilot flame; providing fuel from a second fuel plenum and through a second set of fuel injectors of the radial inflow swirler in order to increase a fuel/air ratio in the shear layer adjacent the pilot flame; providing fuel to the main set of fuel injectors; and, establishing a main combustion flame through ignition of the fuel from the main set of injectors by the pilot flame.

15 16. The method of claim 15, wherein the pilot flame is established generally along a longitudinal axis of the combustor.

17. The method of claim 15, wherein the first fuel injectors consist of one or more axially spaced holes in each swirler.

18. The method of claim 17, wherein the second fuel injectors consists of
20 one or more holes positioned between the first fuel injectors and an end of the swirler.

19. The method of claim 15, wherein when establishing a main combustion flame, the main set of injectors pass a fuel into a surrounding airstream simultaneous with fuel injected through both the first and second set of injectors.

20. The method of claim 19, wherein the main combustion flame is ignited
25 by the reaction occurring when fuel from the main injectors mixes with an enhanced shear layer of the pilot flame generated by the fuel injected through both the first and second fuel injectors.

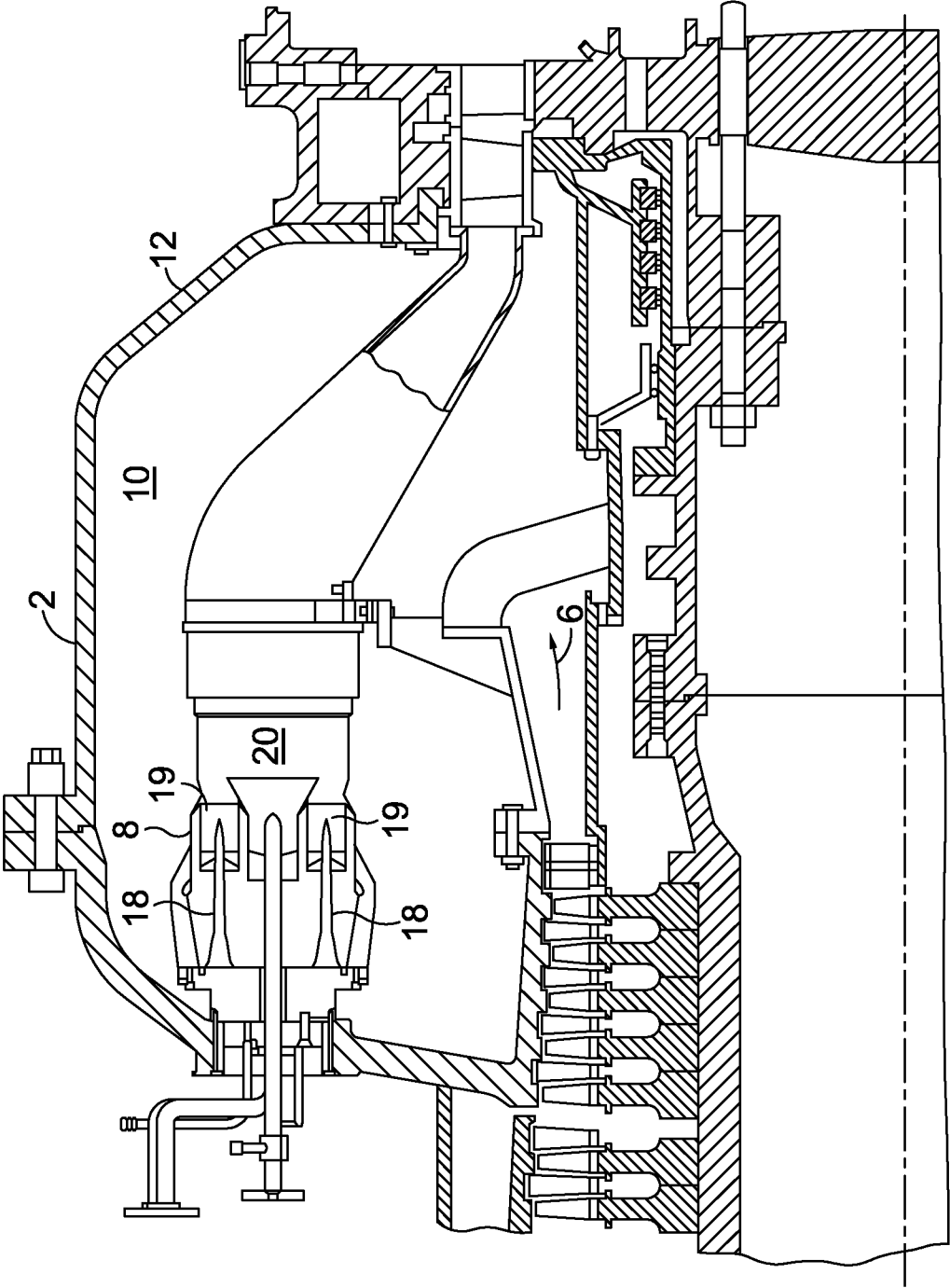
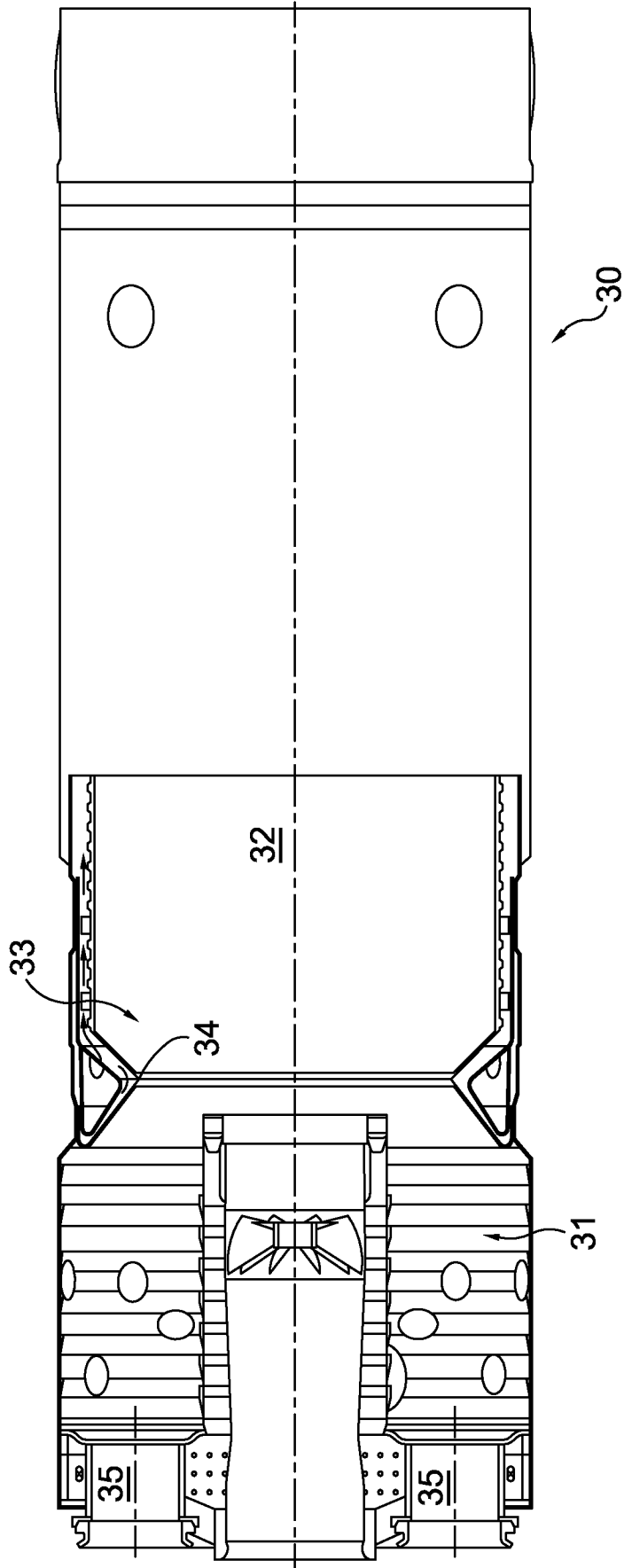


FIG. 1.
PRIOR ART



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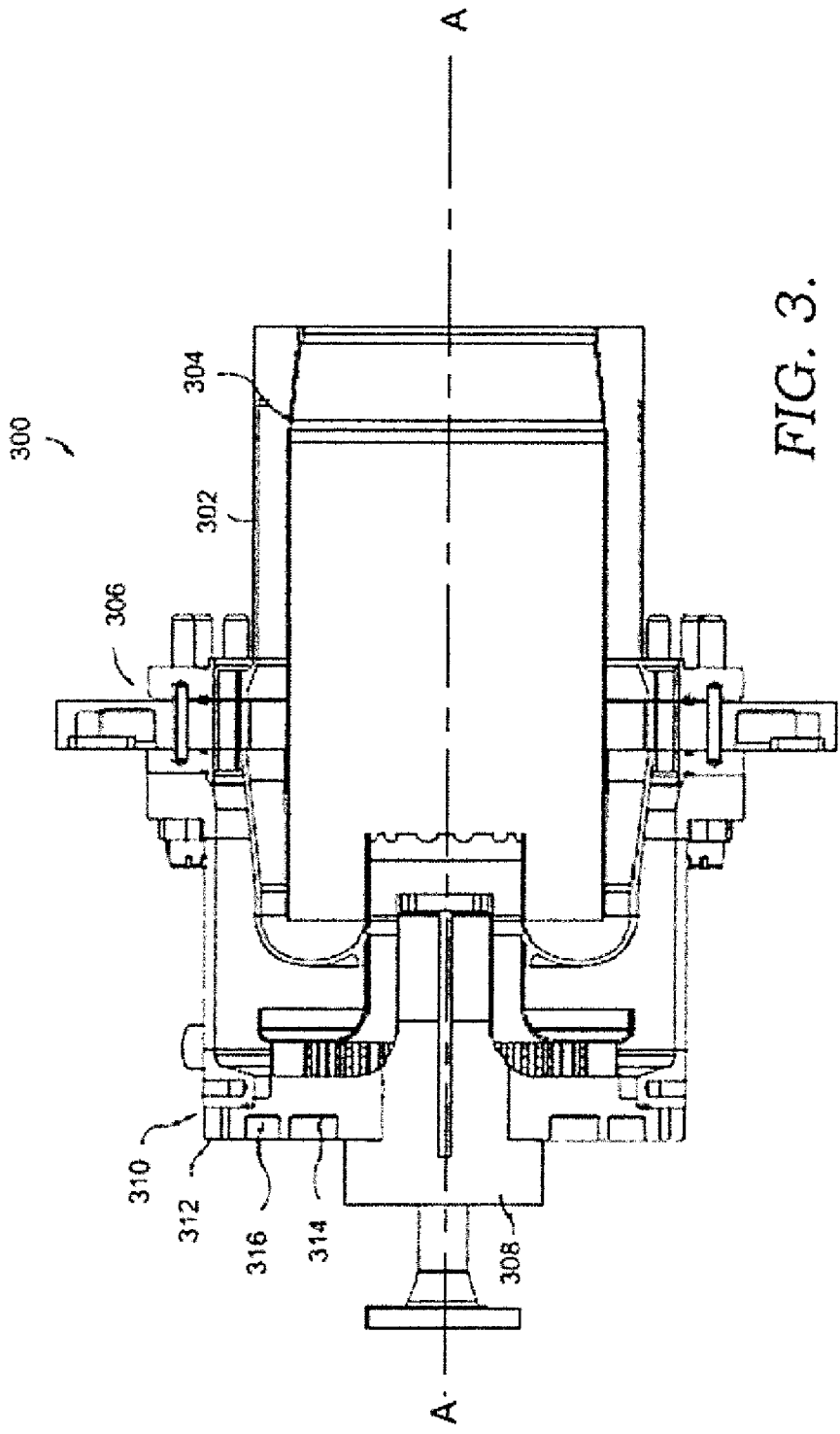


FIG. 3.

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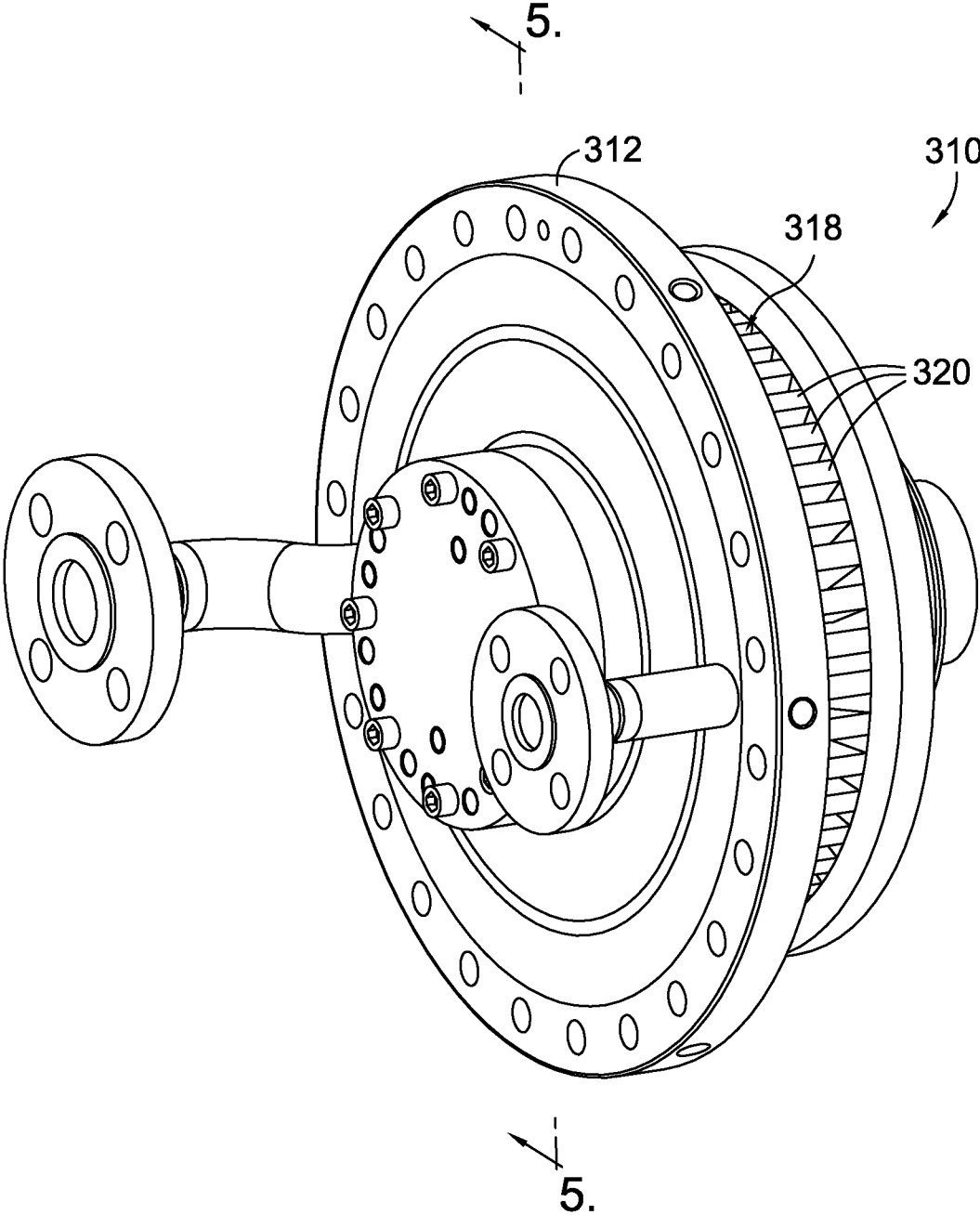


FIG. 4.

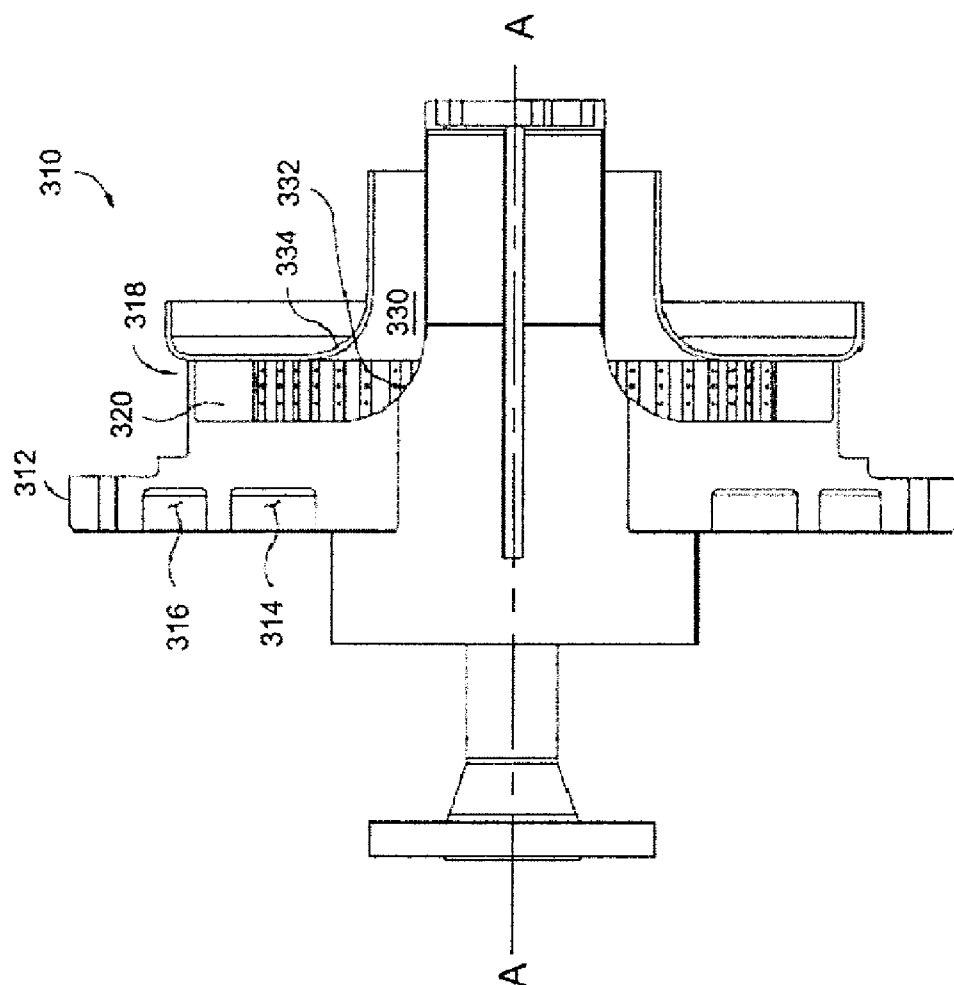


FIG. 5.

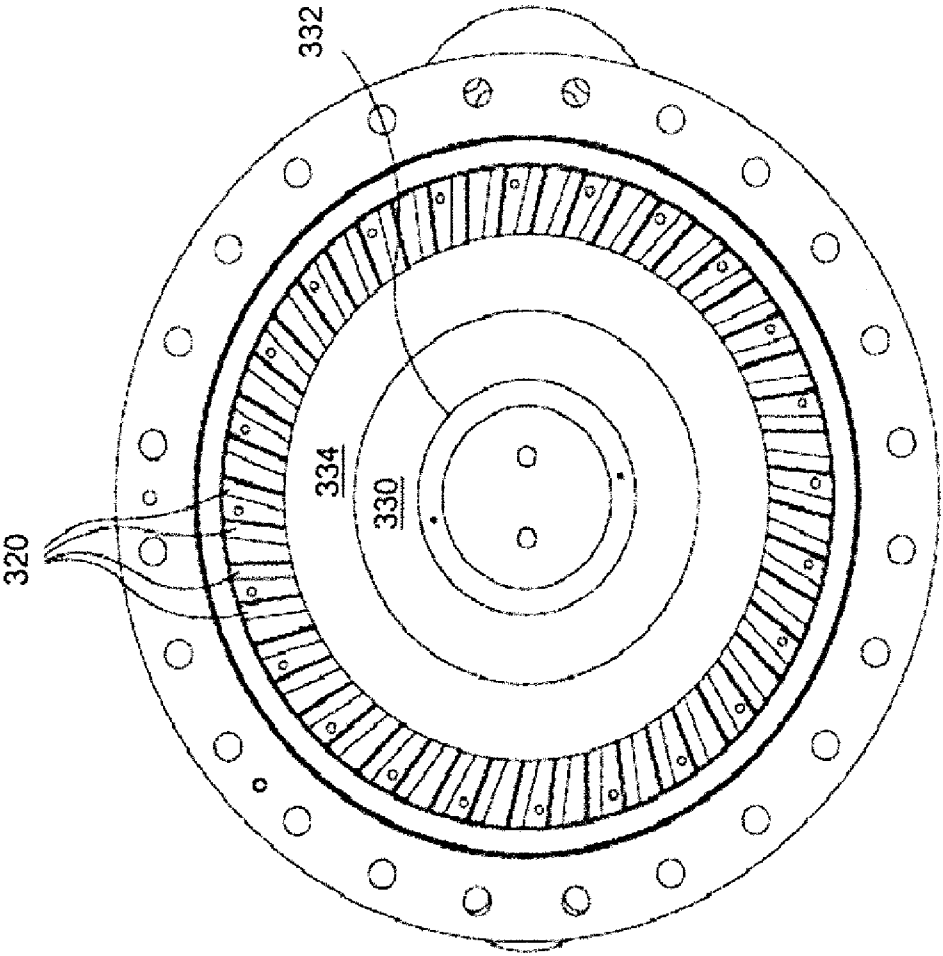


FIG. 6.

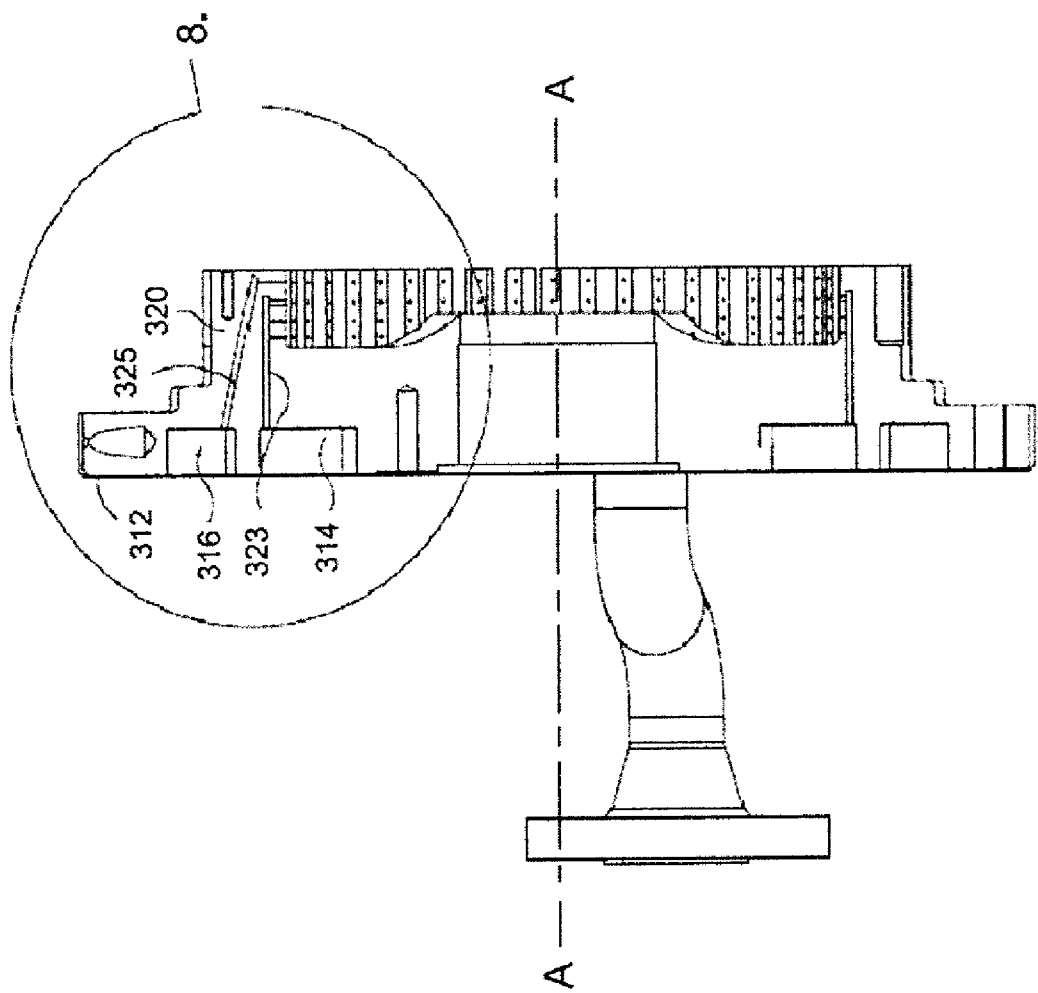


FIG. 7.

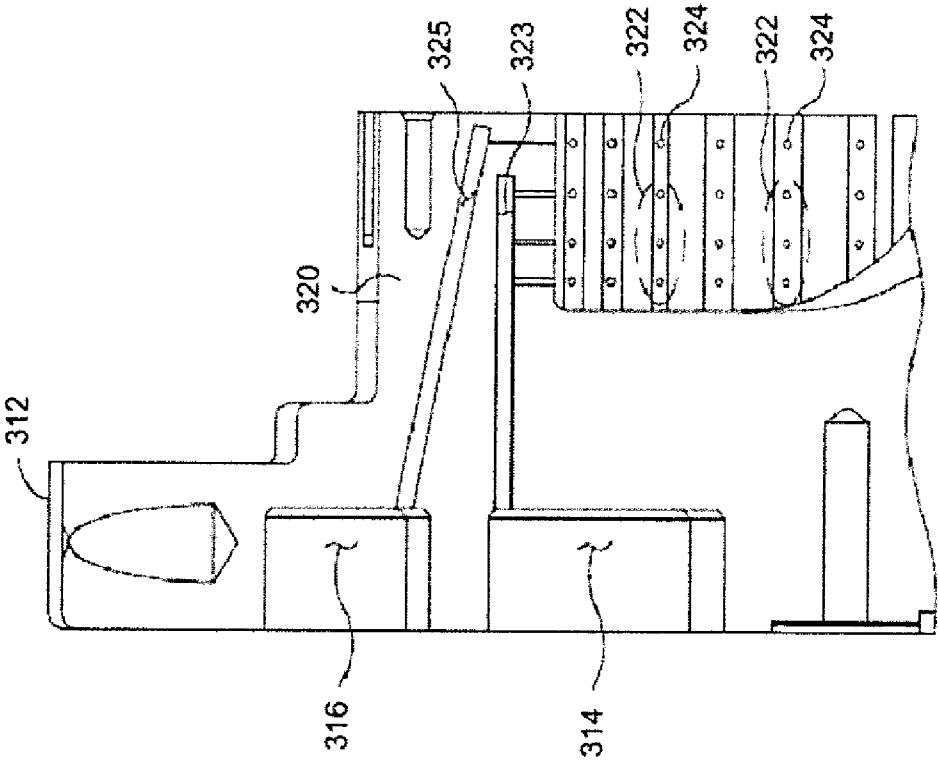
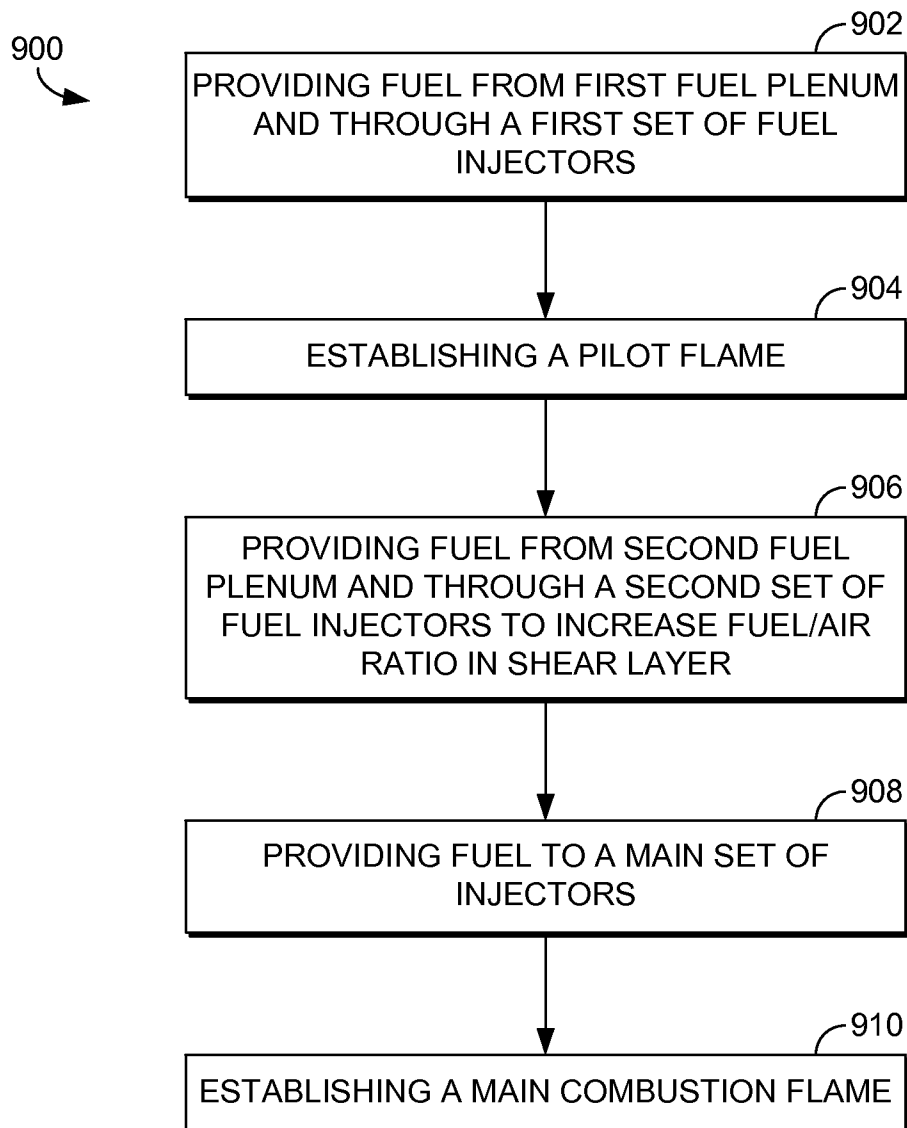


FIG. 8.

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*FIG. 9.*