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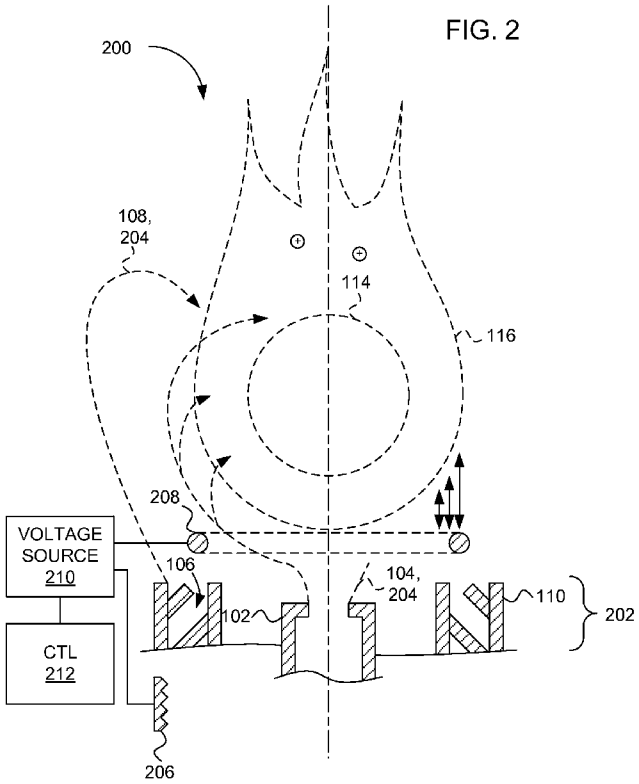
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(54) Title: ELECTRICALLY STABILIZED SWIRL-STABILIZED BURNER

(57) Abstract: A swirl-stabilized burner includes a charge source configured to apply a majority charge to a combustion reaction and at least one stabilization electrode configured to apply electrical attraction or repulsion to the majority charge to control position or stability of the swirl-stabilized combustion reaction.

FIG. 2



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ELECTRICALLY STABILIZED SWIRL-STABILIZED BURNER

CROSS REFERENCE TO RELATED APPLICATION

The present application claims priority benefit from U.S. Provisional Patent Application No. 61/803,780, entitled "ELECTRICALLY STABILIZED SWIRL-STABILIZED BURNER", filed March 20, 2013; which, to the extent not inconsistent with the disclosure herein, is incorporated by reference.

BACKGROUND

Swirl-stabilized burners (also referred to as "swirl stabilized") are known. **FIG. 1** is a diagram showing a swirl-stabilized burner 100 made according to the prior art. A fuel nozzle 102 outputs a fuel stream 104. An oxidizer source 106 provides an oxidizer gas for combustion. For example, the oxidizer source 106 can supply an oxidizer stream 108 such as oxygen, air, flue gas, or a mixture of gases carrying at least one oxidizer. According to a variant, the fuel and/or oxidizer can be in the form of a liquid or a liquid that flashes to a vapor. An aerodynamic swirler 110 imparts relatively high rotational velocity on the oxidizer stream 108. Optionally, the swirler 110 can impart a relatively high rotational velocity on the fuel stream 104 or on both the fuel stream 104 and the oxidizer stream 108. Centrifugal (or centripetal) force on the swirled oxidizer stream causes the oxidizer stream 108 to expand radially as shown when the oxidizer stream exits from the swirler 110. The centrifugal expansion can additionally cause the fuel stream 104 to expand at a larger angle than it normally would owing to a partial vacuum caused by the radial expansion of the oxidizer stream 108. Optionally, the fuel nozzle 102 can include a splitter 112 configured to impart radial velocity on the fuel jet 104. Radial expansion of the oxidizer stream

108 and/or the fuel stream 104 forms a low pressure volume 114. The low pressure volume 114 causes the fuel stream 104 and the oxidizer stream 108 to flow toward the low pressure volume 114. The low pressure volume 114 also causes recycling of heat into the low pressure volume 114. Thus, a combustion reaction 116 can be held at a location generally corresponding to the low pressure volume 114.

Optionally, the swirl-stabilized burner 100 can be a pre-mixed burner. In embodiments where the swirl-stabilized burner 100 is a premixed burner, a single pre-mixed fuel and oxidizer stream (not shown) can flow through a swirler 110. The radial expansion of the pre-mixed fuel and oxidizer stream causes a low pressure volume 114 as described above. The low pressure volume 114 causes the combustion reaction 116 to be supported away from the swirler 110. The low pressure volume 114 is intended to prevent flashback along the pre-mixed fuel and oxidizer stream under normal flow conditions.

Optionally, the swirl-stabilized burner 100 can be a stage of a larger burner. For example, in a gas turbine, hot exhaust gas can exit the final stage of a turbine (not shown) with swirl imparted. The swirled exhaust can be expanded to form a flow stream similar to the oxidizer stream. Additional fuel (and optionally air) can be introduced to the swirled exhaust gas to cause an afterburner combustion reaction 116.

SUMMARY

According to an embodiment, an electrically stabilized swirl-stabilized burner includes a nozzle assembly configured to output a fluid stream including at least one fuel and at least one oxidizer selected to support a combustion reaction, a swirler configured to impart rotational velocity on the fluid stream, at least one ionizer configured to output charges at a first polarity into the fluid stream or the combustion reaction, and at least one stabilization electrode positioned proximate to the combustion reaction and configured to be held at a

stabilization voltage selected to affect a location corresponding to the combustion reaction.

According to an embodiment, a method for operating an electrically- and swirl-stabilized burner includes emitting fuel and oxidant from a nozzle assembly along an axis in a downstream direction with a rotational velocity around the axis, supporting a swirl-stabilized combustion reaction with the fuel and oxidant, supplying electrical charges to the combustion reaction, supporting an electrode downstream from the nozzle assembly, and applying a voltage to the electrode to cause the electrical charges carried by the combustion reaction to interact with the voltage carried by the electrode. The charge and/or voltage can be constant (DC) or varying (AC) in polarity. The charge and voltage can be set at fixed magnitudes, for example by manual adjustment. Alternatively, the charge and/or voltage can be varied according to feedback (or feed-forward) control responsive to combustion reaction position.

BRIEF DESCRIPTION OF THE DRAWINGS

Non-limiting embodiments of the present disclosure are described by way of example with reference to the accompanying figures, which are schematic and are not intended to be drawn to scale. Unless indicated as representing the background art, the figures represent aspects of the disclosure.

FIG. 1 is a side-sectional diagram of a swirl-stabilized burner, according to the prior art.

FIG. 2 is a side-sectional diagram of an electrically stabilized swirl-stabilized burner, according to an embodiment.

FIG. 3 is a side-sectional diagram of an electrically stabilized swirl-stabilized burner, according to another embodiment.

FIG. 4 is a side-sectional diagram of an electrically stabilized swirl-stabilized burner, according to another embodiment.

FIG. 5 is a side-sectional diagram of an electrically stabilized swirl-stabilized burner, according to another embodiment.

FIG. 6 is a flow chart representing a method for operating an electrically stabilized swirl-swirl stabilized burner of **FIGS. 2-5**, according to an embodiment.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. Other embodiments may be used and/or other changes may be made without departing from the spirit or scope of the disclosure.

Swirl-stabilized burners 100 have shown a tendency for instability, especially under conditions of variable oxidizer stream, fuel stream 104, or oxidizer stream and fuel stream flow rates.

What is needed is a technology that can improve the stability and/or other attributes of swirl-stabilized burners.

FIG. 2 is a side-sectional diagram of an electrically stabilized swirl-stabilized burner 200, according to an embodiment. The electrically stabilized swirl-stabilized burner 200 includes a nozzle assembly 202 configured to output a rotating fluid stream 204. The fluid stream 204 includes at least one fuel and at least one oxidizer selected to support a combustion reaction 116. The nozzle assembly 202 includes a swirler 110 configured to impart rotational velocity on the fluid stream 204 sufficient to cause the fluid stream to expand upon leaving the nozzle assembly 202. The radial expansion of the fluid stream 204 upon removing radial confinement generally forms a low pressure region 114 located along the axis of rotation. The low pressure region 114 causes expanded fluid stream 204 to be drawn inward and/or in a direction countercurrent to the mass flow linear direction of the fluid stream 204 just before it leaves radial

confinement. The low pressure region 114 and the inward and countercurrent flow it produces in the fluid stream 204 causes the combustion reaction 116 to be held near the low pressure region 114 such that the flame front speed matches the linear mass flow speed from the nozzle assembly 202.

The nozzle assembly 202 can include a fuel stream source 102 configured to output a liquid, solid, or gaseous fuel stream 104. The swirler 110 can be configured to impart the rotational velocity on the fuel stream 104. The nozzle assembly 202 can include an oxidizer stream source 106 configured to output an oxidizer stream 108. The swirler 110 can be configured to impart the rotational velocity on the oxidizer stream 108. The nozzle assembly 202 can include a premixed fuel and oxidizer stream source (not shown) configured to output premixed fuel and oxidizer as the fluid stream 204. The swirler 110 can be configured to impart the rotational velocity on the premixed fuel and oxidizers stream. Moreover, the fluid stream 204 can include flue gas, inert carriers such as (in the case of air) nitrogen, and/or other non-fuel and non-oxidizer species.

Swirl-stabilized burners have shown promise with respect to supporting stable flame fronts without attachment to a bluff body. However, swirl-stabilized burners have also shown a tendency to be sensitive to changes in fluid flow rate. Swirl-stabilized burners can be somewhat complex to start-up. Additionally, some swirl-stabilized burners have shown a tendency toward unwanted flame location oscillations.

According to embodiments, a majority electrical charge is imparted on the fluid stream 204 (or a portion thereof) or onto the combustion reaction 116 and carried by the combustion reaction 116. The majority electrical charge can be substantially constant or can be alternating polarity, for example. Various combinations of one or more stabilization electrodes are configured to apply electrostatic or electrodynamic attraction or repulsion to the majority electrical charge in the combustion reaction to control or stabilize the combustion reaction.

At least one charge source (also referred to as an ionizer herein) 206 is configured to output charges at a first polarity into the fluid stream 204 or to the combustion reaction 116. At least one stabilization electrode 208 is positioned

proximate to the combustion reaction 116 and is configured to be held at a stabilization voltage selected to affect a location corresponding to the combustion reaction 116.

The burner 200 can include a voltage source 210 operatively coupled to at least the ionizer 206. The voltage source 210 can be configured to output at least one voltage to the ionizer 206. The ionizer 206 can be configured to output charges having the same polarity as the at least one voltage. The polarity can be DC, the polarity can be positive, the polarity can be negative, and/or the polarity can be time-varying. Additionally or alternatively, the voltage source 210 can be operatively coupled to the stabilization electrode 208. The voltage source 210 can be configured to apply a plurality of voltages to at least one of either the ionizer 206 or the stabilization electrode 208. Additionally or alternately, the voltage source 210 can be configured to apply a plurality of voltages to both the ionizer 206 and the stabilization electrode 208.

The burner 200 can include a controller 212 configured to control at least the ionizer 206. The controller 212 can be configured to control at least an electrical continuity between an activation voltage and the at least one stabilization electrode 208. Additionally or alternatively, the controller 212 can be configured to control electrical continuity between an activation voltage and the at least one stabilization electrode 208 and can be configured to control a charge stream output by the ionizer 206.

The burner 200 can include a voltage source 210 operatively coupled to at least the stabilization electrode 208. The voltage source 210 can be configured to output a voltage to the stabilization electrode 208, the voltage being selected to modulate a location of the combustion reaction 116 by attracting or repelling charges output by the ionizer 206 and carried by the combustion reaction 116. The at least one stabilization electrode 208 can include one or more segments of a substantially toric conductor disposed between the nozzle assembly 202 and a low pressure region 114 produced by the swirler 110. The stabilization electrode 208 can carry a voltage opposite in polarity to the majority charge polarity carried by the combustion reaction 116 or can be held at or near voltage ground to

attract the combustion reaction 116 and pull the combustion reaction toward the nozzle assembly 202. The stabilization electrode 208 can carry a voltage having the same polarity as the polarity of the majority charge carried by the combustion reaction 116 to repel the combustion reaction 116 and push the combustion reaction 116 away from the nozzle assembly 202. The electrical attraction or repulsion applied by the stabilization electrode 208 can be used to move the location of the combustion reaction 116 relative to the low pressure region 114. Additionally or alternatively, the electrical attraction or repulsion applied by the stabilization electrode 208 can be used to reduce oscillations in combustion reaction 116 location. Additionally or alternatively, the electrical attraction or repulsion applied by the stabilization electrode 208 can be used to control a combustion reaction location during start-up or shut-down of the burner 200.

FIG. 3 is a side-sectional diagram of an electrically stabilized swirl-stabilized burner 300, according to an embodiment. Referring to **FIG. 3**, the at least one stabilization electrode 208 can include one or more segments of a conductor 302 disposed away from the nozzle assembly 202 and the combustion reaction 116. A controller 212 can be operatively coupled to the voltage source 210 and can be configured to control an activation voltage applied to the at least one stabilization electrode 208, 302. The ionizer 206 can include at least one corona electrode 304 in electrical continuity with a fuel source portion of the nozzle assembly 202. Additionally or alternatively, the controller 212 can be operatively coupled to the voltage source 210 and can be configured to control at least one output voltage delivered to the ionizer 206, 304.

The stabilization electrode 208, 302 can optionally be embedded in a bluff body configured to hold the combustion reaction 116 in the event the combustion reaction is blown off the low pressure region 114.

The distal stabilization electrode 302 can receive an activation voltage having the same polarity as the majority charge carried by the combustion reaction 116 to repel the majority charge and push the combustion reaction 116 closer to the nozzle assembly 202. Alternatively, the distal stabilization electrode 302 can receive an activation voltage corresponding to voltage ground or having

an opposite polarity to the polarity of the majority charge carried by the combustion reaction 116 to attract the majority charge and pull the combustion reaction 116 away from the nozzle assembly 202.

FIG. 4 is a side-sectional diagram of an electrically stabilized swirl-stabilized burner 400, according to an embodiment. Referring to **FIG. 4**, the at least one stabilization electrode 208 can include a distal stabilization electrode 402 disposed away from the nozzle assembly 202 and a nominal position 403 of the combustion reaction 116. A proximal stabilization electrode 404 can be disposed between the nozzle assembly 202 and the nominal position 403 of the combustion reaction 116. The voltage controller 406 can be configured to apply respective voltages to the distal stabilization electrode 402 and the proximal stabilization electrode 404. The respective voltages can be selected to stabilize a location of the combustion reaction 116 near the nominal position 403. Additionally or alternatively, the respective voltages can be selected to drive a location of the combustion reaction 116 responsive to a combustion variable. The combustion variable can be selected from the group consisting of fuel flow rate, fuel pressure, oxidizer flow rate, oxidizer vacuum, oxidizer pressure, air flow rate, air vacuum, air pressure, flue gas flow rate, flue gas pressure, flue gas vacuum, oxygen (O_2) concentration, carbon monoxide (CO) concentration, oxide of nitrogen (NOx) concentration, and output heat demand.

According to an embodiment, the ionizer 206 can include at least one corona electrode 408 in electrical continuity with the swirler 110.

FIG. 5 is a side-sectional diagram of an electrically stabilized swirl-stabilized burner 500, according to an embodiment. Referring to **FIG. 5**, the at least one stabilization electrode 208 can include an annular electrode 502 configured to variably attract a concentration of charges 504 output by the ionizer 206 and carried by the combustion reaction 116. The variable attracting of the charges 504 by the annular electrode 502 can be selected to cause the combustion reaction 116 to become increasingly oblate with increasing attraction, can be selected to cause the combustion reaction 116 to occur in increasingly close proximity to the annular electrode 502 with increasing attraction, and can

be selected to cause the combustion reaction 116 to occur in an increasingly stable location with increasing attraction. The electrically stabilized swirl-stabilized burner 500 can include a controller 212 operatively coupled to the annular electrode 502.

The at least one stabilization electrode 208 can include an annular electrode 502 configured to variably repel a concentration of charges 504 output by the ionizer 206 and carried by the combustion reaction 116. The variable repelling of the charges 504 by the annular electrode 502 can be selected to cause the combustion reaction 116 to become increasingly elongated with increased repelling. Additionally or alternatively, the variable repelling of the charges 504 by the annular electrode 502 can be selected to cause the combustion reaction 116 to occur at increasing distance from the annular electrode 502 with increased repelling.

According to an embodiment, the at least one stabilization electrode 208 can include an annular electrode 502 configured to variably attract or repel a concentration of charges 504 output by the ionizer 206 and carried by the combustion reaction 116. A controller 212 operatively coupled to the annular electrode 502 can be configured to variably couple the annular electrode 502 to at least one activation voltage node 506.

Referring to **FIG. 5**, the controller 212 can be operatively coupled to the ionizer 206 through an isolating coupling 508. The isolating coupling can include at least one capacitor, an inductor, an opto-coupling, and/or can include a resonant coupling.

The controller 212 can be operatively coupled to the ionizer 206 and the at least one stabilization electrode 208. A sensor 510 can be operatively coupled to the controller 212 and configured to sense at least one parameter corresponding to the combustion reaction 116. The controller 212 can be configured to control a charge flow from the ionizer 206 responsive to sensor 510 feedback. The controller 212 can be configured to control application of at least one activation voltage 506 to the at least one stabilization electrode 208 responsive to sensor 510 feedback. At least one parameter can include a combustion reaction 116

model, a combustion reaction 116 location, and/or an instability in location of the combustion reaction 116. Additionally or alternatively, at least one parameter can include at least one selected from the group consisting of a current flow from the combustion reaction 116, an image of the combustion reaction 116, fuel flow rate, fuel pressure, oxidizer flow rate, oxidizer vacuum, oxidizer pressure, air flow rate, air vacuum, air pressure, flue gas flow rate, flue gas pressure, flue gas vacuum, oxygen (O_2) concentration, carbon monoxide (CO) concentration, oxide of nitrogen (NOx) concentration, and heat output from the combustion reaction 116.

The electrically stabilized swirl-stabilized burner 500 can include a controller 212 operatively coupled to the at least one stabilization electrode 208 through an electrically isolating coupling.

FIG. 6 is a flow chart representing a method 600 for operating an electrically stabilized swirl-stabilized burner of **FIGS. 2-5**, according to an embodiment. The method 600 begins with step 602 wherein fuel and oxidant are emitted from a nozzle assembly along an axis in a downstream direction with a rotational velocity around the axis. Proceeding to step 604, the fuel and oxidant support a swirl-stabilized combustion reaction. In step 606, electrical charges are supplied to the combustion reaction. Step 608 includes supporting an electrode downstream from the nozzle assembly. Proceeding to step 610, a voltage is applied to the electrode to cause the electrical charges carried by the combustion reaction to interact with the voltage carried by the electrode. Causing the electrical charges carried by the combustion reaction to interact with the voltage carried by the electrode is selected to stabilize the combustion reaction.

Referring to step 610, causing the electrical charges carried by the combustion reaction to interact with the voltage carried by the electrode generally includes applying an electrostatic force to the charges carried by the combustion reaction. According to an embodiment the force includes a component applied in a direction parallel to the axis. The force can include an electrostatic attraction component selected to pull the electrical charges toward the electrode.

Additionally or alternatively, the force can include an electrostatic repulsion component selected to push the electrical charges away from the electrode.

The charges supplied to the combustion reaction in step 606 can have a first polarity. In some embodiments, the voltage applied to the electrode in step 610 has a second polarity the same as the first polarity. In some embodiments, the voltage applied to the electrode in step 610 has a second polarity opposite to the first polarity. In some embodiments, applying the voltage to the electrode in step 610 includes placing the electrode in electrical continuity with an electrical ground.

Various forms of electrodes are contemplated. For example, supporting an electrode in step 608 can include supporting a toroidal electrode concentric to the axis. Additionally or alternatively, supporting an electrode can include supporting a plurality of electrodes distributed concentric to the axis.

Various positions of electrodes are contemplated, some of which are depicted in **FIGS 2-5**. In one embodiment (e.g., see **FIG. 2**), supporting an electrode in step 608 includes supporting a single electrode disposed at a position intermediate between the nozzle assembly and a target combustion reaction position. In another embodiment (e.g., see **FIG. 5**), supporting an electrode in step 608 includes supporting a single electrode disposed concentric to the axis at a distance along the axis corresponding to a target combustion reaction position. In another embodiment (e.g., see **FIG. 3**), supporting an electrode in step 608 includes supporting a single electrode disposed away from the nozzle assembly distal from a target combustion reaction position along the axis. In another embodiment (e.g., see **FIG. 4**), supporting an electrode in step 608 includes supporting a first electrode disposed intermediate between the nozzle assembly and a target combustion reaction position and supporting a second electrode disposed away from the nozzle assembly distal from a target combustion reaction position.

The method can include charging the combustion reaction with an AC or a DC signal. In other words, step 606 can include supplying electrical charges to the combustion reaction comprises supplying charges having an alternating

polarity or can include supplying electrical charges to the combustion reaction comprises supplying charges having a constant polarity.

Various forms of combustion reaction charging apparatuses are contemplated. For example, as shown in **FIGS. 2-5**, supplying electrical charges to the combustion reaction in step 606 can include emitting electrical charges into the fuel or the oxidant (including the fuel and oxidant mixture). In another embodiment, supplying electrical charges to the combustion reaction in step 606 can include applying a voltage to a charge electrode in electrical continuity with the combustion reaction. The charge electrode may, for example, include a conductive (e.g., stainless steel) rod disposed on the axis. The rod can be supported distally and project to a location coincident with a target combustion reaction position. Alternatively, the rod can include an insulated portion supported to carry voltage to a location near and axial to the nozzle assembly, and a bare portion that projects along the axis in a downstream direction. When using a charge electrode the applied voltage can be between about 10 kilovolts and 100 kilovolts, for example. (Electrical current to achieve the effects described herein is very low – e.g. between about 100 micro-amps and 10 milliamps, so total electrical power is relatively low compared to combustion reaction heat output.)

Either the charges supplied to the combustion reaction or the voltage applied to the electrode can optionally be controlled to actively control combustion reaction position and/or stability. For example, supplying a voltage to a charge electrode can include applying a variable voltage that is a function of a distance between a position of the combustion reaction and a target position of the combustion reaction. Alternatively, for embodiments where the charges are supplied to the combustion reaction by outputting charged particles to the fuel, oxidant, or fuel and oxidant, the charge current can be a function of the distance between the position of the combustion reaction and the target position of the combustion reaction.

Still referring to **FIG. 6**, the method 600 can further include the steps of detecting a position of the combustion reaction (step 612), comparing the

position (of the combustion reaction) to a target position (step 614), and, in step 616, adjusting the voltage applied to the electrode to cause an electrostatic force to be applied to the charged particles carried by the combustion reaction to be proportional to a distance from the combustion reaction position to the target position. Steps 610, 612, 614, and 616 can thus form a control loop for the apparatus described herein.

The voltage adjustment (step 616) can be selected to cause the electrostatic force applied to the charged particles to be proportional to a square root of the distance from the combustion reaction position to the target position over a range of the distance. Step 616 can optionally be performed without frequent control loops (610, 612, 614, 616) by manual adjustment of a voltage applied to the electrode, for example. Once adjusted, the voltage can be held substantially constant. This can operate, for example, where the electrode is disposed to apply an electrostatic attraction force toward the target combustion reaction position.

In another embodiment, the voltage adjustment (step 616) can be selected to cause the electrostatic force applied to the charged particles to be proportional to a square of the distance from the combustion reaction position to the target position over a range of the distance. This approach can also optionally be performed by manual adjustment of a voltage applied to the electrode (e.g., where the electrode is disposed to apply a repulsive force toward the target combustion reaction position).

In another embodiment, the voltage adjustment can be selected in step 616 to cause the electrostatic force applied to the charged particles to be linearly proportional to the distance from the combustion reaction to the target position over a range of the distance.

For active control embodiments, various forms of combustion reaction sensors are contemplated. For example, detecting a position of the combustion reaction in step 612 can include detecting a current flow through the electrode or by receiving a radiated signal with a photodiode aligned to receive radiation that varies with combustion reaction position. In another embodiment, detecting a

position of the combustion reaction in step 612 can include capturing an image of the combustion reaction with a focal plane detector (e.g., with a digital video camera).

Various forms of controller hardware are contemplated. For example, detecting a position of the combustion reaction in step 612, comparing the position to a target position in step 614, and, in step 616, adjusting the voltage applied to the electrode can be performed in part by a microprocessor or microcontroller executing instructions carried by a non-transitory computer readable medium. In another embodiment (or a particular embodiment), detecting a position of the combustion reaction (step 612), comparing the position to a target position (step 614), and adjusting the voltage applied to the electrode (step 616) can be performed in part by a proportional, integral, differential (PID) controller.

While various aspects and embodiments have been disclosed herein, other aspects and embodiments are contemplated. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

CLAIMS

What is claimed is:

1. An electrically stabilized swirl-stabilized burner, comprising:

a nozzle assembly configured to output a rotating fluid stream including at least one fuel and at least one oxidizer selected to support a combustion reaction;

at least one ionizer configured to output charges at a first polarity to the fluid stream or to to the combustion reaction; and

at least one stabilization electrode positioned proximate to the combustion reaction and configured to be held at a stabilization voltage selected to affect a location corresponding to the combustion reaction.

2. The electrically stabilized swirl-stabilized burner of claim 1, further comprising: a voltage source operatively coupled to at least the ionizer, the voltage source being configured to output at least one voltage to the ionizer;

wherein the ionizer is configured to output charges having the same polarity as the at least one voltage.

3. The electrically stabilized swirl-stabilized burner of claim 2, wherein the polarity is DC.

4. The electrically stabilized swirl-stabilized burner of claim 2, wherein the polarity is positive.

5. The electrically stabilized swirl-stabilized burner of claim 2, wherein the polarity is time-varying.

6. The electrically stabilized swirl-stabilized burner of claim 1, further comprising: a voltage source operatively coupled to the ionizer and the stabilization electrode.

7. The electrically stabilized swirl-stabilized burner of claim 6, wherein the voltage source is configured to apply a plurality of voltages to at least one of either the ionizer or the stabilization electrode.

8. The electrically stabilized swirl-stabilized burner of claim 7, wherein the voltage source is configured to apply a plurality of voltages to both the ionizer and the stabilization electrode.

9. The electrically stabilized swirl-stabilized burner of claim 1, further comprising:

a controller configured to control at least the ionizer.

10. The electrically stabilized swirl-stabilized burner of claim 1, further comprising:

a controller configured to control at least an electrical continuity between an activation voltage and the at least one stabilization electrode.

11. The electrically stabilized swirl-stabilized burner of claim 1, further comprising:

a controller configured to control electrical continuity between an activation voltage and the at least one stabilization electrode and to control a charge stream output by the ionizer.

12. The electrically stabilized swirl-stabilized burner of claim 1, further comprising: a voltage source operatively coupled to at least the stabilization electrode, the voltage source being configured to output a voltage to the stabilization electrode, the voltage being selected to modulate a location of the combustion reaction by attracting or repelling charges output by the ionizer and carried by the combustion reaction.

13. The electrically stabilized swirl-stabilized burner of claim 12, wherein the at least one stabilization electrode includes one or more segments of a substantially toric conductor disposed between the nozzle assembly and a low pressure region produced by the swirler.

14. The electrically stabilized swirl-stabilized burner of claim 12, wherein the at least one stabilization electrode includes one or more segments of a conductor disposed away from the nozzle assembly and the combustion reaction.

15. The electrically stabilized swirl-stabilized burner of claim 12, further comprising a controller operatively coupled to the voltage source and configured to control an activation voltage applied to the at least one stabilization electrode.

16. The electrically stabilized swirl-stabilized burner of claim 12, wherein the ionizer includes at least one corona electrode in electrical continuity with a fuel source portion of the nozzle assembly.

17. The electrically stabilized swirl-stabilized burner of claim 16, further comprising a controller operatively coupled to the voltage source and configured to control at least one output voltage delivered to the ionizer.

18. The electrically stabilized swirl-stabilized burner of claim 1, wherein the at least one stabilization electrode further comprises:

a distal stabilization electrode disposed away from the nozzle assembly and a nominal position of the combustion reaction; and

a proximal stabilization electrode disposed between the nozzle assembly and the nominal position of the combustion reaction;

further comprising:

a voltage controller configured to apply respective voltages to the distal stabilization electrode and the proximal stabilization electrode.

19. The electrically stabilized swirl-stabilized burner of claim 18, wherein the respective voltages are selected to stabilize a location of the combustion reaction near the nominal position.

20. The electrically stabilized swirl-stabilized burner of claim 18, wherein the respective voltages are selected to drive a location of the combustion reaction responsive to a combustion variable.

21. The electrically stabilized swirl-stabilized burner of claim 20, wherein the combustion variable is selected from the group consisting of fuel flow rate, fuel pressure, oxidizer flow rate, oxidizer vacuum, oxidizer pressure, air flow rate, air vacuum, air pressure, flue gas flow rate, flue gas pressure, flue gas vacuum, oxygen (O_2) concentration, carbon monoxide (CO) concentration, oxide of nitrogen (NOx) concentration, and output heat demand.

22. The electrically stabilized swirl-stabilized burner of claim 1, wherein the ionizer includes at least one corona electrode in electrical continuity with the swirler.

23. The electrically stabilized swirl-stabilized burner of claim 1, wherein the at least one stabilization electrode comprises an annular electrode configured to variably attract a concentration of charges output by the ionizer and carried by the combustion reaction.

24. The electrically stabilized swirl-stabilized burner of claim 23, wherein the variable attracting of the charges by the annular electrode is selected to cause the combustion reaction to become increasingly oblate with increasing attraction.

25. The electrically stabilized swirl-stabilized burner of claim 23, wherein the variable attracting of the charges by the annular electrode is selected to cause

the combustion reaction to occur in increasingly close proximity to the annular electrode with increasing attraction.

26. The electrically stabilized swirl-stabilized burner of claim 23, wherein the variable attracting of the charges by the annular electrode is selected to cause the combustion reaction to occur in an increasingly stable location with increasing attraction.

27. The electrically stabilized swirl-stabilized burner of claim 23, further comprising a controller operatively coupled to the annular electrode.

28. The electrically stabilized swirl-stabilized burner of claim 1, wherein the at least one stabilization electrode comprises an annular electrode configured to variably repel a concentration of charges output by the ionizer and carried by the combustion reaction.

29. The electrically stabilized swirl-stabilized burner of claim 28, wherein the variable repelling of the charges by the annular electrode is selected to cause the combustion reaction to become increasingly elongated with increased repelling.

30. The electrically stabilized swirl-stabilized burner of claim 28, wherein the variable repelling of the charges by the annular electrode is selected to cause the combustion reaction to occur at increasing distance from the annular electrode with increased repelling.

31. The electrically stabilized swirl-stabilized burner of claim 1, wherein the at least one stabilization electrode comprises an annular electrode configured to variably attract or repel a concentration of charges output by the ionizer and carried by the combustion reaction.

32. The electrically stabilized swirl-stabilized burner of claim 31, further comprising: a controller operatively coupled to the annular electrode, the controller being configured to variably couple the annular electrode to at least one activation voltage node.

33. The electrically stabilized swirl-stabilized burner of claim 1, further comprising: a controller operatively coupled to the ionizer through an isolating coupling.

34. The electrically stabilized swirl-stabilized burner of claim 33, wherein the isolating coupling includes at least one capacitor.

35. The electrically stabilized swirl-stabilized burner of claim 33, wherein the isolating coupling includes an inductor.

36. The electrically stabilized swirl-stabilized burner of claim 33, wherein the isolating coupling includes an opto-coupling.

37. The electrically stabilized swirl-stabilized burner of claim 33, wherein the isolating coupling includes a resonant coupling.

38. The electrically stabilized swirl-stabilized burner of claim 1, further comprising:

a controller operatively coupled to the ionizer and the at least one stabilization electrode; and

a sensor operatively coupled to the controller and configured to sense at least one parameter corresponding to the combustion reaction.

39. The electrically stabilized swirl-stabilized burner of claim 38, wherein the controller is configured to control a charge flow from the ionizer responsive to sensor feedback.

40. The electrically stabilized swirl-stabilized burner of claim 38, wherein the controller is configured to control application of at least one activation voltage to the at least one stabilization electrode responsive to sensor feedback.

41. The electrically stabilized swirl-stabilized burner of claim 40, wherein the at least one parameter includes a combustion reaction model.

42. The electrically stabilized swirl-stabilized burner of claim 40, wherein the at least one parameter includes a combustion reaction location.

43. The electrically stabilized swirl-stabilized burner of claim 40, wherein the at least one parameter includes an instability in location of the combustion reaction.

44. The electrically stabilized swirl-stabilized burner of claim 40, wherein the at least one parameter includes at least one selected from the group consisting of a current flow from the combustion reaction, an image of the combustion reaction, fuel flow rate, fuel pressure, oxidizer flow rate, oxidizer vacuum, oxidizer pressure, air flow rate, air vacuum, air pressure, flue gas flow rate, flue gas pressure, flue gas vacuum, oxygen (O_2) concentration, carbon monoxide (CO) concentration, oxide of nitrogen (NOx) concentration, and heat output from the combustion reaction.

45. The electrically stabilized swirl-stabilized burner of claim 1, further comprising: a controller operatively coupled to the at least one stabilization electrode through an electrically isolating coupling.

46. A method for operating an electrically- and swirl-stabilized burner, comprising:

emitting fuel and oxidant from a nozzle assembly along an axis in a downstream direction with a rotational velocity around the axis;

supporting a swirl-stabilized combustion reaction with the fuel and oxidant;

supplying electrical charges to the combustion reaction;

supporting an electrode downstream from the nozzle assembly; and

applying a voltage to the electrode to cause the electrical charges carried by the combustion reaction to interact with the voltage carried by the electrode.

47. The method for operating an electrically- and swirl-stabilized burner of claim 46, wherein causing the electrical charges carried by the combustion reaction to interact with the voltage carried by the electrode is selected to stabilize the combustion reaction.

48. The method for operating an electrically- and swirl-stabilized burner of claim 46, wherein causing the electrical charges carried by the combustion reaction to interact with the voltage carried by the electrode includes applying an electrostatic force to the charges carried by the combustion reaction.

49. The method for operating an electrically- and swirl-stabilized burner of claim 48, wherein the force includes a component applied in a direction parallel to the axis.

50. The method for operating an electrically- and swirl-stabilized burner of claim 49, wherein the force includes an attraction component selected to pull the electrical charges toward the electrode.

51. The method for operating an electrically- and swirl-stabilized burner of claim 49, wherein the force includes a repulsion component selected to push the electrical charges away from the electrode.

52. The method for operating an electrically- and swirl-stabilized burner of claim 46,

wherein the charges supplied to the combustion reaction have a first polarity; and

wherein the voltage applied to the electrode has a second polarity the same as the first polarity.

53. The method for operating an electrically- and swirl-stabilized burner of claim 46, wherein the charges supplied to the combustion reaction have a first polarity; and

wherein the voltage applied to the electrode has a second polarity opposite to the first polarity.

54. The method for operating an electrically- and swirl-stabilized burner of claim 46, wherein applying the voltage to the electrode comprises placing the electrode in electrical continuity with an electrical ground.

55. The method for operating an electrically- and swirl-stabilized burner of claim 46, wherein supporting an electrode comprises supporting a toroidal electrode concentric to the axis.

56. The method for operating an electrically- and swirl-stabilized burner of claim 46, wherein supporting an electrode comprises supporting a plurality of electrodes distributed concentric to the axis.

57. The method for operating an electrically- and swirl-stabilized burner of claim 46, wherein supporting an electrode comprises supporting a single electrode disposed at a position intermediate between the nozzle assembly and a target combustion reaction position.

58. The method for operating an electrically- and swirl-stabilized burner of claim 46, wherein supporting an electrode comprises supporting a single electrode disposed concentric to the axis at a distance along the axis corresponding to a target combustion reaction position.

59. The method for operating an electrically- and swirl-stabilized burner of claim 46, wherein supporting an electrode comprises supporting a single electrode disposed away from the nozzle assembly distal from a target combustion reaction position along the axis.

60. The method for operating an electrically- and swirl-stabilized burner of claim 46, wherein supporting an electrode comprises:

supporting a first electrode disposed intermediate between the nozzle assembly and a target combustion reaction position; and

supporting a second electrode disposed away from the nozzle assembly distal from a target combustion reaction position.

61. The method for operating an electrically- and swirl-stabilized burner of claim 46, wherein supplying electrical charges to the combustion reaction comprises supplying charges having an alternating polarity.

62. The method for operating an electrically- and swirl-stabilized burner of claim 46, wherein supplying electrical charges to the combustion reaction comprises supplying charges having a constant polarity.

63. The method for operating an electrically- and swirl-stabilized burner of claim 46, wherein supplying electrical charges to the combustion reaction comprises emitting electrical charges into the fuel or the oxidant.

64. The method for operating an electrically- and swirl-stabilized burner of claim 63, wherein supplying electrical charges to the combustion reaction

comprises emitting the electrical charges with a current that is a function of a distance between a position of the combustion reaction and a target position of the combustion reaction.

65. The method for operating an electrically- and swirl-stabilized burner of claim 46, wherein supplying electrical charges to the combustion reaction comprises:

applying a voltage to a charge electrode in electrical continuity with the combustion reaction.

66. The method for operating an electrically- and swirl-stabilized burner of claim 65, wherein the voltage is between about 10 kilovolts and 100 kilovolts.

67. The method for operating an electrically- and swirl-stabilized burner of claim 65, wherein applying a voltage to a charge electrode comprises applying a variable voltage that is a function of a distance between a position of the combustion reaction and a target position of the combustion reaction.

68. The method for operating an electrically- and swirl-stabilized burner of claim 46, further comprising:

detecting a position of the combustion reaction;

comparing the position to a target position; and

adjusting the voltage applied to the electrode to cause an electrostatic force to be applied to the charged particles carried by the combustion reaction to be proportional to a distance from the combustion reaction position to the target position.

69. The method for operating an electrically- and swirl-stabilized burner of claim 68, wherein the voltage adjustment is selected to cause the electrostatic force applied to the charged particles to be proportional to a square root of the

distance from the combustion reaction position to the target position over a range of the distance.

70. The method for operating an electrically- and swirl-stabilized burner of claim 68, wherein the voltage adjustment is selected to cause the electrostatic force applied to the charged particles to be linearly proportional to the distance from the combustion reaction to the target position over a range of the distance.

71. The method for operating an electrically- and swirl-stabilized burner of claim 68, wherein detecting a position of the combustion reaction comprises:

detecting a current flow through the electrode.

72. The method for operating an electrically- and swirl-stabilized burner of claim 68, wherein detecting a position of the combustion reaction comprises:

receiving a radiated signal with a photodiode.

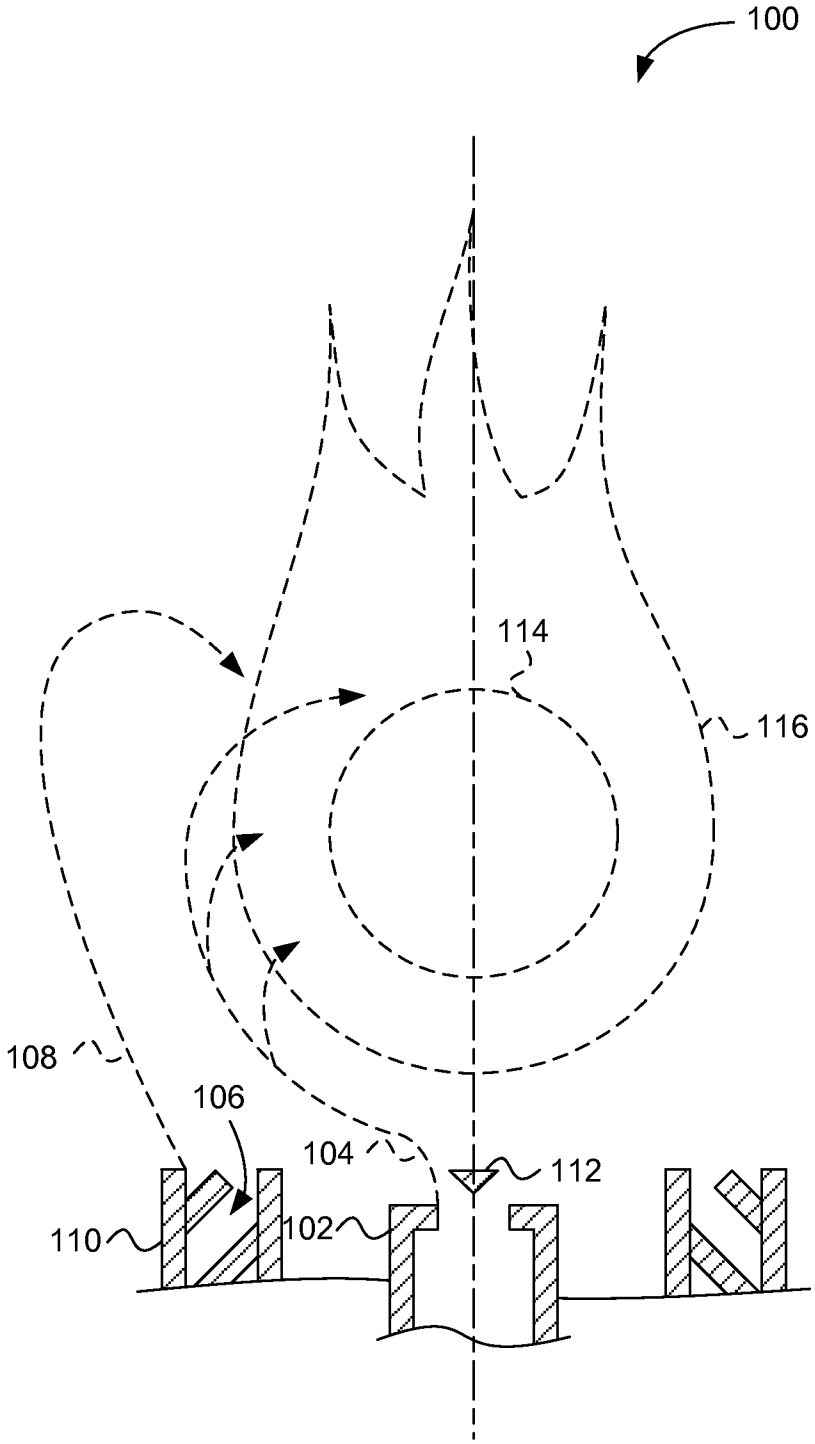
73. The method for operating an electrically- and swirl-stabilized burner of claim 68, wherein detecting a position of the combustion reaction comprises:

capturing an image of the combustion reaction with a focal plane detector.

74. The method for operating an electrically- and swirl-stabilized burner of claim 68, wherein detecting a position of the combustion reaction, comparing the position to a target position, and adjusting the voltage applied to the electrode is performed in part by a microprocessor or microcontroller executing instructions carried by a non-transitory computer readable medium.

75. The method for operating an electrically- and swirl-stabilized burner of claim 68, wherein detecting a position of the combustion reaction, comparing the position to a target position, and adjusting the voltage applied to the electrode is performed in part by a proportional, integral, differential (PID) controller.

FIG. 1



PRIOR ART

FIG. 2

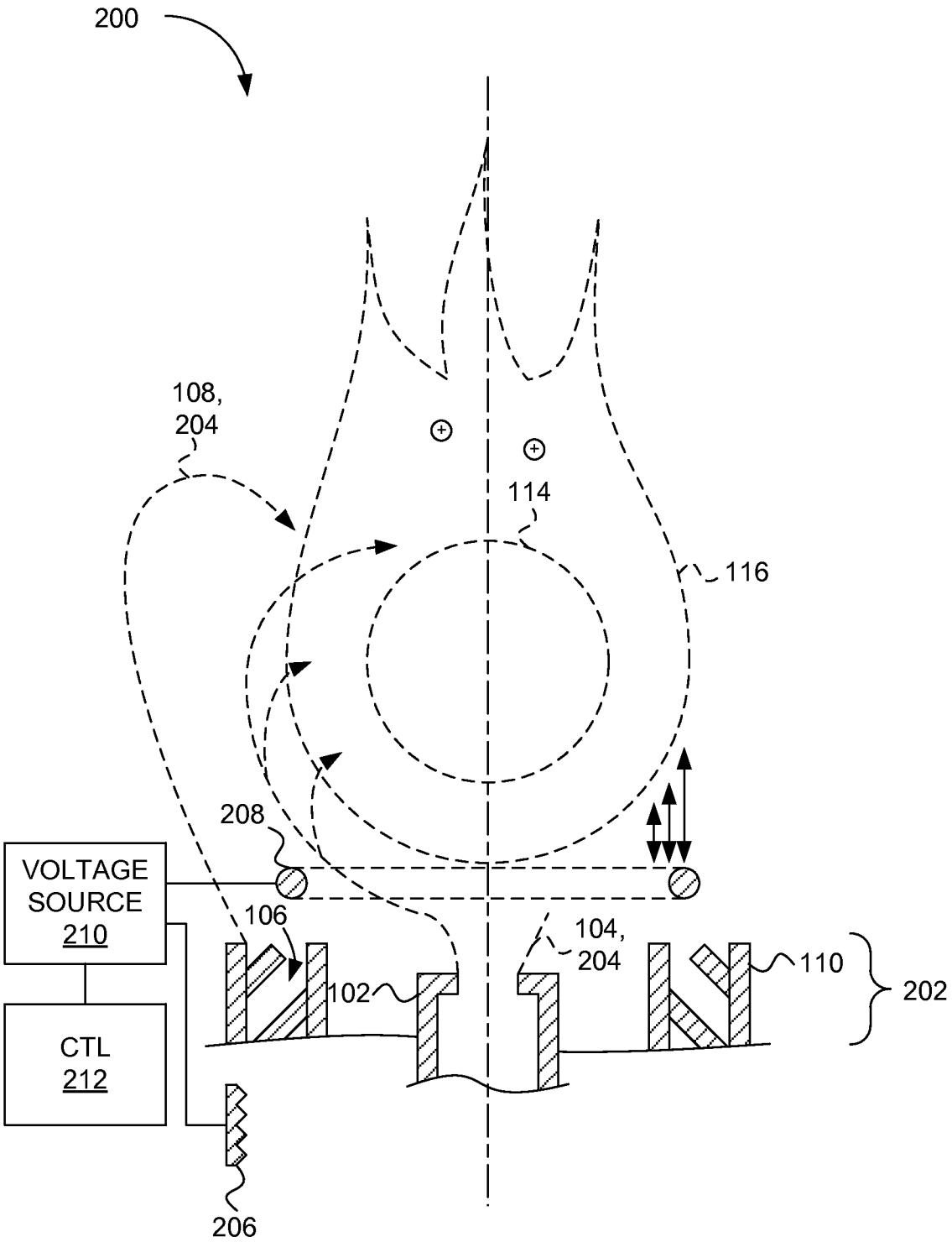

200
108,
204
114
116
208
VOLTAGE
SOURCE
210
CTL
212
106
102
104,
204
110
202
206

FIG. 3

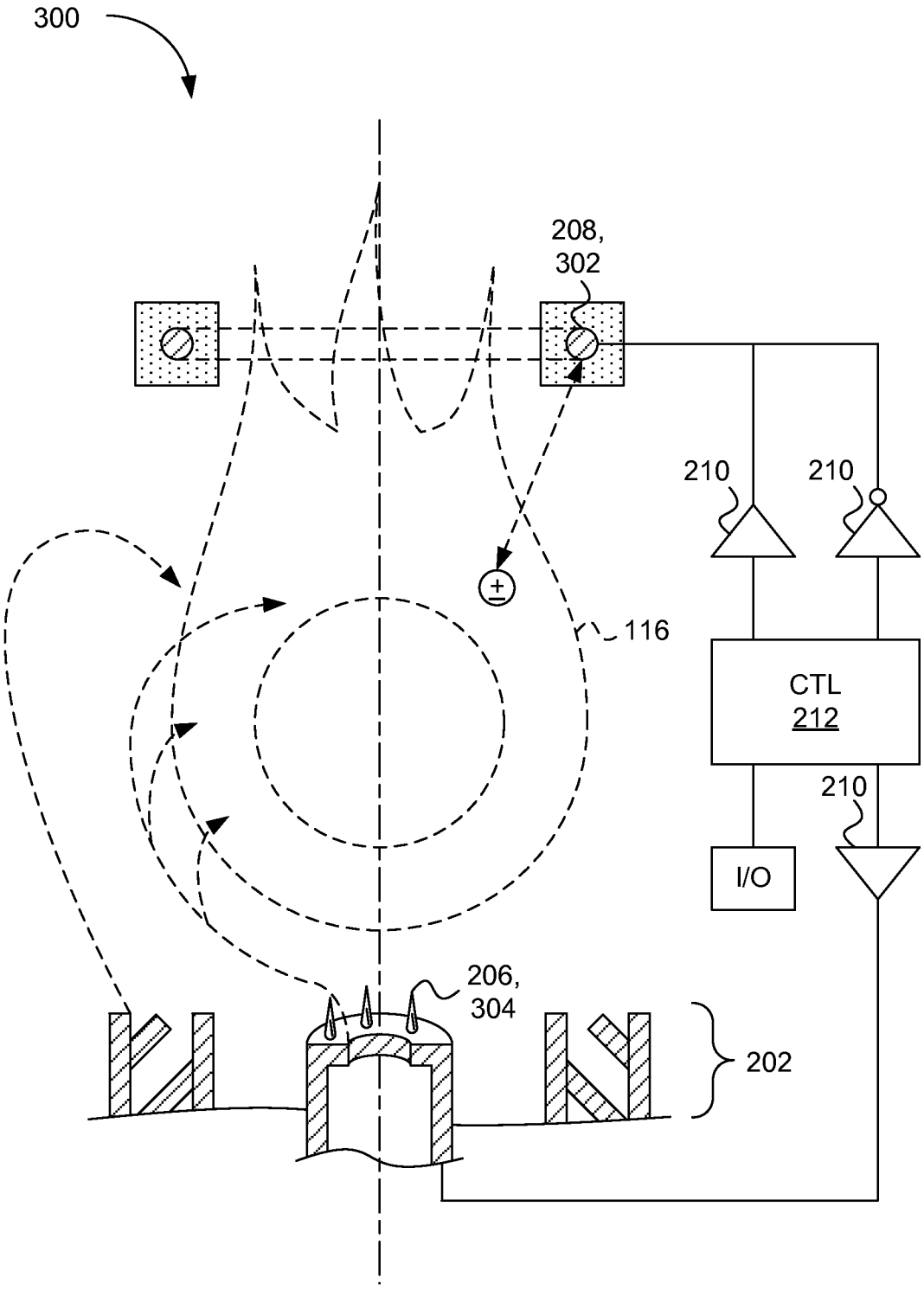


FIG. 4

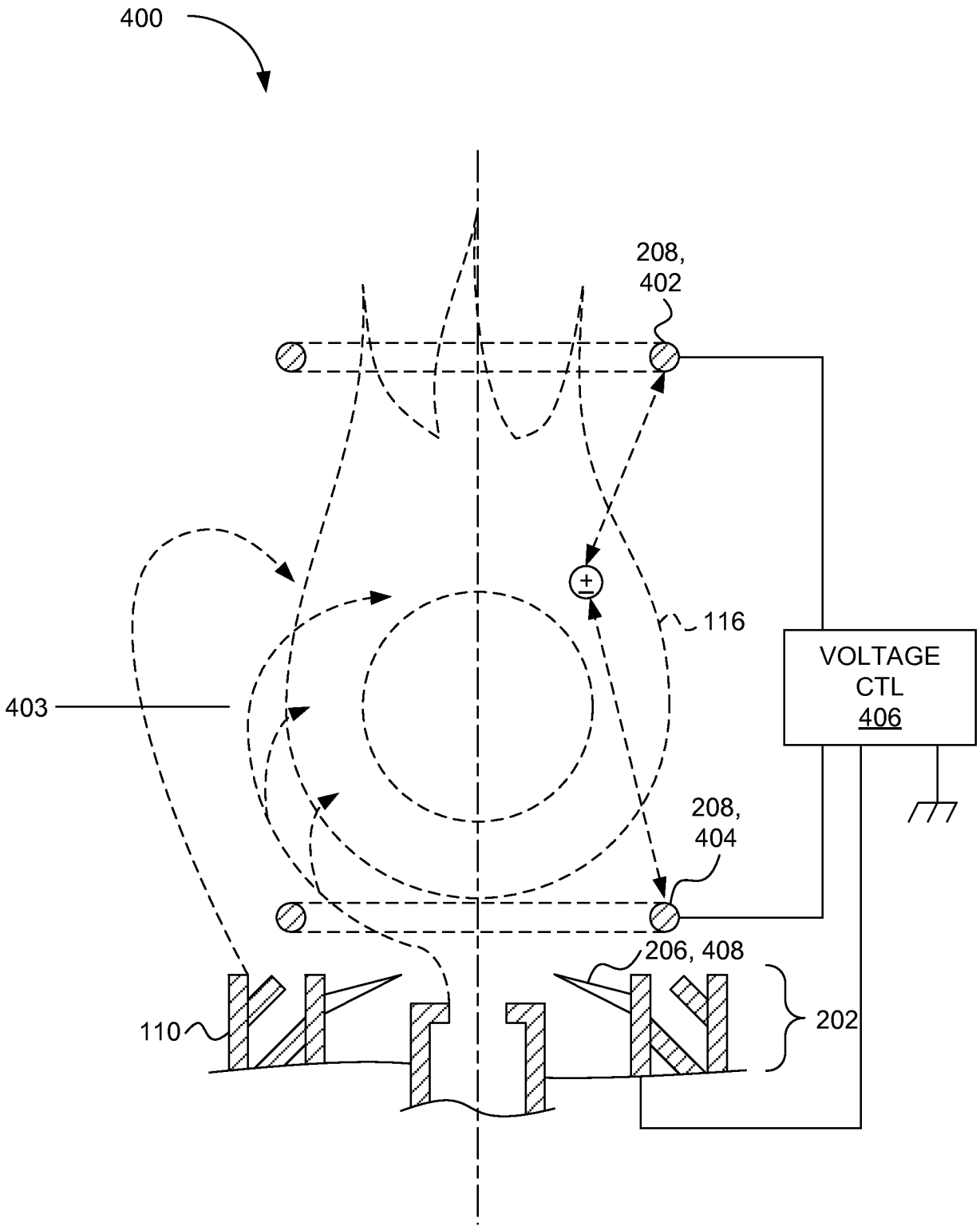


FIG. 5

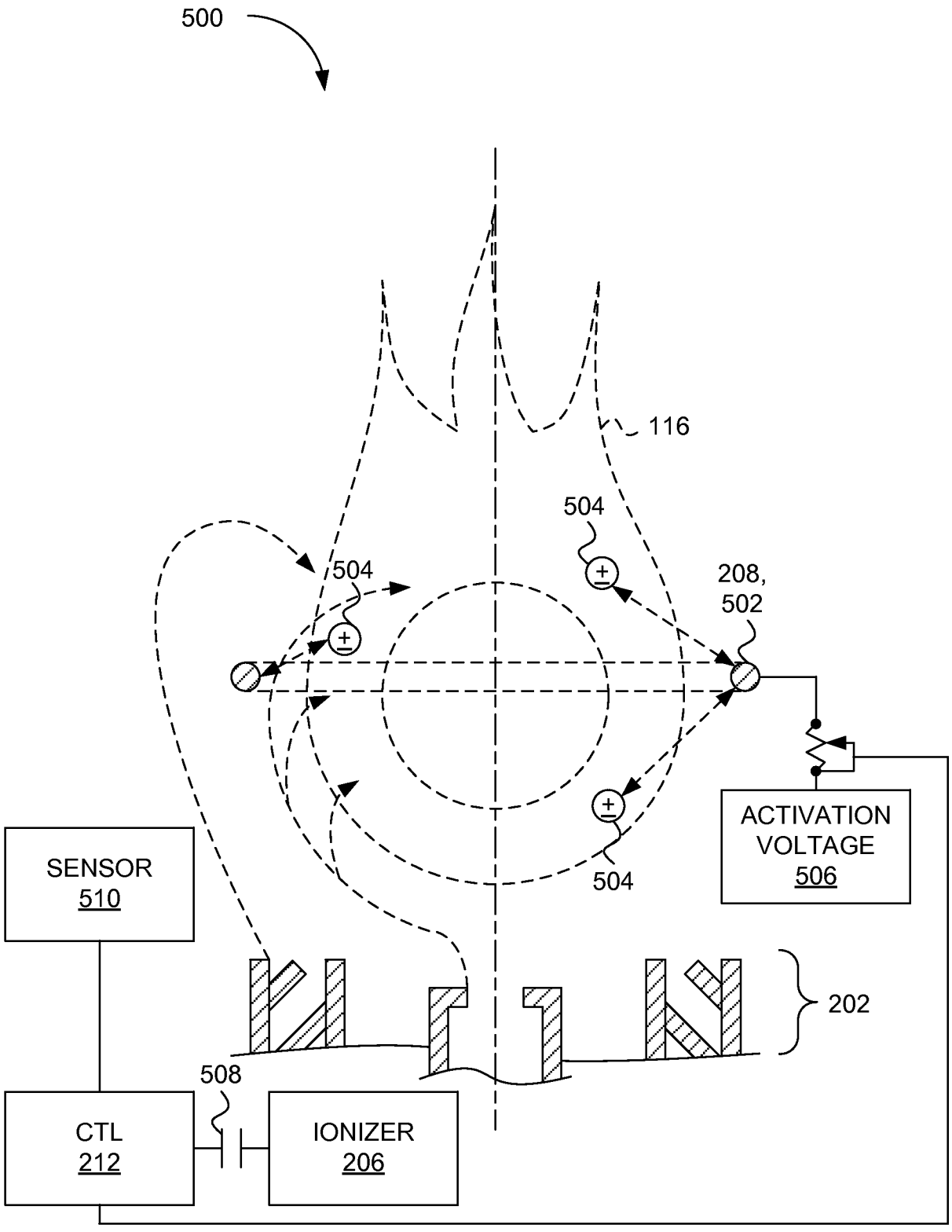
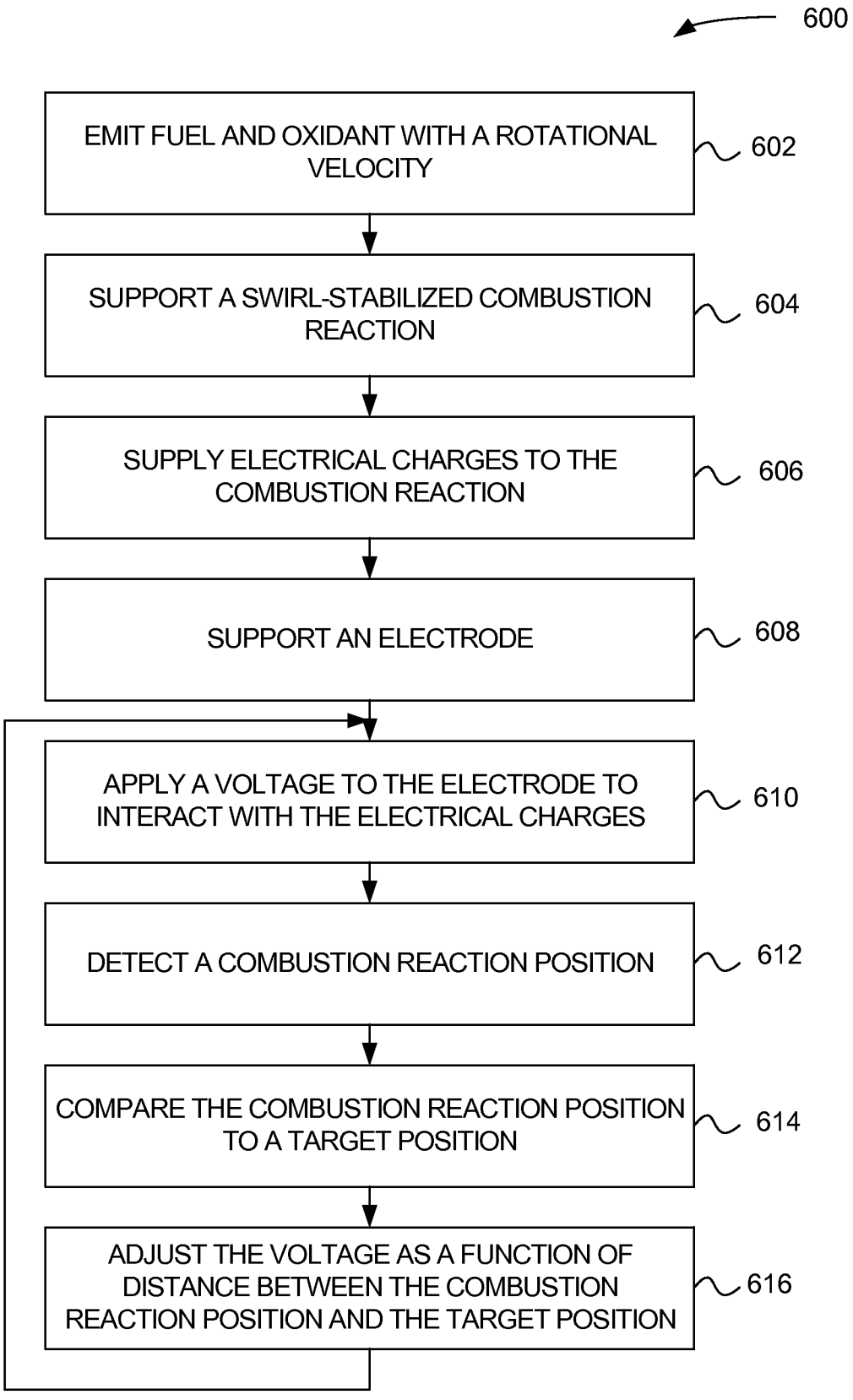

500
116
504
504
208,
502
504
ACTIVATION
VOLTAGE
506
SENSOR
510
202
508
CTL
212
IONIZER
206

FIG. 6


600
EMIT FUEL AND OXIDANT WITH A ROTATIONAL VELOCITY
602
SUPPORT A SWIRL-STABILIZED COMBUSTION REACTION
604
SUPPLY ELECTRICAL CHARGES TO THE COMBUSTION REACTION
606
SUPPORT AN ELECTRODE
608
APPLY A VOLTAGE TO THE ELECTRODE TO INTERACT WITH THE ELECTRICAL CHARGES
610
DETECT A COMBUSTION REACTION POSITION
612
COMPARE THE COMBUSTION REACTION POSITION TO A TARGET POSITION
614
ADJUST THE VOLTAGE AS A FUNCTION OF DISTANCE BETWEEN THE COMBUSTION REACTION POSITION AND THE TARGET POSITION
616