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(54) **SYSTEM AND METHOD FOR TUBE LEVEL AIR FLOW CONDITIONING**

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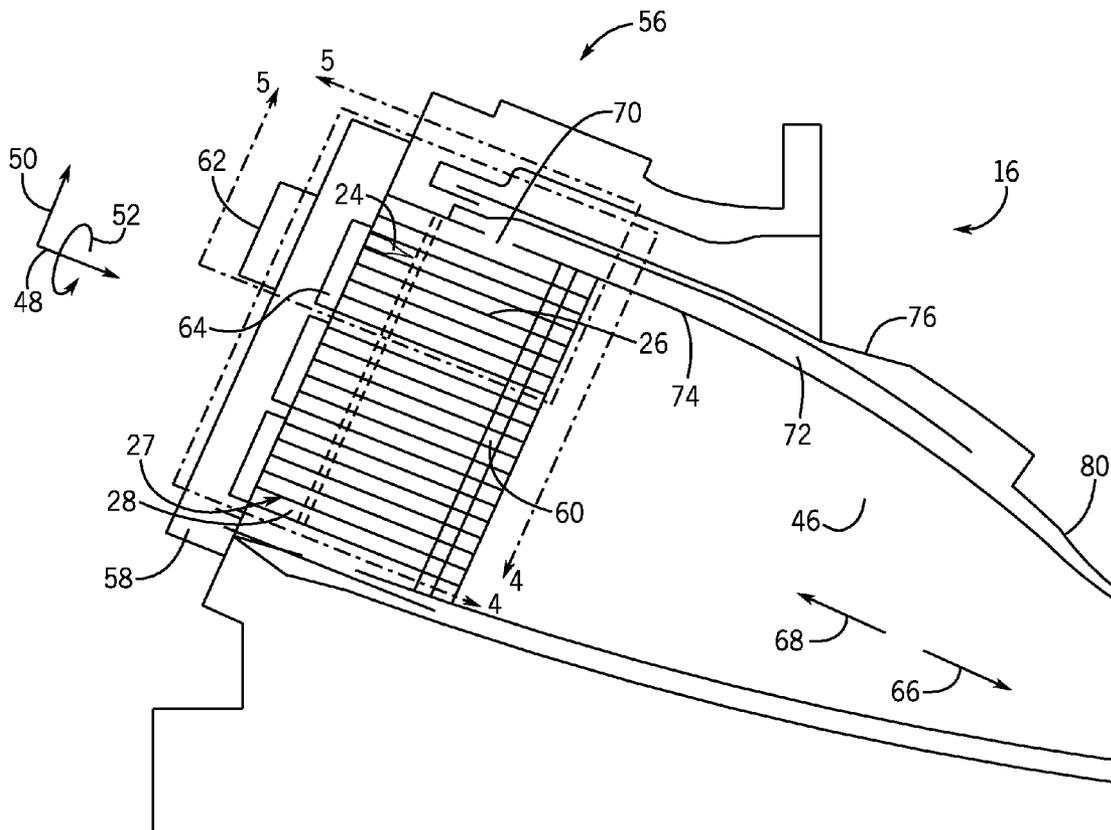
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(57) **ABSTRACT**

A system includes a multi-tube fuel nozzle. The multi-tube fuel nozzle includes multiple tubes. Each tube includes a first end, a second end, and an annular wall disposed about a central passage. The first end is configured to be disposed about a fuel injector. Each tube also includes an air flow conditioner having multiple air ports disposed adjacent the first end. The multiple air ports extend through the wall into the central passage.

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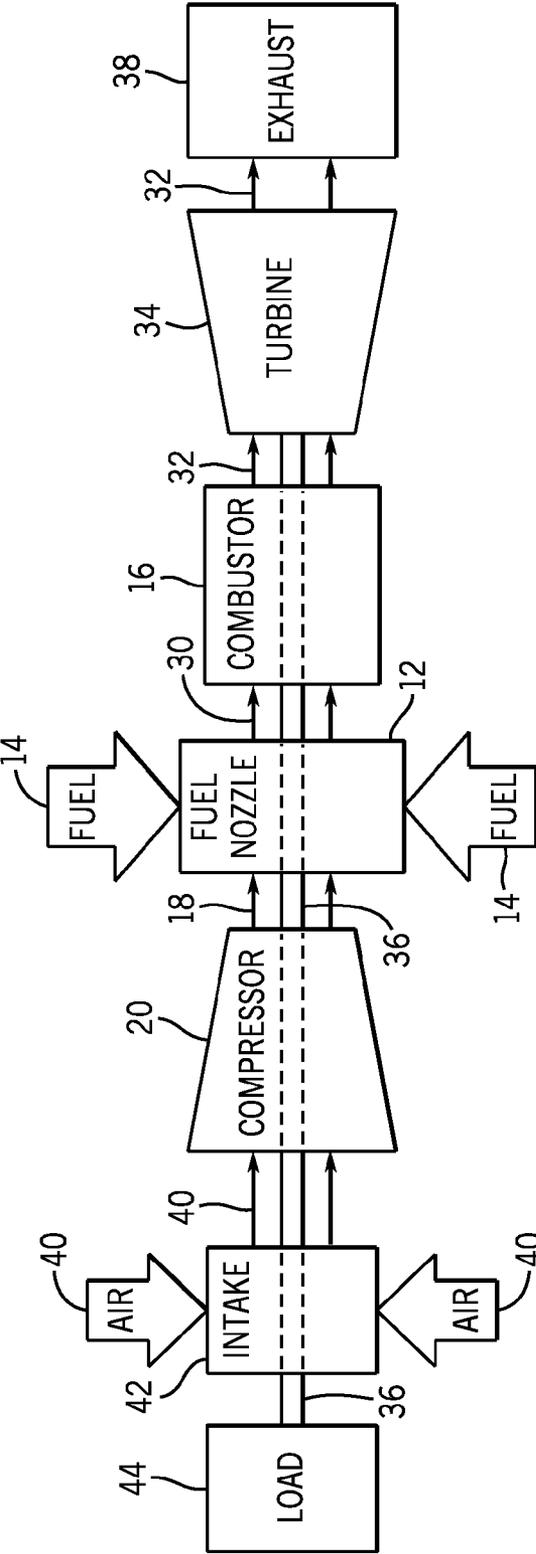


FIG. 1

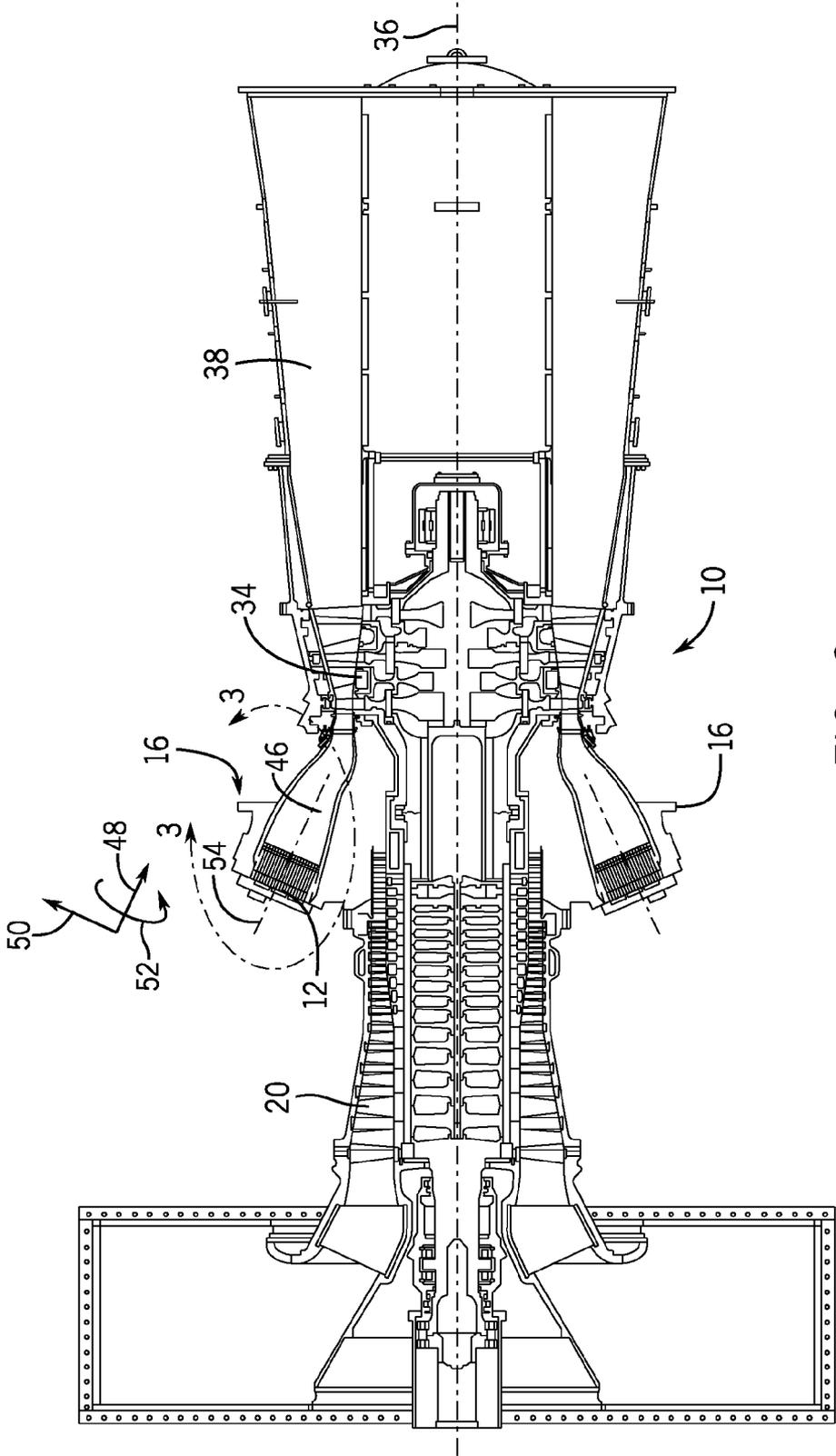


FIG. 2

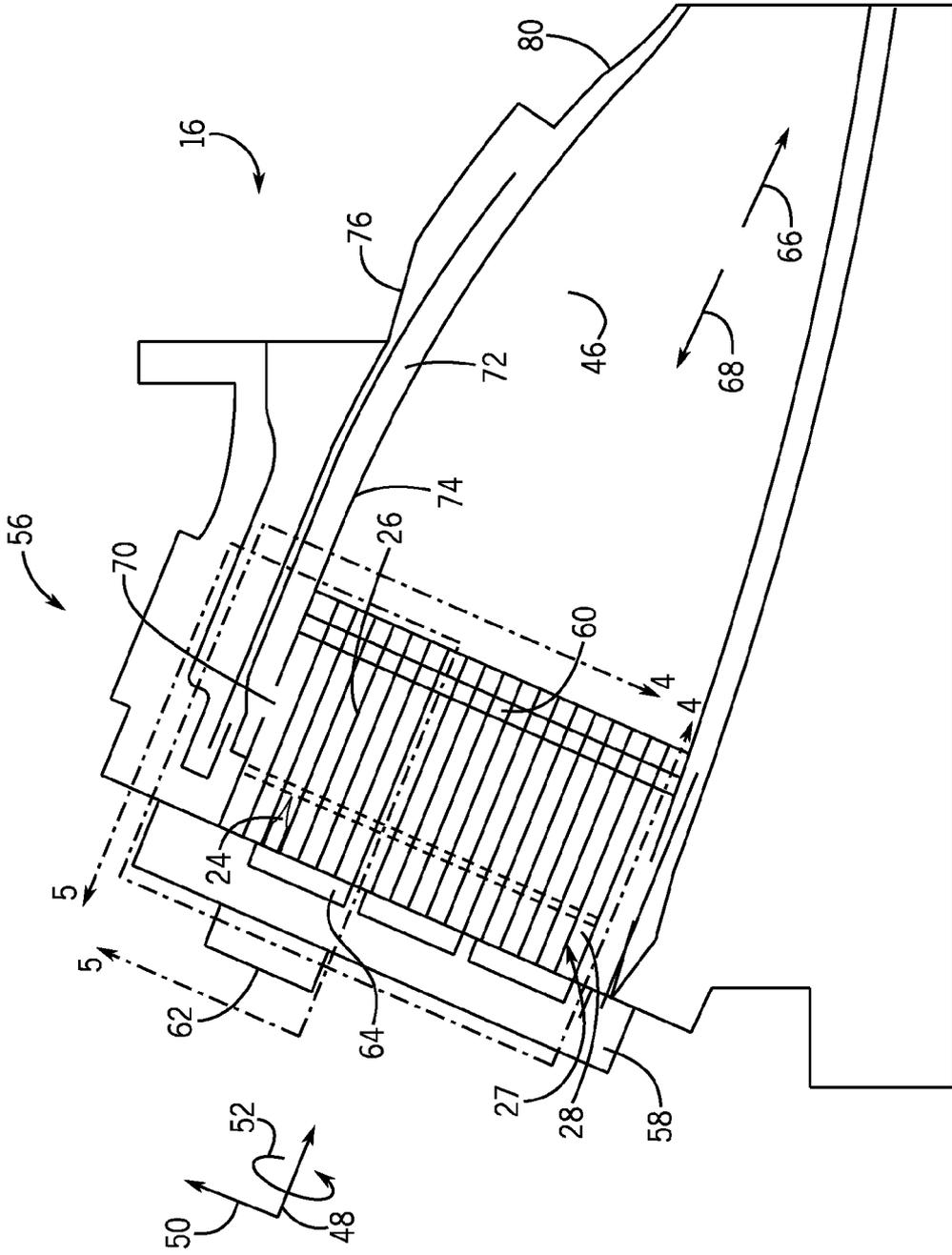
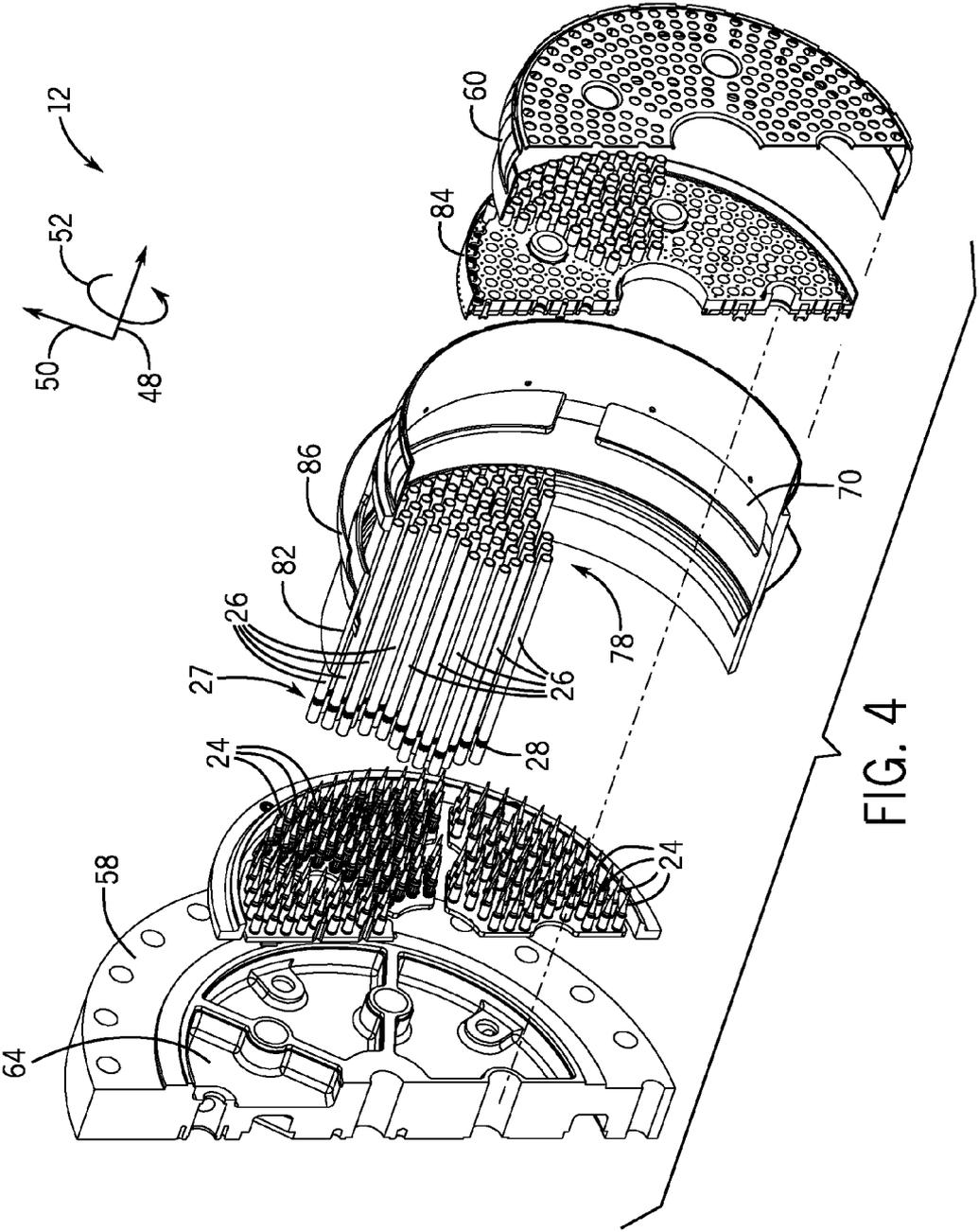


FIG. 3



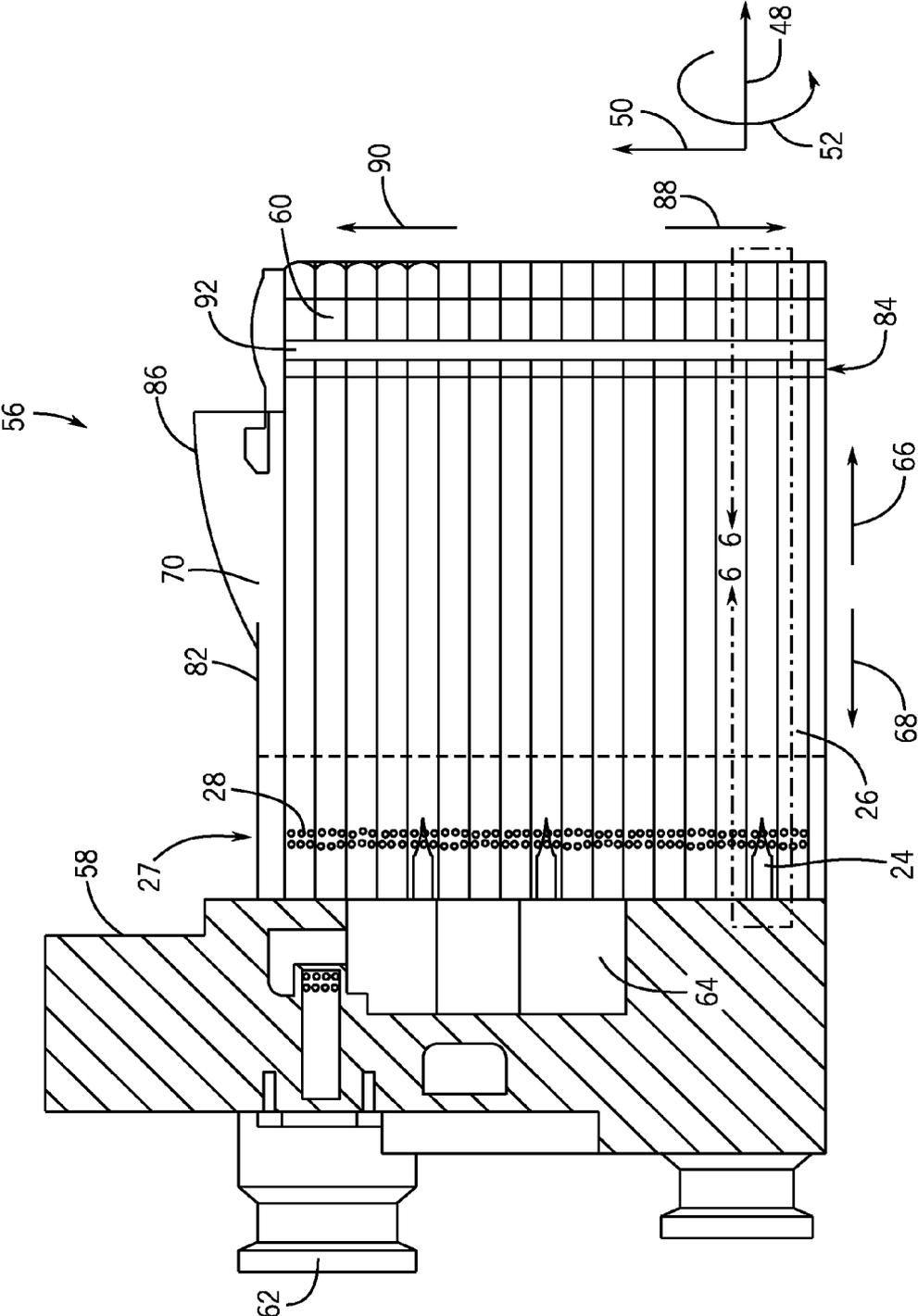


FIG. 5

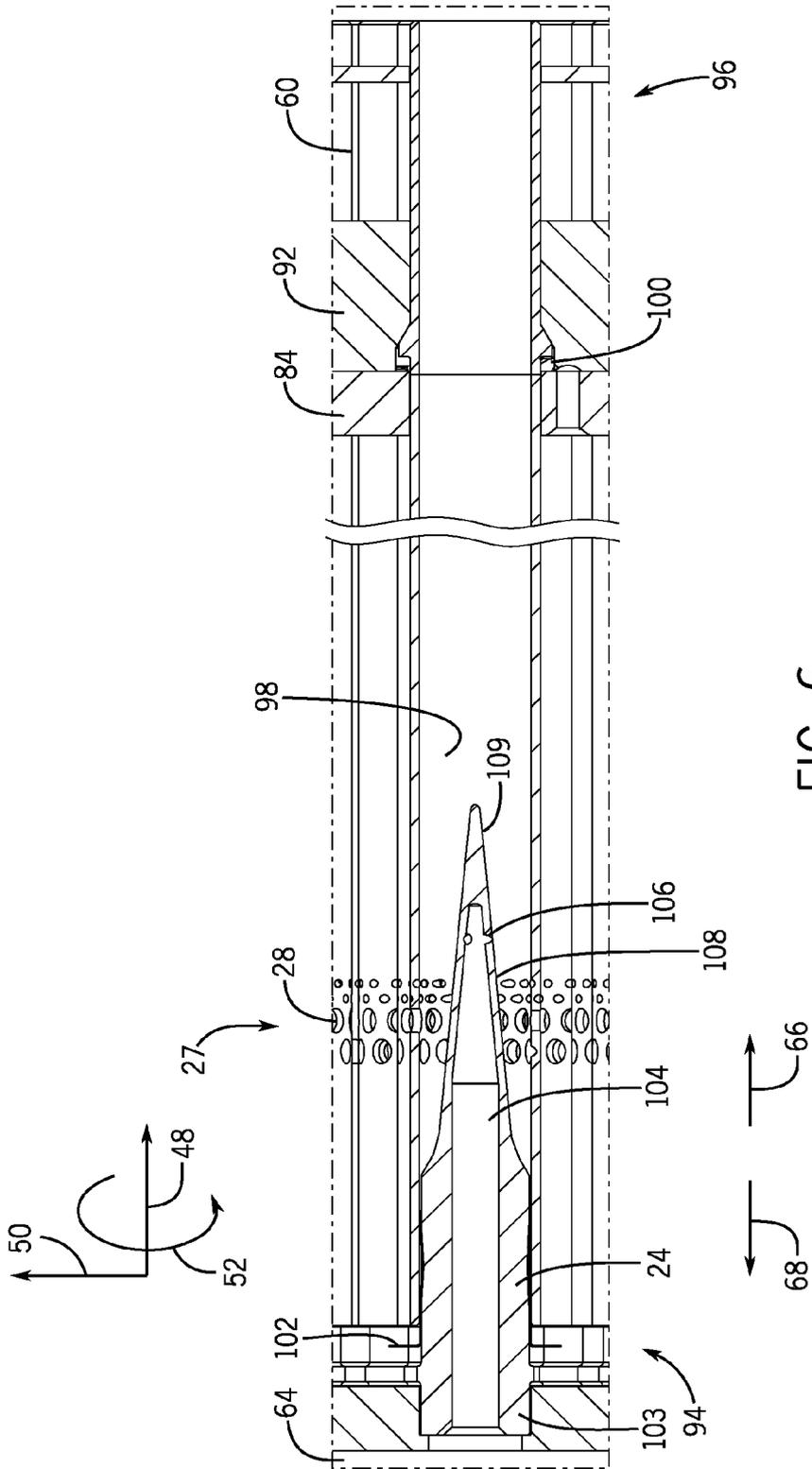


FIG. 6

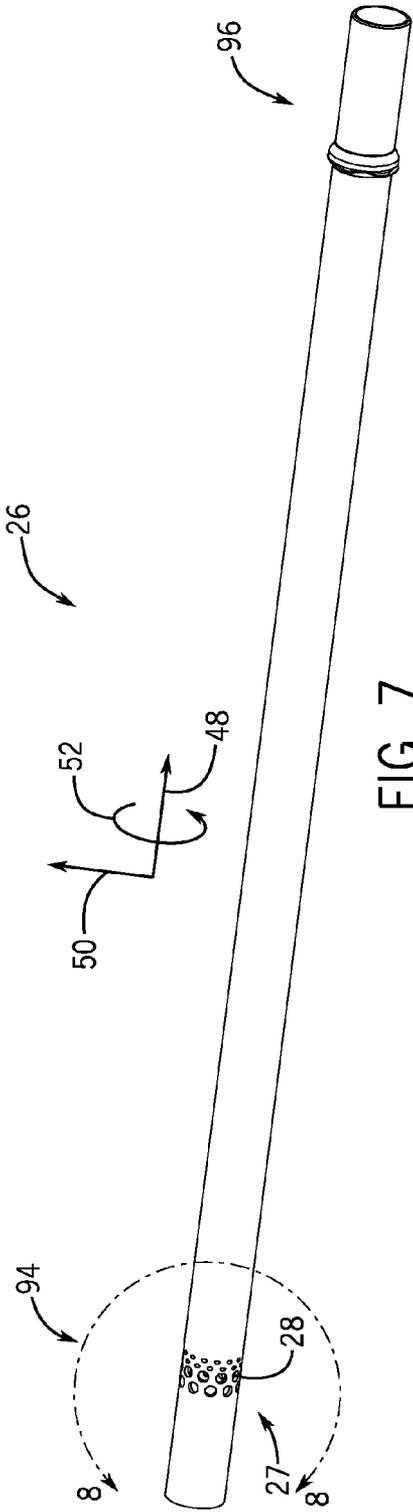


FIG. 7

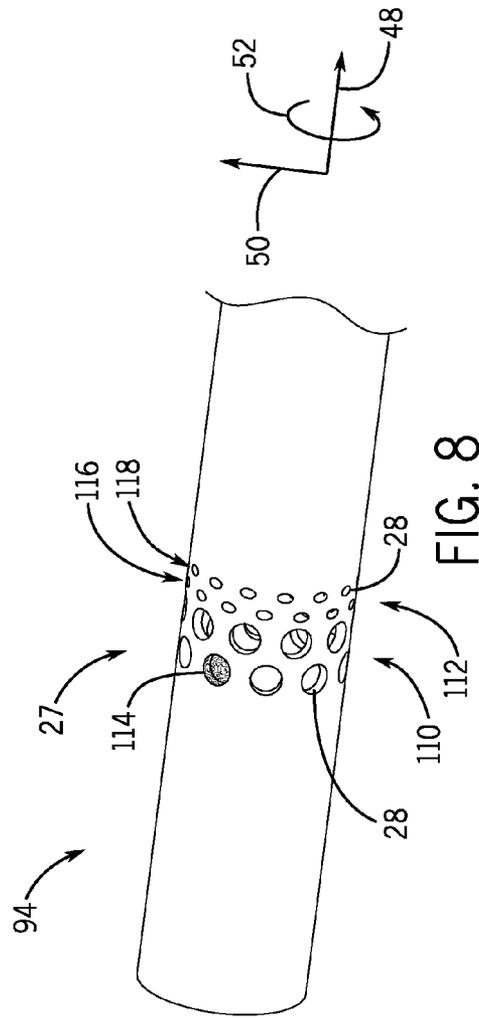
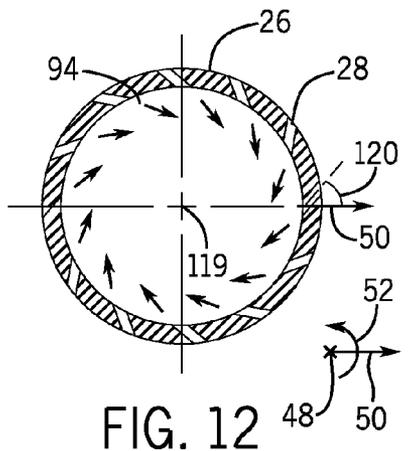
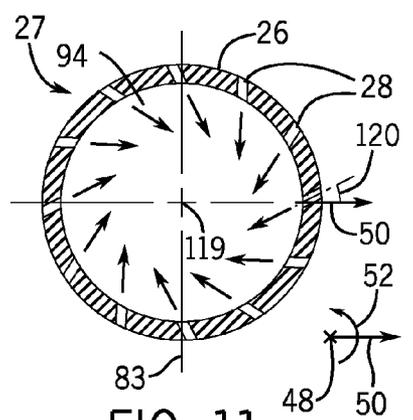
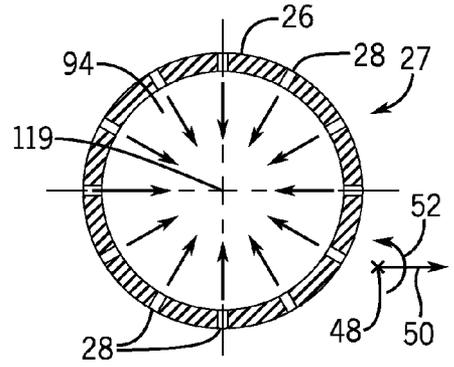
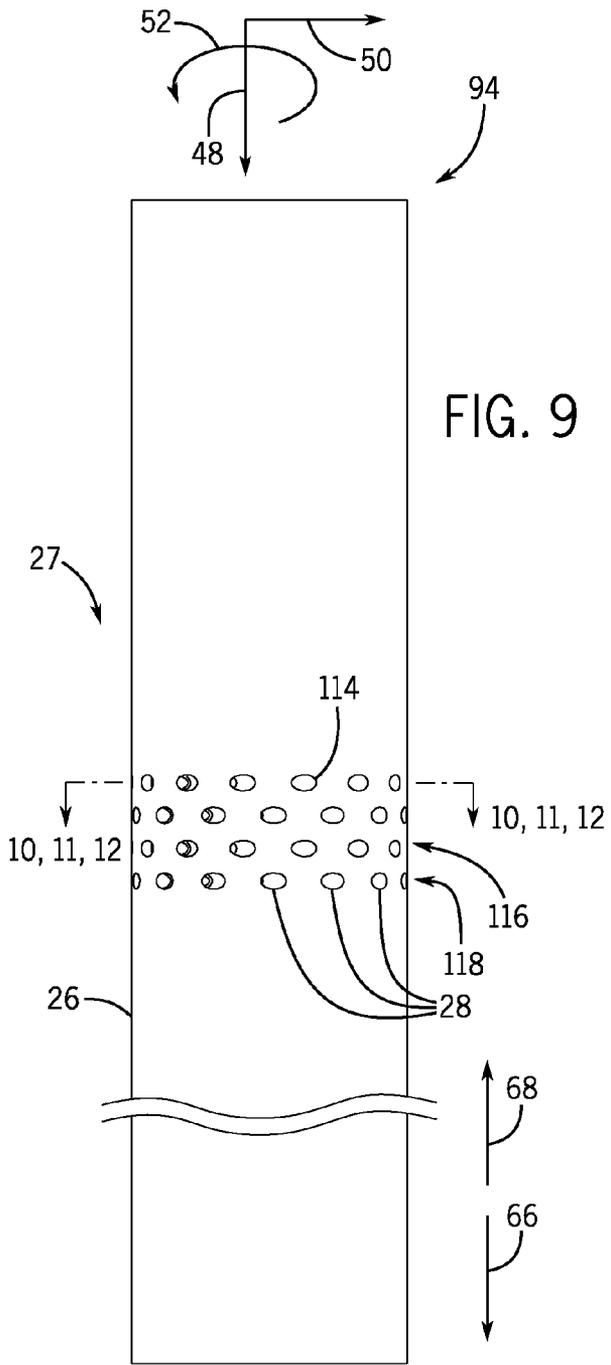


FIG. 8



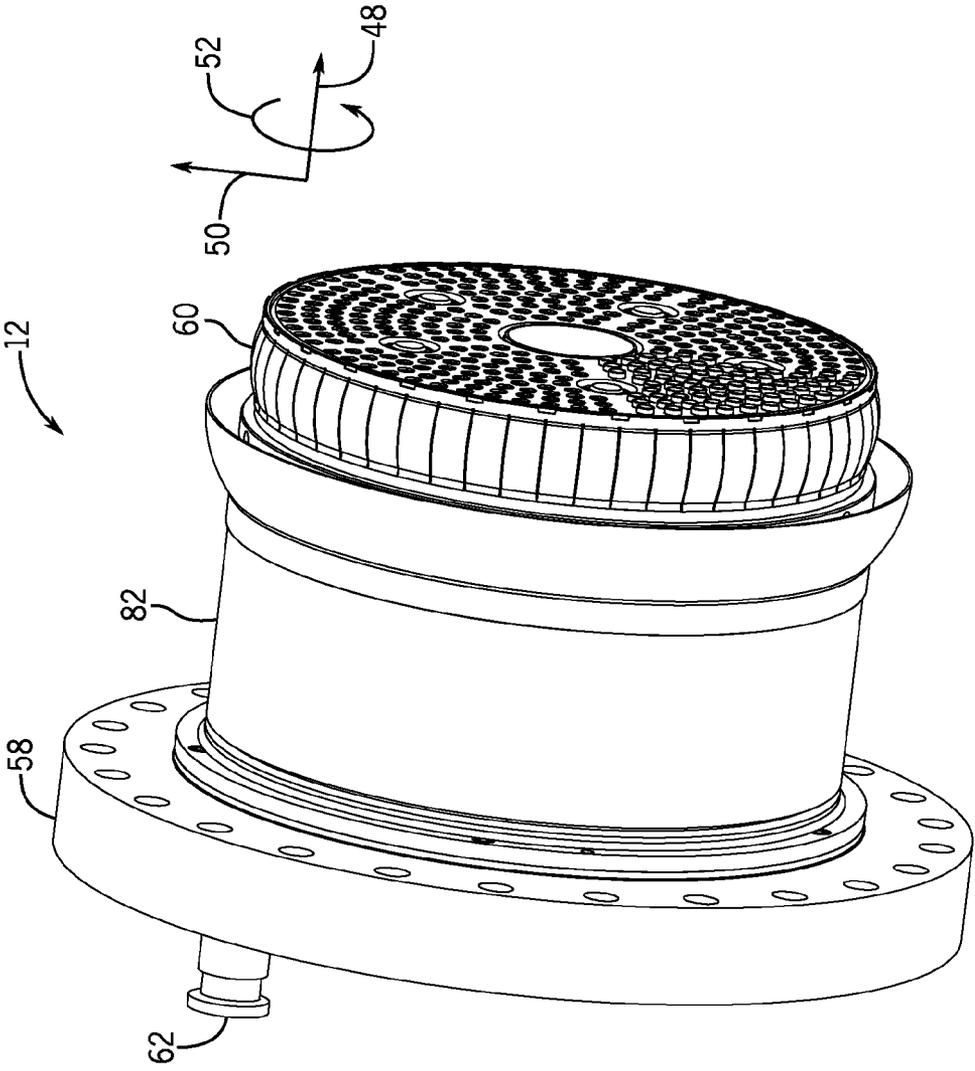


FIG. 13

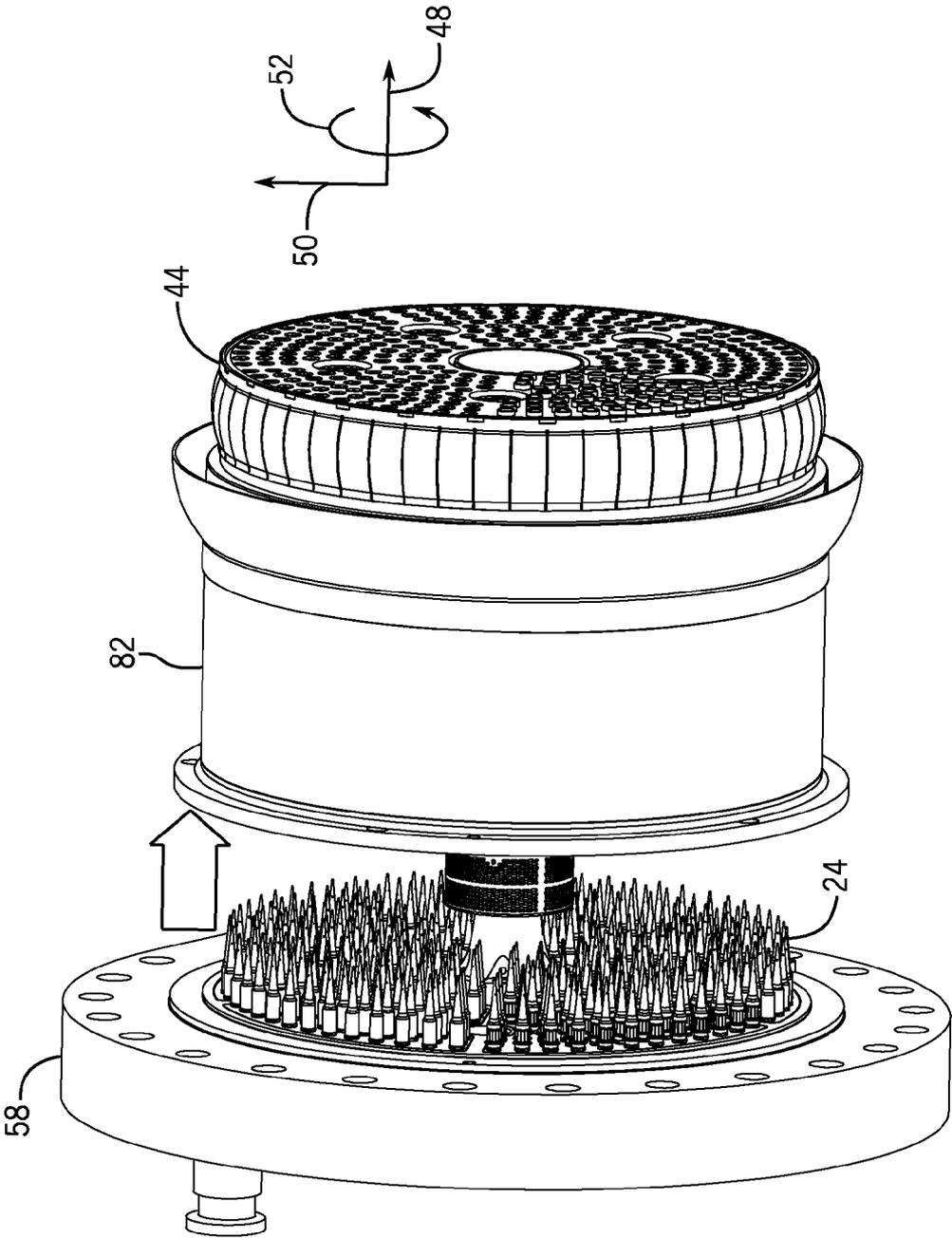


FIG. 14

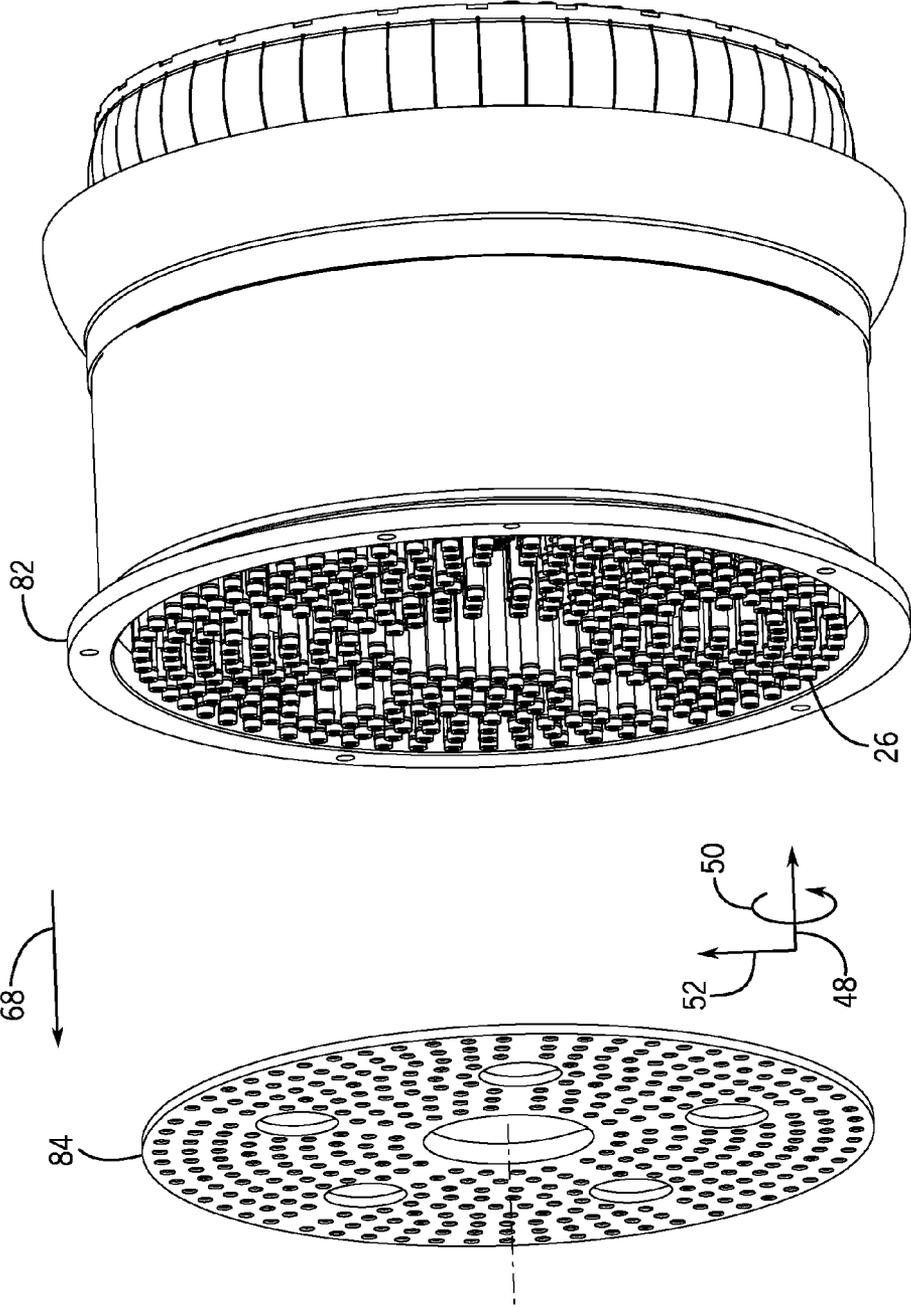


FIG. 15

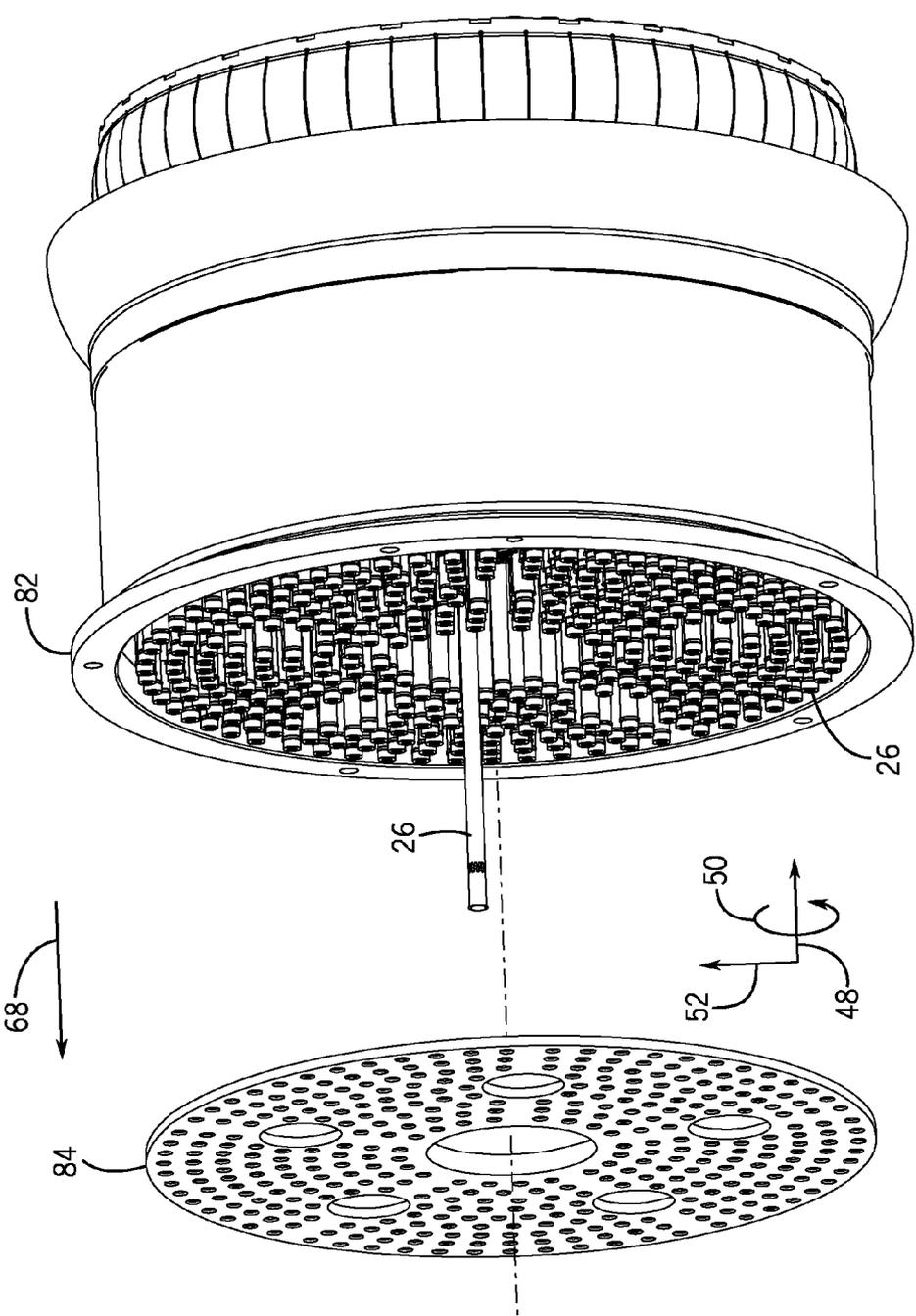


FIG. 16

**SYSTEM AND METHOD FOR TUBE LEVEL AIR FLOW CONDITIONING**

**BACKGROUND OF THE INVENTION**

[0001] The subject matter disclosed herein relates to tube level air flow conditioning for turbine systems.

[0002] Gas turbine systems generally include one or more combustors that combust a mixture of compressed air and fuel to produce hot combustion gases. Unfortunately, existing combustors may receive fuel and air at pressures and/or flow rates, which can fluctuate due to various limitations of the combustors, fuel nozzles, and associated equipment. These air and fuel fluctuations may drive or cause fluctuations in the fuel to air ratio, thereby increasing the possibility of flame holding, flashback, and/or increased emissions (e.g., nitrogen oxides). Conventional systems can also be slower at achieving mixing therefore reducing the overall efficiency of the system. There is therefore a need for a system that can achieve faster and more uniform fuel air mixing while also being durable and easily maintainable.

**BRIEF DESCRIPTION OF THE INVENTION**

[0003] Certain embodiments commensurate in scope with the originally claimed invention are summarized below. These embodiments are not intended to limit the scope of the claimed invention, but rather these embodiments are intended only to provide a brief summary of possible forms of the invention. Indeed, the invention may encompass a variety of forms that may be similar to or different from the embodiments set forth below.

[0004] In accordance with a first embodiment, a system includes a multi-tube fuel nozzle. The multi-tube fuel nozzle includes multiple tubes. Each tube includes a first end, a second end, and an annular wall disposed about a central passage. The first end is configured to be disposed about a fuel injector. Each tube also includes an air flow conditioner having multiple air ports disposed adjacent the first end. The multiple air ports extend through the wall into the central passage.

[0005] In accordance with a second embodiment a system includes a combustor end cover assembly and a multi-tube fuel nozzle coupled to the combustor end cover assembly. The multi-tube fuel nozzle includes a retainer plate and multiple tubes disposed between the end cover assembly and the retainer plate. Each tube includes a first end adjacent the end cover assembly, a second end adjacent the retainer plate, and an annular wall disposed about a central passage. The first end is configured to be disposed about a fuel injector. Each tube also includes an air flow conditioner having multiple air ports disposed adjacent the first end. The multiple air ports extend through the wall into the central passage.

[0006] In accordance with a third embodiment, a method for removal of tubes from a multi-tube fuel nozzle includes removing the multi-tube fuel nozzle having multiple tubes disposed between a retainer plate and an end cover from a gas turbine engine. Each tube includes a first end disposed adjacent the end cover and about a fuel injector, a second end disposed adjacent the retainer plate, and an annular wall disposed about a central passage. The method also include removing the end cover from the multi-tube fuel nozzle, removing the retainer plate from the multi-tube fuel nozzle by sliding the retainer plate along the multiple tubes from the second end to the first end of each tube, and removing at least one tube from the multi-tube fuel nozzle.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0007] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0008] FIG. 1 is a block diagram of an embodiment of a gas turbine system having a multi-tube fuel nozzle within a combustor, wherein the tubes are configured to uniformly distribute air;

[0009] FIG. 2 is a cutaway side view of the embodiment of a gas turbine system of FIG. 1;

[0010] FIG. 3 is a cutaway side view of an embodiment of the combustor of FIG. 2, taken within line 3-3, illustrating a multi-tube fuel nozzle coupled to an end cover assembly of the combustor;

[0011] FIG. 4 is an exploded perspective view of the multi-tube fuel nozzle and end cover assembly of FIG. 3;

[0012] FIG. 5 is a partial cross-sectional side view of the combustor of FIG. 3, illustrating multiple tubes and fuel injectors of the multi-tube fuel nozzle;

[0013] FIG. 6 is a cross-sectional side view of an embodiment of the first and second ends of an individual tube and respective fuel injector of the multi-tube fuel nozzle of FIG. 5;

[0014] FIG. 7 is a perspective view of an embodiment of an individual mixing tube, illustrating an air flow conditioner with air ports in the mixing tube;

[0015] FIG. 8 is a partial perspective view of an embodiment of the mixing tube of FIG. 7, taken within line 8-8, illustrating details of an air flow conditioner with air ports along the first end of the mixing tube;

[0016] FIG. 9 is a partial side view of an embodiment of the first end of the mixing tube of FIG. 7, illustrating an air flow conditioner with air ports;

[0017] FIG. 10 is a cross-sectional view of an embodiment of the mixing tube of FIG. 9, taken along line 10-10 through air ports of the air flow conditioner;

[0018] FIG. 11 is a cross-sectional side view of an embodiment of the mixing tube of FIG. 9, taken along line 11-11 through air ports of the air flow conditioner;

[0019] FIG. 12 is a cross-sectional side view of an embodiment of the mixing tube of FIG. 9, taken along line 12-12 through air ports of the air flow conditioner; and

[0020] FIGS. 13-16 are a series of views of an embodiment of a multi-tube fuel nozzle and a combustor end cover, illustrating a method of removal of tubes of the multi-tube fuel nozzle.

**DETAILED DESCRIPTION OF THE INVENTION**

[0021] One or more specific embodiments of the present invention will be described below. In an effort to provide a concise description of these embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

[0022] When introducing elements of various embodiments of the present invention, the articles "a," "an," "the,"

and “said” are intended to mean that there are one or more of the elements. The terms “comprising,” “including,” and “having” are intended to be inclusive and mean that there may be additional elements other than the listed elements.

[0023] The present disclosure is directed to systems for conditioning air flow within a multi-tube fuel nozzle of a turbine system. The turbine system may include one or more multi-tube fuel nozzles. Each multi-tube fuel nozzle includes multiple tubes (e.g., premixing tubes) wherein each tube has an air flow conditioner and a fuel injector. In the multi-tube fuel nozzle, pressurized air may enter each mixing tube through an air flow conditioner, which may include multiple air ports extending through an annular wall of the mixing tube. The annular wall of each tube is disposed about a central passage. The individual mixing tubes are each configured to be disposed about a fuel injector, which disperses fuel into the central passage of the mixing tube, creating the fuel air mixture. The air ports of the air flow conditioners are configured to condition the air entering the mixing tubes to target specific pressure drops and more uniformly mix air and fuel before it is subsequently directed into the combustion region. The air ports of each air flow conditioner may be configured with various features to optimize air side system pressure drops and best provide uniform air flow. Accordingly, the air ports of each air flow conditioner may be circumferentially arranged about the annular wall to take advantage of an air pressure profile that is substantially uniform circumferentially. The air flow conditioner on each mixing tube may include a first set and a second set of air ports, wherein the second set of air ports are located downstream of the first set of air ports. The second set of air ports may have a total area that is larger than the area of the first set of air ports to compensate for a region of lower air pressure area downstream in the fuel nozzle air plenum. The sets of air ports of each air flow conditioner may include multiple rows that are offset from each other in a circumferential direction to more equally distribute air pressure as the compressed air moves downstream. The air ports of each air flow conditioner may be configured to guide air flow into the mixing tubes in a substantially radial direction, but in other embodiments they might be configured to guide the air flow in a direction having various directional components (e.g., radial, angled axially upstream, angled axially downstream, angled circumferentially clockwise, angled circumferentially counterclockwise, of any combination thereof). These angled air ports (e.g., angled circumferentially clockwise or counterclockwise) may impart swirl to the air directed within the central passage of the mixing tubes which can increase the uniformity of the fuel-air mixture. The tubes may each be configured based on their location within the multi-tube fuel nozzle to receive substantially equal distribution of air flow.

[0024] Turning now to the drawings and referring first to FIG. 1, a block diagram of an embodiment of a gas turbine system 10 is illustrated. The gas turbine system 10 includes one or more fuel nozzles 12 (e.g., multi-tube fuel nozzles), a fuel supply 14, and a combustor 16. The fuel nozzle 12 receives compressed air 18 from an air compressor 20 and fuel 22 from a fuel supply 14. Although the present embodiments are discussed in context of air as an oxidant, the present embodiments may use air, oxygen, oxygen-enriched air, oxygen-reduced air, oxygen mixtures, or any combination thereof. As discussed in further detail below, the fuel nozzle 12 includes a plurality of fuel injectors 24 (e.g., 10 to 1000) and associated mixing tubes 26 (e.g., 10 to 1000), wherein each mixing tube 26 has an air flow conditioner 27 with air ports 28 (e.g., 1 to 100) to direct and condition an air flow into the respective tube 26, and each mixing tube 26 has a respec-

tive fuel injector 24 (e.g., in a coaxial or concentric arrangement) to inject fuel into the respective tube 26. In turn, each mixing tube 26 mixes the air and fuel along its length, and then outputs an air-fuel mixture 30 into the combustor 16. In certain embodiments, the mixing tubes 26 may be described as micromixing tubes, which may have diameters between approximately 0.5 to 2, 0.75 to 1.75, or 1 to 1.5 centimeters. The mixing tubes 26 may be arranged in one or more bundles (e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or more) of closely spaced tubes, generally in a parallel arrangement relative to one another. In this configuration, each mixing tube 26 is configured to mix (e.g., micromix) on a relatively small scale within each mixing tube 26, which then outputs a fuel-air mixture 30 into the combustion chamber. The air flow conditioner 27 (e.g., with ports 28) of the disclosed embodiments provides air conditioning on a tube level (i.e., for each individual mixing tube 26), such that the flow and/or pressure of air into each tube 26 and among the plurality of tubes 26 can be controlled to provide better mixing of fuel and air.

[0025] The combustor 16 ignites the fuel-air mixture 30, thereby generating pressurized exhaust gases 32 that flow into a turbine 34. The pressurized exhaust gases 32 flow against and between blades in the turbine 34, driving the turbine 34 to rotate. The turbine blades are coupled to a shaft 36, which in turn also rotates as the exhaust gases 32 escape the combustor 16. Eventually, the exhaust 32 of the combustion process exits the turbine system 10 via an exhaust outlet 38. Blades within the compressor 20 are additionally coupled to the shaft 36, and rotate as the shaft 36 is driven to rotate by the turbine 34. The rotation of the blades within the compressor 20 compresses air 40 that has been drawn into the compressor 20 by an air intake 42. The resulting compressed air 18 is then fed into the multi-tube fuel nozzle 12 of the combustors 16, as discussed above, where it is mixed with fuel 22 and ignited, creating a substantially self-sustaining process. Further, the shaft 36 may be coupled to load 44. As will be appreciated, the load 44 may be any suitable device that may generate power via the rotational output of a turbine system 10, such as a power generation plant or an external mechanical load. The relationship between the consistency of the fuel-air mixture 30 and the efficient operation of the gas turbine system 10 can therefore be appreciated. The implementation of the multiple mixing tubes 26, each having an air flow conditioner 27 with multiple air ports 28 to condition the air 18 will be discussed in greater detail below.

[0026] FIG. 2 shows a cutaway side view of the embodiment of gas turbine system 10 of FIG. 1. As depicted, the embodiment includes a compressor 20, which is coupled to an annular array of combustors 16. Each combustor 16 includes at least one fuel nozzle 12 (e.g., a multi-tube fuel nozzle) which feeds the fuel-air mixture 30 to a combustion chamber 46 located within each combustor 16. As will be discussed in detail below, certain embodiments of the mixing tubes 26 of the fuel nozzle 12 include unique features to more uniformly distribute the compressed air 18 creating a more uniform fuel-air mixture 30. Uniformity of the fuel-air mixture 30 provides more efficient combustion, thereby increasing performance and reducing emissions. Combustion of the fuel-air mixture 30 within combustors 16, as mentioned above in regard to FIG. 1, causes vanes or blades within the turbine 24 to rotate as exhaust gases 22 (e.g., combustion gases) pass toward an exhaust outlet 38. Throughout the discussion, a set of axes will be referenced. These axes are based on a cylindrical coordinate system and point in an axial direction 48, a radial direction 50, and a circumferential direction 52. For example, the axial direction 48 extends along a length or longitudinal axis 54 of the fuel nozzle 12, the radial direction

**50** extends away from the longitudinal axis **54**, and the circumferential direction **52** extends around the longitudinal axis **54**.

[0027] FIG. 3 is a cutaway side view of the combustor **16** of the gas turbine system **10** of FIG. 2 and taken within line 3-3 of FIG. 2. As shown, the combustor **16** includes a head end **56** and a combustion chamber **46**. The fuel nozzle **12** is positioned within the head end **56** of the combustor **16**. Within the fuel nozzle **12** are suspended the multiple mixing tubes **26** (e.g., air-fuel pre-mixing tubes). Illustrated is an embodiment of the mixing tubes **26** having air flow conditioners **27** with air ports **28** that enable compressed air **18** to enter and mix with fuel **22**. The mixing tubes **26** generally extend axially between an end cover assembly **58** of the combustor **16** and a cap face assembly **60** of the fuel nozzle **12**. The mixing tubes **26** may be coupled to the end cover assembly **58** and the cap face assembly **60**, as further described below. The end cover assembly **58** may include a fuel inlet **62** and fuel plenum **64** for providing fuel **22** to multiple fuel injectors **24**. As discussed above, each individual fuel injector **24** is coupled to an individual mixing tube **26**. During the combustion process, fuel **22** moves axially through each of the mixing tubes **26** from the end cover assembly **58** (via the fuel injectors **24**) through the cap face assembly **60** and to the combustion chamber **46**. The direction of this movement along the longitudinal axis **54** of the fuel nozzle **12** will be referred to as the downstream direction **66**. The opposite direction will be referred to as the upstream direction **68**.

[0028] As described above, the compressor **20** compresses air **40** received from the air intake **42**. The resulting flow of pressurized compressed air **18** is provided to the fuel nozzles **12** located in the head end **56** of the combustor **16**. The air enters the fuel nozzles **12** through air inlets **70** to be used in the combustion process. More specifically, the pressurized air **18** flows from the compressor **20** in an upstream direction **68** through an annulus **72** formed between a liner **74** (e.g., an annular liner) and a flow sleeve **76** (e.g., an annular flow sleeve) of the combustor **16**. At the end of this annulus **72**, the compressed air **18** is forced into the air inlets **70** of the fuel nozzle **12** and fills an air plenum **78** within the fuel nozzle **12**. The pressurized air **18** in the air plenum **78** then enters the multiple mixing tubes **26** through the air ports **28** of the air flow conditioner **27**. In addition to allowing the air **18** to enter the mixing tubes **26**, the air ports **28** of the air flow conditioner **27** may condition the air **18** in various ways, as discussed further below. Inside the mixing tubes **26**, the air **18** is then mixed with the fuel **22** provided by the fuel injectors **24**. The fuel-air mixture **30** flows in a downstream direction **66** from the mixing tubes **26** into the combustion chamber **46**, where it is ignited and combusted to form the combustion gases **22** (e.g., exhaust gases). The combustion gases **32** flow from the combustion chamber **46** in the downstream direction **66** to a transition piece **80**. The combustion gases **22** then pass from the transition piece **80** to the turbine **34**, where the combustion gases **22** drive the rotation of the blades within the turbine **34**.

[0029] FIG. 4 illustrates an exploded perspective view of the multi-tube fuel nozzle **12** taken within line 4-4 of FIG. 3. This figure further illustrates the arrangement, according to some embodiments, of the multiple fuel injectors **24** on the end cover **58** and their relation to the multiple mixing tubes **26**. The fuel plenums **64** distribute the fuel **22** to the fuel injectors **24**. As discussed above, the mixing tubes **26** are arranged to be disposed between the end cover assembly **58** and the cap face assembly **60**. The individual mixing tubes **26** are each paired with an individual fuel injector **24** and are configured to be disposed about that fuel injector **24** (e.g., in a coaxial or concentric arrangement). The air ports **28** are

located on this upstream **68** side of the mixing tubes **26** in proximity to the fuel injectors **24**. In certain embodiments, the fuel injectors **24** may be removably coupled to the end cover assembly **58**.

[0030] Additionally, FIG. 4 illustrates a support structure **82** (e.g., annular barrel, fuel nozzle cap) of the fuel nozzle **12** that surrounds the mixing tubes **26** and other structures within the fuel nozzle **12**. The support structure **82** extends from the end cover assembly **58** to the cap face assembly **60**, generally protects and supports the structures positioned within the fuel nozzle **12**, and defines the air plenum **78** within the fuel nozzle **12**. The air inlets **70** are located on the support structure **82** and direct the compressed air **18** radially into the air plenum **78** on the interior of the fuel nozzle **12**. A retainer plate **84** is located upstream **68** and proximate to the removable cap face assembly **60**. In certain embodiments, the nozzle **12** includes an annular air flow conditioning diffuser **86** surrounding the air inlets **70**.

[0031] FIG. 5 is a partial cross-sectional side view of the combustor **16** as taken within line 5-5 of FIG. 3. The head end **56** of the combustor **16** contains a portion of the multi-tube fuel nozzle **12**. The support structure **82** surrounds the multi-tube fuel nozzle **12** and the multiple mixing tubes **26**. As discussed above, in some embodiments, each mixing tube **26** may extend axially between the end cover assembly **58** and the cap face assembly **60**. The mixing tubes **26** may further extend through the cap face assembly **60** to feed the fuel-air mixture **30** directly to the combustion chamber **46**. Each mixing tube **26** is positioned to surround a fuel injector **24** (e.g., coaxial or concentric arrangement), such that the injector **24** receives fuel **22** from the fuel plenum **64** and directs the fuel into the tube **26**. The fuel plenum **64** is fed fuel **22** entering the fuel inlet **62** located on the end cover assembly **58**.

[0032] As described above, compressed air **18** enters the fuel nozzle **12** through air inlets **70**, which may be surrounded by a diffuser **86**. The diffuser **86** may be annular and configured to pre-condition and distribute the pressurized air into the fuel nozzle **12** across the mixing tubes **26** in a variety of directions. The direction of the air flow within the fuel nozzle **12** will be substantially radially inward **88**, but may have an upstream **68** component or downstream **66** component. The air flow will vary across mixing tubes **26** that are located in more radially outward **90** locations within the fuel nozzle **12**, closer to the air inlets **70**. After entering the fuel nozzle **12** through the air inlet **70** and moving across the mixing tubes **26**, the pressurized air **18** enters each mixing tube **26** through one or more air ports **28** of an air flow conditioner **27**. In certain embodiments, the configuration of air ports **28** of the air flow conditioner **27** is varied among individual mixing tubes **26** based on their radial **50** locations within the fuel nozzle air plenum **78**. This customization can compensate for the variations in air pressure and movement across the mixing tubes **26**, namely the pressure drop that occurs in the radially inward **88** direction. In certain embodiments, the axial **48** positions of the air ports **28** along the mixing tubes **26** may be varied to compensate for axial **48** variations in air pressure. For additional management of the flow of pressurized air **18** the air ports **28** of the air flow conditioner **27** may be configured to have any of a variety of shapes, sizes, and arrangements as will be further discussed below. As also shown in FIG. 5, in some embodiments, the retainer plate **84** and/or an impingement plate **92** may be positioned within the fuel nozzle **12** surrounding the downstream **66** end of the mixing tubes **26** generally proximate to the cap face assembly **60**. The impingement plate **92** may include a plurality of impinge-

ment cooling orifices, which may direct jets of air to impinge against a rear surface of the cap face assembly 60 to provide impingement cooling.

[0033] Illustrated in FIG. 6 is a cross-sectional view of an individual mixing tube 26 and fuel injector 24, as taken within line 6-6 of FIG. 5. The central portion of tube 26 has been omitted to show greater detail of the first and second ends 94 and 96. The fuel injector 24 may be generally positioned within a central passage 98 at the first end 94 (e.g., upstream 68 end) of each mixing tube 26. This first end 94 is located on the upstream 68 side of the multi-tube fuel nozzle 12 adjacent to the end cover assembly 58. In certain embodiments the air ports 28 of the air flow conditioner 27 are located at or near this first end 94 generally proximate to the fuel injector 24. In other embodiments, the air ports 28 of the air flow conditioner 27 are located in locations further upstream 68 or downstream 66 from the fuel injector 24. The location of the air ports 28 can be configured to selectively direct the air 18 in various paths depending on the flow of fuel 22 and pressurized air 18 in a specific location within the fuel nozzle 12. In some embodiments, the retainer plate 84 may support a second end 96 of the mixing tubes 26 located on the downstream 66 side. In certain embodiments, the retainer plate 84 may additionally help secure the second end 96 of the mixing tubes 26 to the impingement plate 82.

[0034] FIG. 6 also illustrates an embodiment of the spatial relationship among the mixing tubes 26, the cap face assembly 60 and/or the end cover assembly 58. In some embodiments, the mixing tubes 26 may be attached to components within the head end 56 of the combustor 16, such as the cap face assembly 60, the retainer plate 84, and/or the impingement plate 92 by various fasteners or connections, such as weld, brazed joints, brackets, threaded fasteners, snap-fits, joints, or other connections. In other embodiments, the mixing tubes 26 are held in a floating configuration and are merely supported by one or more of the cap face assembly 60, the retainer plate 84, the impingement plate 92, various springs, or other supporting structures. Such floating configurations may advantageously accommodate thermal growth of the mixing tubes 18 and other components of the combustor 14. Floating configurations also allow the customization and configuration of mixing tubes 26 with various air port 28 configurations to be more easily made. If fuel-air mixtures 20 are found to be non-uniform, individual tubes 26 may be easily removed and replaced with tubes 26 that have different air port 28 (e.g. air flow conditioner 27) configurations that better compensate for air pressure variations within the fuel nozzle 12. The floating configurations may additionally be implemented by the inclusion of an axial spring 100 to provide resilient axial 48 support and constraint to the movement of the mixing tubes 26. In accordance with the illustrated embodiment, the axial spring 100 may be positioned between a retainer plate 84 and impingement plate 92. Further, a radial spring 102 may be located between the fuel injector 24 and the first end 94 of the mixing tube 26, and may provide resilient radial 50 constraint to the movement and thermal growth of the mixing tube 26. There may further be features implemented such as additional springs, channels and/or guides, to block circumferential 52 movement of the mixing tubes 26.

[0035] As further illustrated in FIG. 6, the fuel injector 24 has an annular wall 103 around an inner fuel passage 104, which leads to one or more fuel ports 106 in a tapered portion 108 of the fuel injector 24 disposed inside of the mixing tube 26 (e.g., in a coaxial or concentric arrangement). In operation, the fuel injector 24 flows fuel 22 from the fuel plenum 64 downstream 66 to a region inside of the mixing tube 26 via the

one or more fuel ports 106. In certain embodiments, the fuel ports 106 may be positioned axially upstream 68, axially downstream 66, axially aligned with, or any combination thereof, relative to the air ports 28. In the illustrated embodiment, the fuel ports 106 are located on the tapered portion 108, which may have a linear or curved taper in the downstream direction 66. For example, the tapered portion 108 may be formed as a conical wall, an inwardly curved annular wall (e.g., curved inwardly toward the axis of the injector 24), an outwardly curved annular wall (e.g., curved outwardly away from the axis of the injector 24), or a combination thereof. In the illustrated embodiment, the tapered portion 108 extends from a first position upstream 68 of the air ports 28 to a second position downstream 66 of the air ports 28 of the mixing tube 26. As illustrated, the tapered portion 108 of the fuel injector 24 gradually decreases in diameter (i.e., converges) in the downstream direction 66, thereby gradually increasing the cross-sectional area between the fuel injector 24 and the mixing tube 26 in the downstream direction 66. In this manner, the illustrated embodiment provides a gradual pressure drop between the fuel injector 24 and the mixing tube 26, thereby helping to improve the flow and mixing of fuel and air. In the illustrated embodiment, the air flow conditioner 27 (e.g., air ports 28) along the mixing tube 26 and the fuel ports 106 along the fuel injector 24 (e.g., tapered portion 108) are both disposed upstream from a tip 109 of the fuel injector 24, such that the air and fuel at least partially mix along the decreasing cross-sectional area between the fuel injector 24 and the mixing tube 26. Furthermore, the illustrated air ports 28 are disposed upstream of the fuel ports 106 to increase the pressure upstream of the fuel ports 106.

[0036] In certain embodiments, the fuel ports 106 and the air ports 28 (e.g., axes of the ports) may be oriented in the radial direction 50, the axial direction 48, an axially upstream angle, an axially downstream angle, the circumferential direction 52 (e.g., clockwise or counter clockwise), or any combination thereof. Furthermore the fuel and air ports 106 and 28 may be oriented in the same direction and/or different directions. For example, the fuel ports 106 may be oriented radially outward while the air ports 28 may be oriented radially outward, and the fuel ports 106 may be oriented in the same and/or opposite circumferential directions 52 as the air ports 28. The circumferential direction of ports 28 and/or 106 may be used to facilitate a swirling flow. The orientation of the fuel ports 106 and air ports 28 also may vary circumferentially 52 around each tube 26, axially along each tube 26, or any combination thereof. Furthermore, the orientation of the fuel ports 106 and air ports 28 also may vary from one tube 26 to another tube 26 among the plurality of mixing tubes 26. In this manner, the orientation of the fuel ports 106 and air ports 28 may be used to improve the fuel-air mixing in each tube 26, while adjusting for flow and pressure variations within the multi-tube fuel nozzle 12. This ability to vary the orientation of ports 28 and 106, particularly the air ports 28, enables tube-level air flow conditioning among the plurality of mixing tubes 26.

[0037] The number, size, and/or shape of the fuel ports 106 and the air ports 28 may be the same and/or different from one another. In certain embodiments, the air ports 28 may include hole diameters that are equal to, greater than, and/or less than hole diameters of the fuel ports 106. For example, the air ports 28 may have diameters of approximately 0.1 to 10 times, 0.2 to 5 times, 0.3 to 4 times, 0.4 to 3 times, or 0.5 to 2 times the diameter of the fuel ports 106. In certain embodiments, the number of air ports 28 may be equal to, greater than, and/or less than the number of the fuel ports 106. For example, the number of air ports 28 may be approximately 0.5 to 50 times,

0.5 to 25 times, 1 to 10 times, or 2 to 5 times the number of fuel ports 106. As an example, the air flow conditioner 27 of each mixing tube 26 may have 5 to 500, 10 to 100, or 15 to 50 air ports 28. In certain embodiments, the shape of the fuel ports 106 and the air ports 28 may include circular ports, rectangular ports, oval ports, triangular ports, polygonal ports, or any combination thereof. Along with the variation in the orientation, the number, size, and/or shape of the fuel ports 106 and air ports 28 also may vary circumferentially 52 around each tube 26, axially along each tube 26, or any combination thereof. Furthermore, the number, size, and/or shape of the fuel ports 106 and air ports 28 also may vary from one tube 26 to another tube 26 among the plurality of mixing tubes 26. In this manner, the number, size, and/or shape of the fuel ports 106 and air ports 28 may be used to improve the fuel-air mixing in each tube 26, while adjusting for flow and pressure variations within the multi-tube fuel nozzle 12. This ability to vary the number, size, and/or shape of ports 28 and 106, particularly the air ports 28, enables tube-level air flow conditioning among the plurality of mixing tubes 26.

[0038] FIG. 7 is an illustration of a single mixing tube 26 separate from the fuel nozzle 12. In certain embodiments, the mixing tubes 26 may be removable from the fuel nozzle 12 for repair, inspection, or replacement. As discussed above, the mixing tubes 26 may be selectively removed and replaced within mixing tubes having alternate configurations of air ports 28 that may better compensate for pressure drops within the fuel nozzle 12. A method of removal and replacement of the mixing tubes 26 will be discussed in greater detail below. FIG. 7 additionally illustrates an entire mixing tube 26, with a first end 94, wherein the air ports 28 are generally located in some embodiments, and a second end 96, wherein the mixing tube 26 is coupled to the cap face assembly 60, retainer plate 84 and/or impingement plate 92. Each mixing tube 26 may further have any of a variety of shapes and sizes. In some embodiments, each mixing tube 26 may have a generally cylindrical shape, and may have a generally circular cross-section, for example. Additionally, in some typical embodiments, the mixing tube 26 may have a diameter of approximately 5 to 20 mm, 5 to 10 mm, 10 to 15 mm, and all subgroups therebetween. For example, a mixing tube 26 may have a diameter of 5, 10, 15, or 20 millimeters, or any other diameter. In certain embodiments, the mixing tube 26 may have a diameter of approximately 6.35 millimeters. It should be understood that all mixing tubes 26 within the combustor 16 may have a substantially similar diameter, but that in certain embodiments it may be advantageous for the mixing tubes 26 to have a variety of diameters. Furthermore, each mixing tube 26 may have an axial length of approximately 10 to 300 cm, 20 to 200 cm, 30 to 150 cm, or any incremental length or range within these ranges. For example, each mixing tube 26 may have an axial length of 10, 15, 20, 35, 30, 75, 80, 85, 90, or 150 cm, or any other length. In certain embodiments, the mixing tubes 26 within the combustor 16 may have substantially similar lengths, although in some embodiments the mixing tubes 26 may have two or more different lengths. Furthermore, the air flow conditioner 27 (e.g., air ports 28) may be located along any axial portion of each tube 26, such as within 0 to 10, 0 to 20, 0 to 30, 0 to 40, or 0 to 50 percent of the length of each tube 26 measured from the upstream end 94 of the tube 26. The air flow conditioner 27 also may include one or more groups of closely spaced air ports 28 at one or more axial regions along each tube 26.

[0039] FIG. 8 is a detailed view of the first end 94 of the mixing tube 26 of FIG. 7, illustrating one embodiment of the

air flow conditioner 27 (e.g., air ports 28) on a mixing tube 26. As discussed below, the air ports 28 may have a variety of shapes, sizes, orientations, numbers, and configurations. FIG. 8 illustrates a configuration with two sets 110 and 112 of elliptical air ports 28 arranged circumferentially 52 around the mixing tube 26, wherein the first set 110 of air ports 28 is located axially upstream 68 from the second set 112 of air ports 28. In this embodiment, the individual air ports 28 of the first set 110 have a cross-sectional area 114 that is substantially larger than the cross-sectional area 114 of the air ports 28 of the second set 112. The larger area 114 of the more downstream air ports 28 can compensate for the downstream drop in pressure experienced across the tubes 26 within the air plenum 78. In other embodiments, air ports 28 may be circular, teardrop shaped or rectangular in cross-sectional shape, or any other shape. Each illustrated set 110 and 112 of air ports 28 includes a plurality of rows 116 and 118 (e.g., two rows) of air ports 28 evenly spaced circumferentially 52 about the mixing tube 26, with the air ports 28 of the first row 116 being offset in the axial direction 48 and the circumferential direction 52 (e.g., staggered) from the air ports 28 in the second row 118. In some embodiments, subsequent rows 118 may not be circumferentially 52 offset (e.g., staggered), but may instead be circumferentially aligned (e.g., in an axial line) with previous rows 116 of air ports 28. In other embodiments, subsequent rows 118 may be partially offset from each other. In some embodiments, the air ports 28 may range in area 114 from about 1 square mm to 100 square mm, 10 square mm to 50 square mm, 25 square mm to 75 square mm, or any subgroup therebetween. For example, the individual air ports 28 may have an area of 1, 5, 10, 15, 20, 25, 30, 75, 80, 85, 90, 95, or 100 square millimeters, or any other area. In the illustrated embodiment, the air flow conditioner 27 includes two rows 116 and 118 of air ports 28 in two sets 110 and 112 of air ports 28. In other embodiments, the air flow conditioner 27 may include 1 to 1000, 2 to 500, 3 to 250, 4 to 100, or 5 to 25 or more sets and rows of air ports 28 with different sizes, shapes, orientations, patterns, or a combination thereof. For example, the air flow conditioner 27 may have 1 to 100 sets of differently sized air ports 28, wherein each set has 1 to 100 rows of equal or differently spaced, angled, or shaped air ports 28. By further example, the size, number, and/or angle of the air ports 28 may be the same, increase, and/or decrease in the axial direction 48 and/or the circumferential direction 52 along each mixing tube 26. In certain embodiments, the air ports 28 may gradually increase or decrease (or alternate) in diameter from one row to another along the mixing tube 26.

[0040] FIG. 9 is an embodiment of the air flow conditioner 27 (e.g., air ports 28) on the first end 94 of a mixing tube 26, wherein the air ports 28 are substantially the same shape and cross-sectional area 114. An embodiment of air ports 28 such as this may take advantage of an area where negligible pressure drop is expected in either the axial 48 or circumferential 52 directions. The air ports 28 of this embodiment are arranged in six rows 116. The axial 48 distance between each row 116 is equal and the air ports 28 of each row 116 are evenly circumferentially 52 spaced about the mixing tube 26. Additionally, each row 116 is fully offset from the next row 118, e.g., staggered in the circumferential direction 52.

[0041] FIG. 10 is cross-section of the mixing tube 26 of FIG. 9, taken through line 10-10 of FIG. 9. As illustrated, the air ports 28 are oriented directly inward toward a central axis 119 of the mixing tube 26, thereby enabling a radially inward injection of air into the mixing tube 26 as indicated by the

arrows. As discussed above, the compressed air 18 enters the mixing tubes 26 via the air plenum 78 of the fuel nozzle 12. The air 18 is directed into the air plenum 78 by a diffuser 86 and air inlet 70 in a substantially radially inward 74 direction. As the air 18 enters the mixing tubes 26, the air ports 28 of the air flow conditioner 27 help direct, distribute, and generally condition the air flow into the mixing tube 26 for improved mixing with the fuel 22 from the fuel injector 24. In this embodiment, the air ports 28 are parallel to the radial axis 48, and therefore impart no swirling motion to the air 18 entering the mixing tubes 26.

[0042] FIG. 11 is cross-section of the mixing tube 26 of FIG. 9, taken through line 11-11 of FIG. 9. As illustrated by the arrows, the air ports 28 are oriented radially inward toward, but offset from, the central axis 119 of the mixing tube 26. In other words, the air ports 28 are generally angled relative to the radial axis 50, as indicated by an angle 120, such that the air ports 28 impart a swirling flow in the circumferential direction 52 about the central axis 119 of the tube 26. As illustrated, the angle 120 of the air port 28 in relation to the radial axis 50 is greater than zero. The angle 120 of individual air ports 28 may range between approximately 0 to 45 degrees, 0 to 30 degrees, 15 to 45 degrees, 15 to 30 degrees, or any subgroup therebetween. For example, the angle 120 of some air ports 28 may be 5, 10, 15, 20, 25, 30, 35, 40, or 45 degrees, or any other angle, and the angle 120 of other air ports 28 may be 5, 10, 15, 20, 25, 30, 40 or 45 degrees, or any other angle. In some embodiments, air ports 28 may be configured to swirl the air in a clockwise direction, while other air ports 28 may be configured to swirl the air in a counterclockwise direction. This variation may be made based on the circumferential location of the individual mixing tube 26 in relation to the fuel nozzle 12 air inlet 70 to better capture the flow of compressed air 18 in the fuel nozzle 12 air plenum 78.

[0043] FIG. 12 is cross-section of the mixing tube 26 of FIG. 9, taken through line 12-12 of FIG. 9. As illustrated by the arrows, the air ports 28 are oriented radially inward toward, but offset from, the central axis 119 of the mixing tube 26. In other words, the air ports 28 are generally angled relative to the radial axis 50, as indicated by the angle 120, such that the air ports 28 impart a swirling flow in the circumferential direction 52 about the central axis 119 of the tube 26. In contrast to FIG. 11, the angle 120 of the air ports 28 in FIG. 12 is greater to provide a greater amount of swirling flow. That is, the angle 120 of the air port 28 in relation to a radial axis 50 is a larger value than of the angle 120 in FIG. 11. For example, the angle 120 of the air ports 28 may range between approximately 45 to 90 degrees, 60 to 90 degrees, 45 to 75 degrees, or 60 to 75 degrees, or any subgroup therebetween. It is also contemplated that individual air ports 28 within a set of air ports 28 may be configured with different angles 120 to customize the flow of compressed air 18 within the fuel nozzle 12. For example, in some embodiments, mixing tubes 26 installed within the fuel nozzle 12 in locations that are more radially outward and closer to the air inlet 70 may be configured to have air ports 28 that have greater angles 120 than the air ports on mixing tubes 26 located within the more radially inward locations within the fuel nozzle 12, further away from the air inlets 70. In some embodiments, air ports 28 on the mixing tubes 26 may be angled to direct the air in directions with an axial 48 component. That is, the air port 28 may be configured to direct the compressed air in a direction with a downstream 66 or upstream 68 component, for even greater control of the flow of compressed air 18 within the

mixing tubes 26. These variations in the angular configuration of the air ports 28 may compensate for variations of compressed air flow within the mixing tube 26, variations of injected fuel 22 dispersion from the fuel injectors 24, or other varying conditions of the environment within the fuel nozzle 12 that may affect the uniformity of the fuel-air mixture 30.

[0044] FIGS. 13-16 are perspective views of the fuel nozzle 12, illustrating a series of steps of a method for removing at least one mixing tube 26 in accordance with certain embodiments. As illustrated in FIG. 13, the multi-tube fuel nozzle 12 is removed from the head end 56 of the combustor 16 and coupled to the end cover assembly 58. Illustrated is the end cover assembly 58 with fuel inlet 62 coupled with the support structure 82 and cap face assembly 60. To access the mixing tubes 26, as illustrated in FIG. 14, the end cover assembly 58 is separated from the support structure 82 and cap face assembly 60. FIG. 14 reveals the fuel injectors 24 coupled to the end cover assembly 58 of the fuel nozzle 12. Next, as shown in FIG. 15, the retainer plate 84 is removed from the cap face assembly 60 by sliding the retainer plate 84 along the mixing tubes 26 in an upstream 68 direction from the second end 96 to the first end 94 of the mixing tubes 26. As shown in FIG. 16, the mixing tubes 26 may then be removed from their location on the cap face assembly 60. Removal of one or more mixing tubes 26 may allow for inspection, replacement, repair, or any other purpose found in the course of manufacturing, installation, and operation of the fuel nozzle 12. Installation of mixing tubes 26 is achieved by following the steps illustrated in FIGS. 13-16 in reverse order. Namely, the one or more mixing tubes 26 may be inserted in place on the cap face assembly 60 (FIG. 16), then the retainer plate 84 installed by sliding across the mixing tubes 26 from the first end 94 to the second end 96, until the tubes 26 are flush with the cap face assembly 60 and/or impingement plate 92 (FIG. 15). The support structure 82 is then coupled with the end cover assembly 58 by aligning the mixing tubes 26 with their respective fuel injectors 24 (FIG. 14). The assembled fuel nozzle 12 (FIG. 13) may then be installed into the head end 56 of the combustor 12.

[0045] Technical effects of the disclosed embodiments include systems and methods for improving the mixing of the air and the fuel within multi-tube fuel nozzles 12 of a gas turbine system. In particular, the fuel nozzle 12 is equipped with multiple mixing tubes 26 having air ports 28 (e.g., air flow conditioner 27) through which pressurized compressed air 18 that enters the fuel nozzle 12 is directed and mixes with fuel 22 injected by multiple fuel injectors 24. The air ports 28 may be configured with different shapes, sizes, spatial arrangements, and configured to direct the air at various angles. This customization increases mixing and uniformity, compensating for the varying air 18 and fuel 22 pressures among the multiple fuel injectors 24 in the multi-tube fuel nozzle 12. The increased mixing of the air 18 and the fuel 22 increases the flame stability within the combustor 16 and reduces the amount of undesirable combustion byproducts. The method of removal and replacement of individual mixing tubes 26 allows for cost-effective and efficient repair of the fuel nozzle 12.

[0046] Although some typical sizes and dimensions have been provided above in the present disclosure, it should be understood that the various components of the described combustor may be scaled up or down, as well as individually adjusted for various types of combustors and various applications. This written description uses examples to disclose embodiments of the invention, including the best mode, and

also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

- 1. A system, comprising:  
a multi-tube fuel nozzle, comprising:  
a plurality of tubes, wherein each tube comprises:  
a first end;  
a second end;  
an annular wall disposed about a central passage, wherein the first end is configured to be disposed about a fuel injector; and  
an air flow conditioner having a plurality of air ports disposed adjacent the first end, wherein the plurality of air ports extend through the wall into the central passage.
- 2. The system of claim 1, wherein the plurality of air ports are circumferentially arranged about the annular wall.
- 3. The system of claim 2, wherein the plurality of air ports comprises a first set of air ports and a second set of air ports, wherein the second set of air ports are located downstream of the first set of air ports relative to the first end.
- 4. The system of claim 3, wherein a first total area of each air port of the first set of air ports is larger than a second total area of each air port of the second set of air ports.
- 5. The system of claim 3, wherein the first set of air ports comprises a first row and a second row of air ports circumferentially arranged about the annular wall, and the first row of air ports are offset from the second row of air ports in a circumferential direction.
- 6. The system of claim 5, wherein the second set of air ports comprises a third row and a fourth row of air ports circumferentially arranged about the annular wall, and the third row of air ports are offset from the fourth row of air ports in the circumferential direction.
- 7. The system of claim 3, wherein the first set of air ports is configured to guide air flow in a radial direction into the central passage.
- 8. The system of claim 7, wherein the second set of air ports is configured to guide the air with a swirling motion about a central axis of the central passage.
- 9. The system of claim 1, wherein the plurality of air ports comprise a plurality of sizes, shapes, angles, spacings, or any combination thereof.
- 10. The system of claim 1, wherein each tube of the plurality of tubes is configured to receive an equal distribution of air flow via the air flow conditioner.
- 11. The system of claim 1, comprising a gas turbine engine or a combustor having the multi-tube fuel nozzle.

- 12. A system, comprising:  
a combustor end cover assembly;  
a multi-tube fuel nozzle coupled to the combustor end cover assembly, comprising:  
a retainer plate; and  
a plurality of tubes disposed between the end cover assembly and the retainer plate, wherein each tube comprises:  
a first end adjacent the end cover assembly;  
a second end adjacent the retainer plate;  
an annular wall disposed about a central passage, wherein the first end is configured to be disposed about a fuel injector; and  
an air flow conditioner having a plurality of air ports disposed adjacent the first end, wherein the plurality of air ports extend through the wall into the central passage.
- 13. The system of claim 12, wherein each tube of the plurality of tubes is configured to be individually removed from or installed between the end cover assembly and the retainer plate.
- 14. The system of claim 13, wherein the retainer plate is configured to be removed from the multi-tube fuel nozzle by sliding the retainer plate along the plurality of tubes from the first end to the second end of each tube upon removal of the end cover assembly.
- 15. The system of claim 12, wherein the plurality of air ports are circumferentially arranged about the annular wall.
- 16. The system of claim 15, wherein the plurality of air ports comprises a first set of air ports and a second set of air ports, wherein the second set of air ports are located downstream of the first set of air ports relative to the first end.
- 17. The system of claim 16, wherein a first total area of each air port of the first set of air ports is larger than a second total area of each air port of the second set of air ports.
- 18. The system of claim 16, wherein the first set of air ports is configured to guide air flow in a radial direction into the central passage.
- 19. The system of claim 18, wherein the second set of holes is configured to guide the air with a swirling motion about a central axis of the central passage.
- 20. A system, comprising:  
a combustor end cover assembly;  
a multi-tube fuel nozzle coupled to the combustor end cover assembly, comprising:  
a retainer plate; and  
a tube disposed between the end cover assembly and the retainer plate, wherein the tube comprises:  
a first end adjacent the end cover assembly;  
a second end adjacent the retainer plate;  
an annular wall disposed about a central passage, wherein the first end is configured to be disposed about a fuel injector; and  
an air flow conditioner having a plurality of air ports disposed adjacent the first end, wherein the plurality of air ports extend through the wall into the central passage.

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