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

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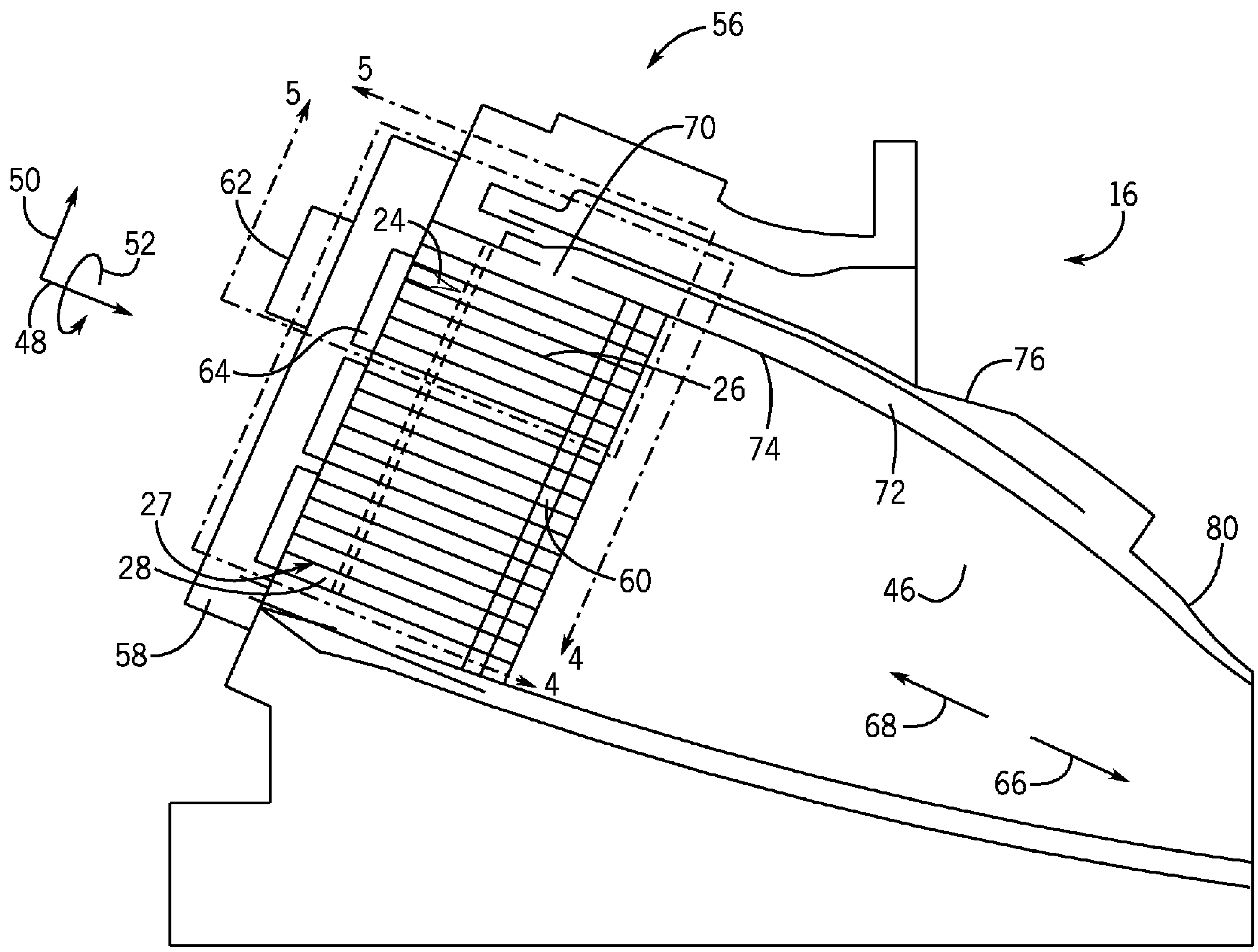
(57) **ABSTRACT**

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.



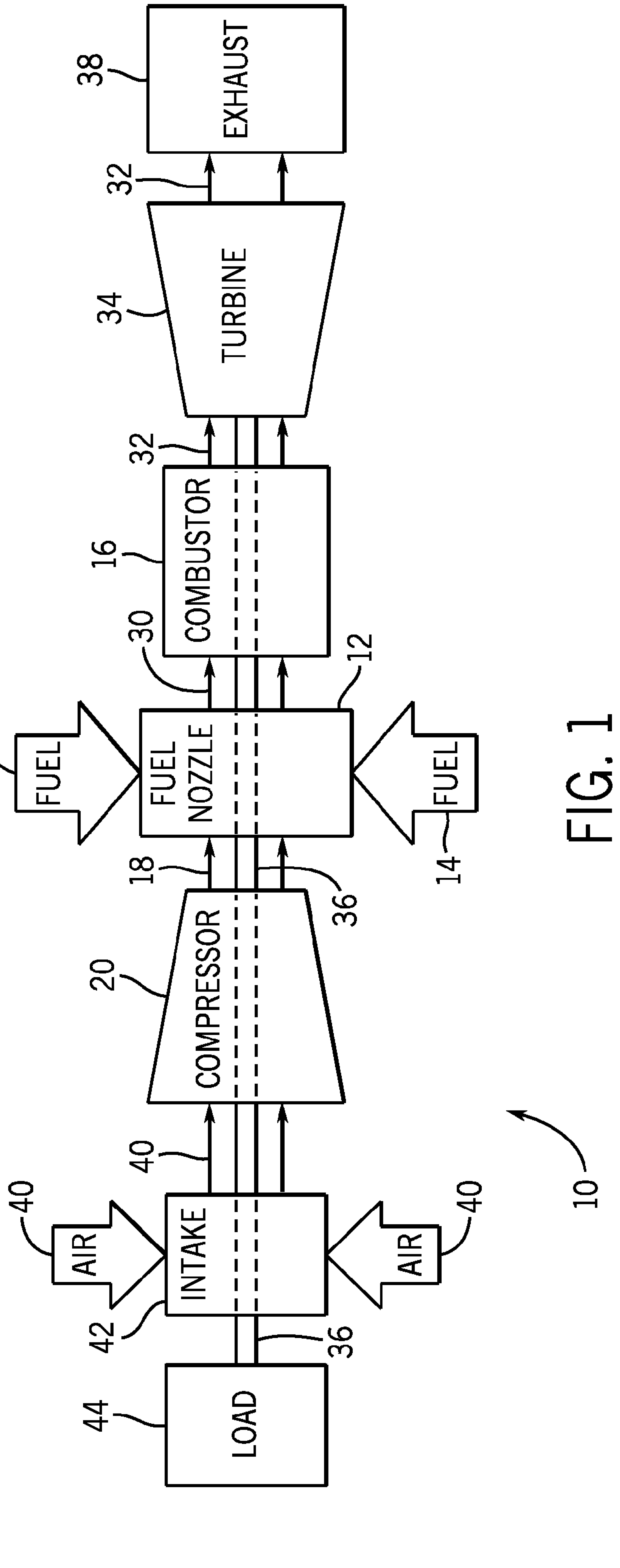

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FIG. 1

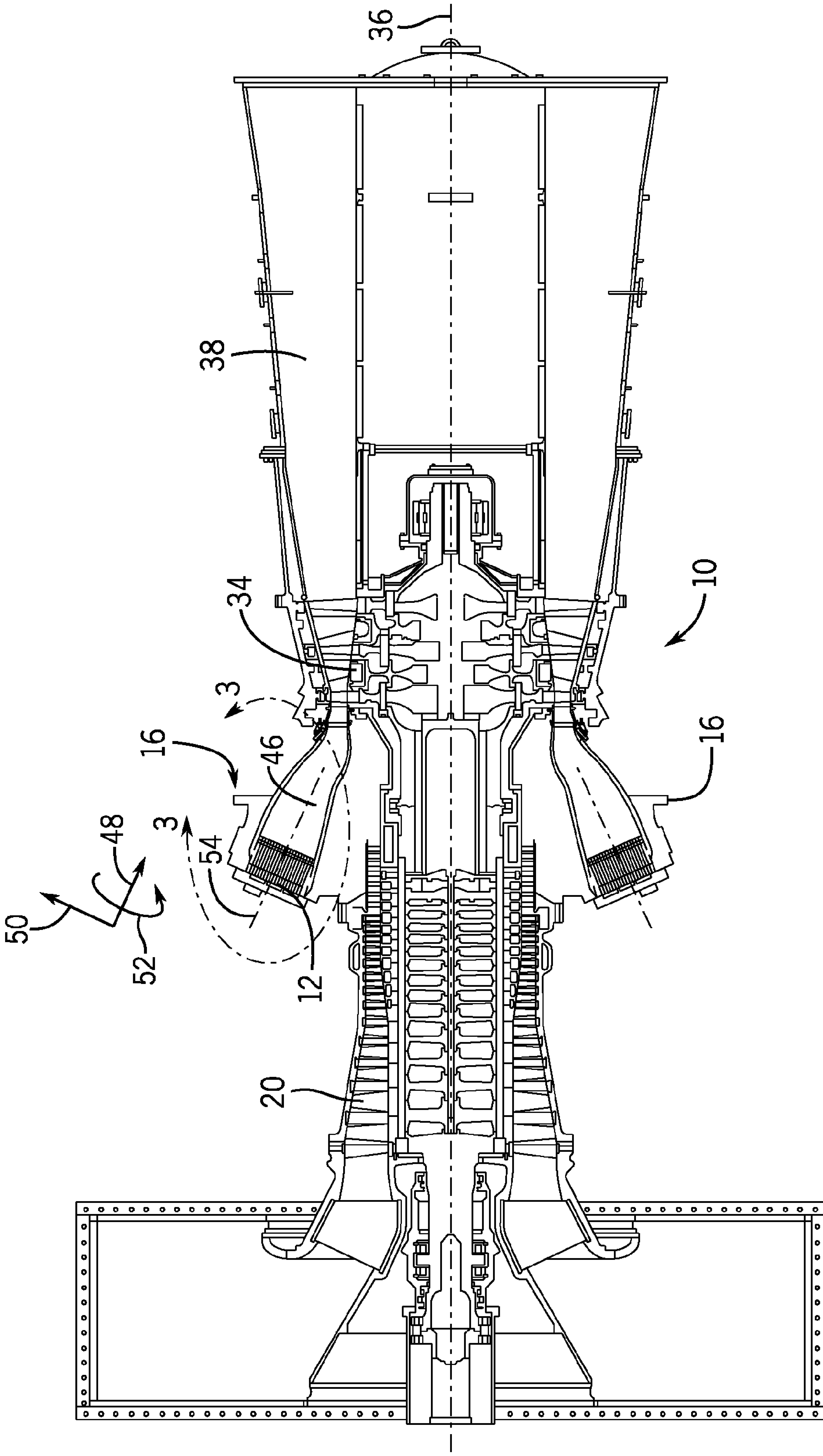
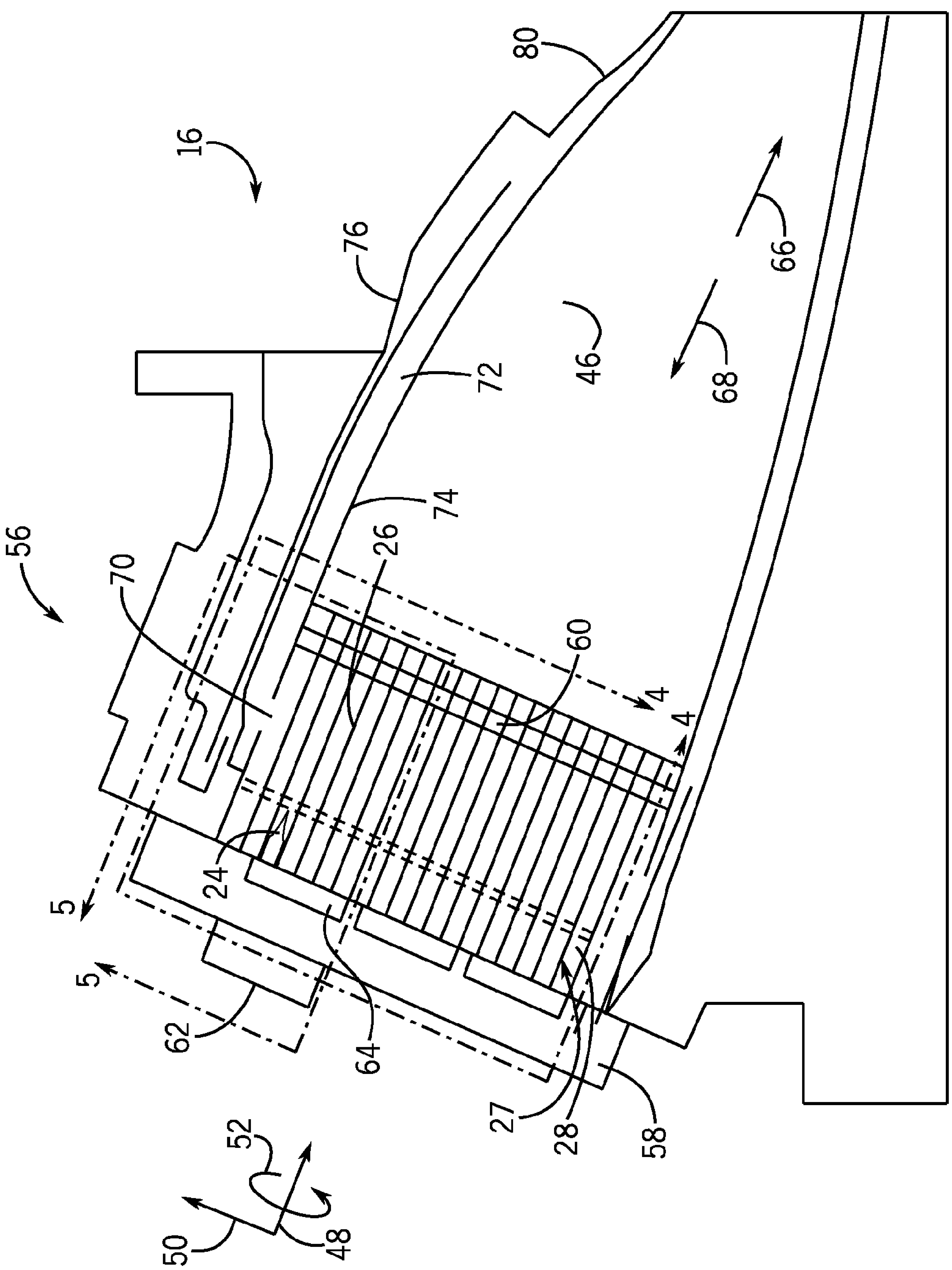


FIG. 2

FIG. 3



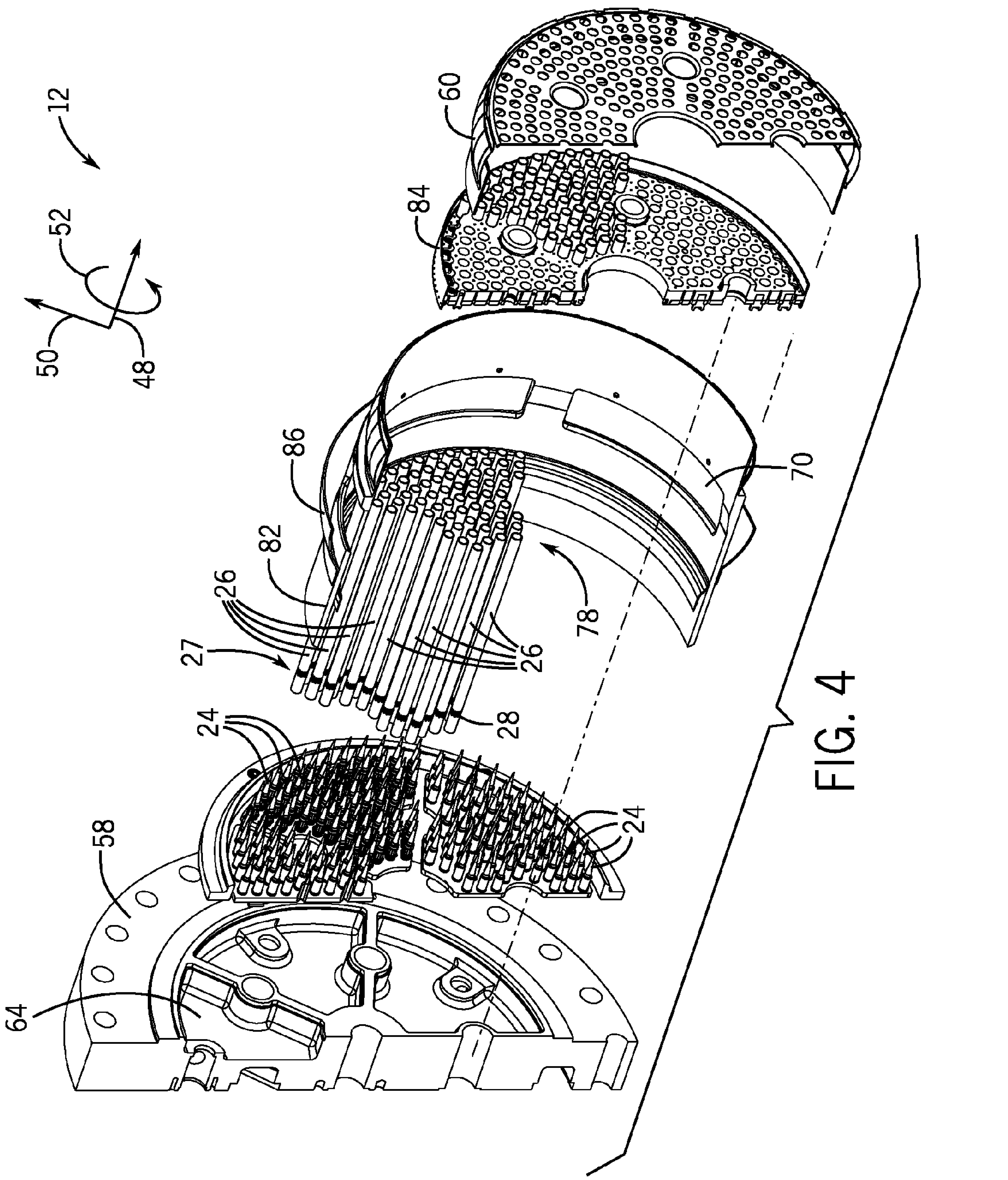


FIG. 4

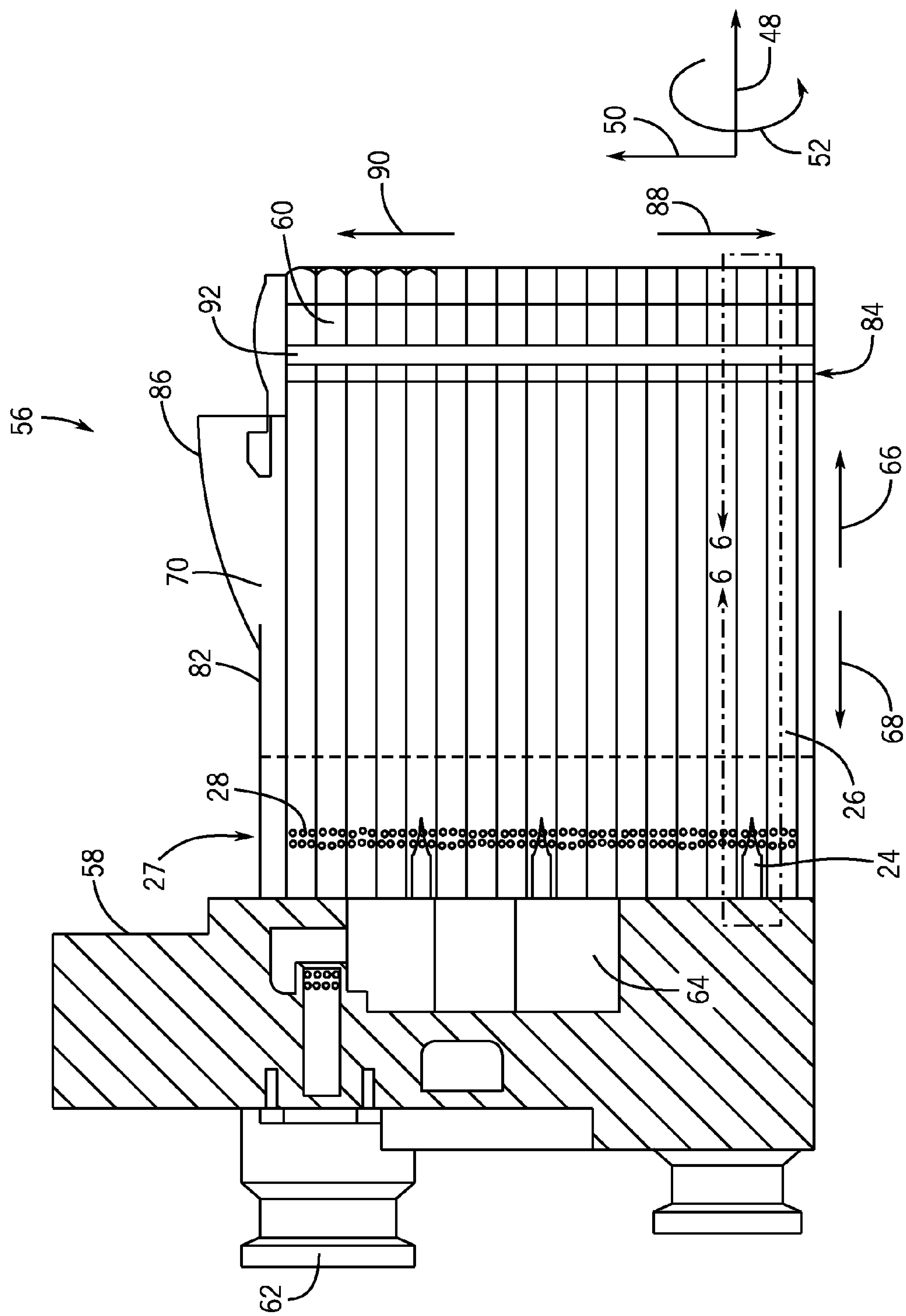


FIG. 5

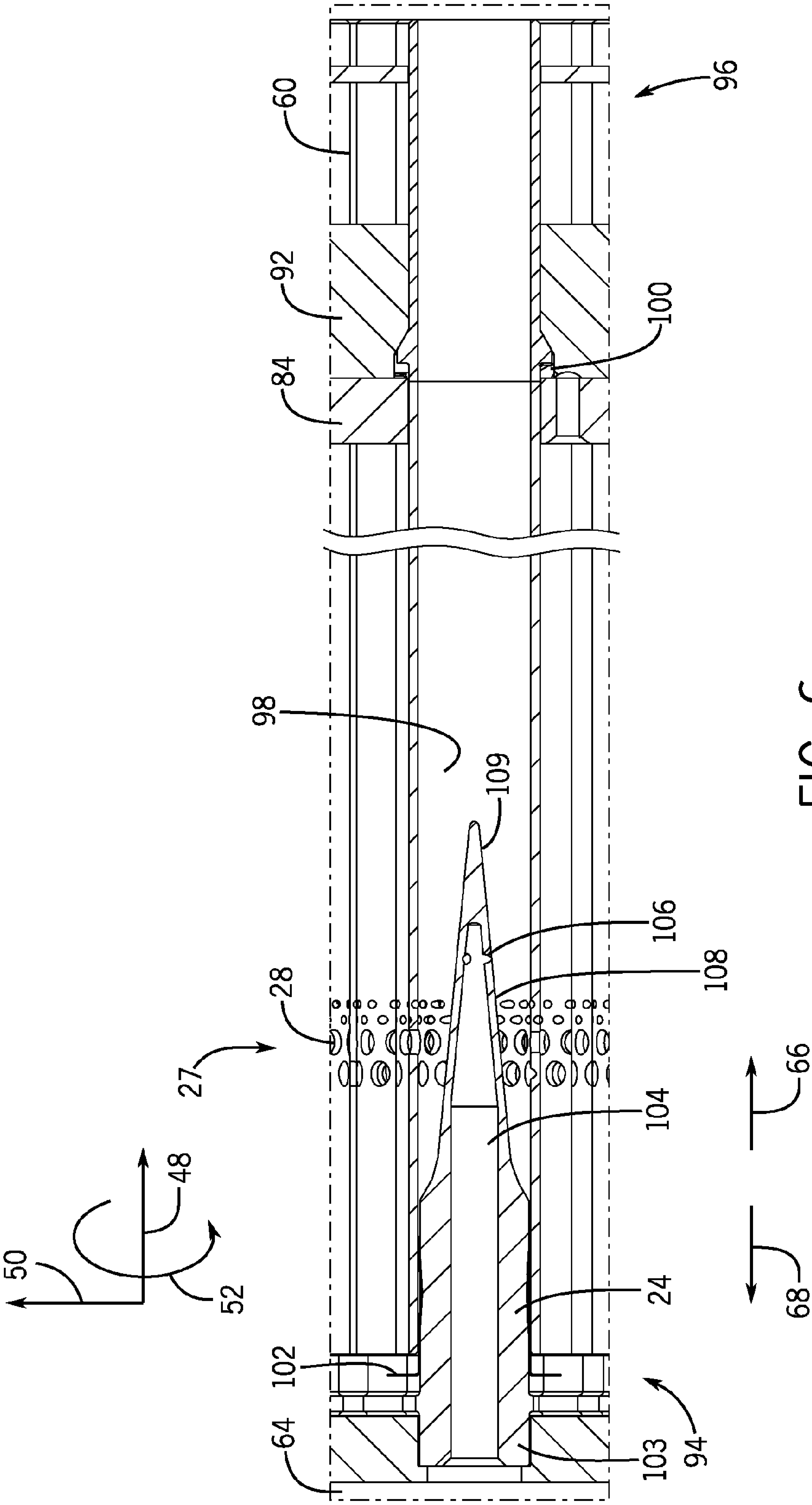

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FIG. 6

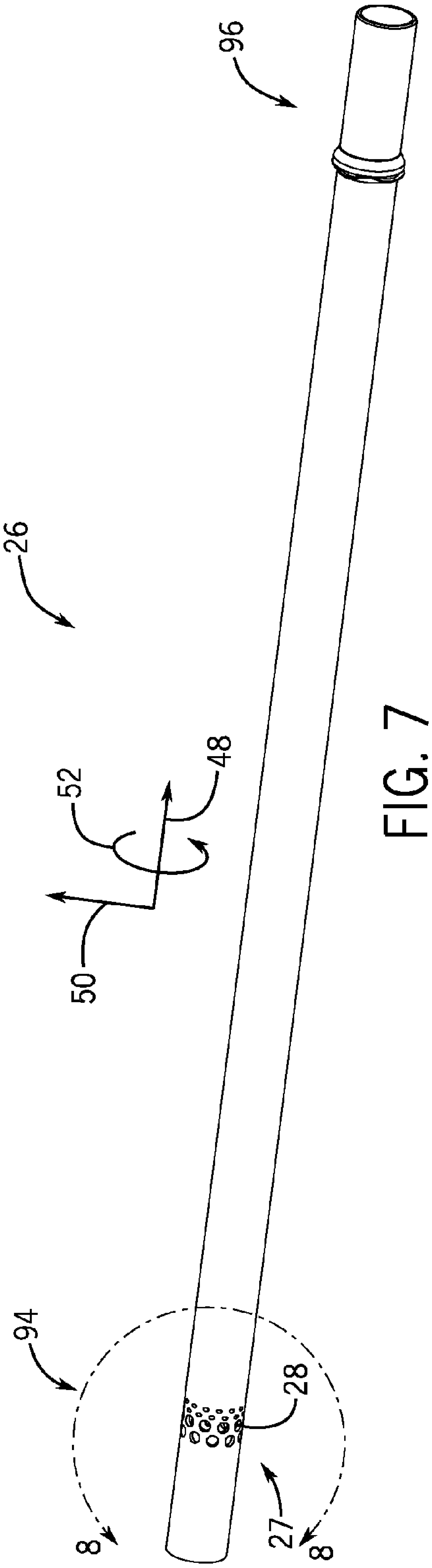

FIG. 7

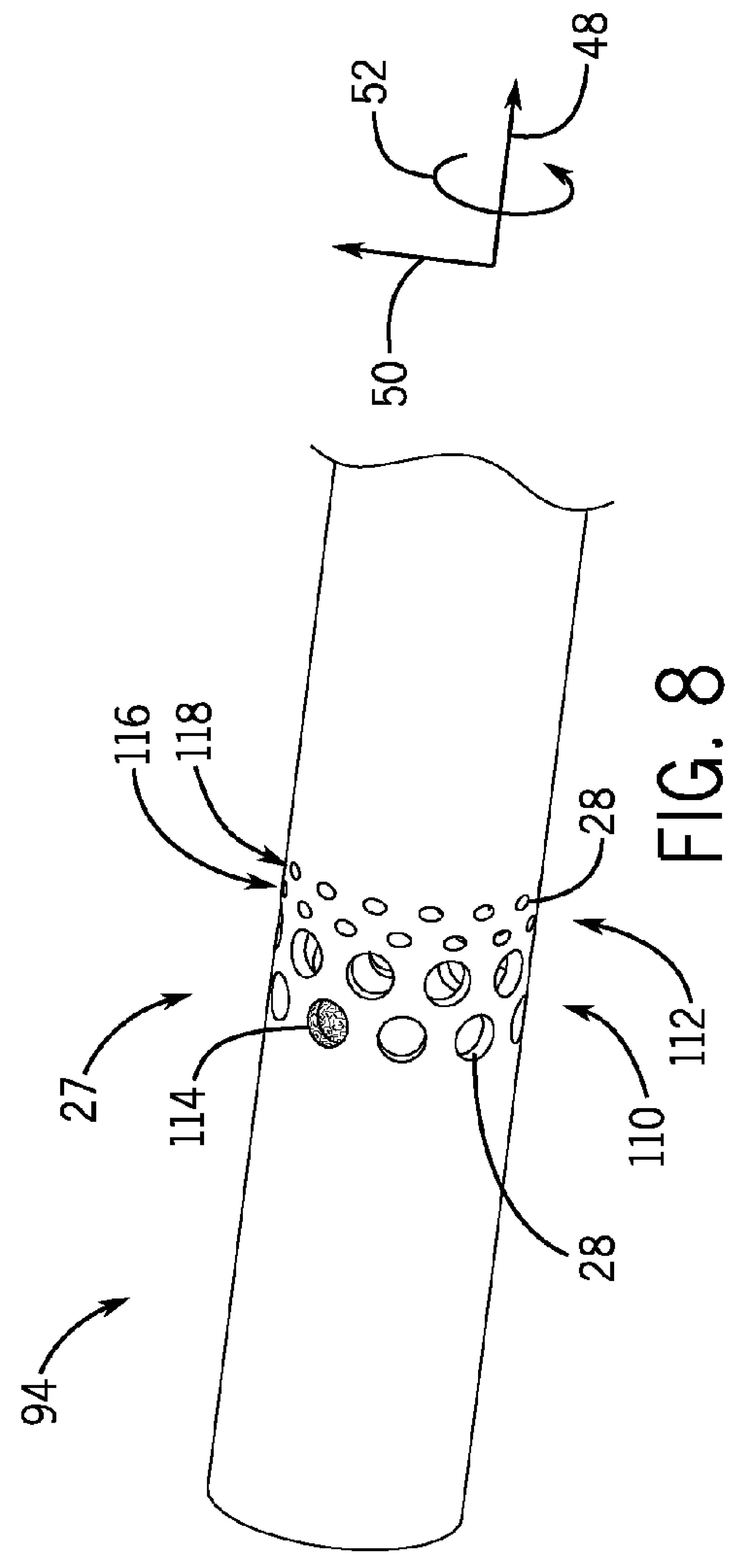

FIG. 8

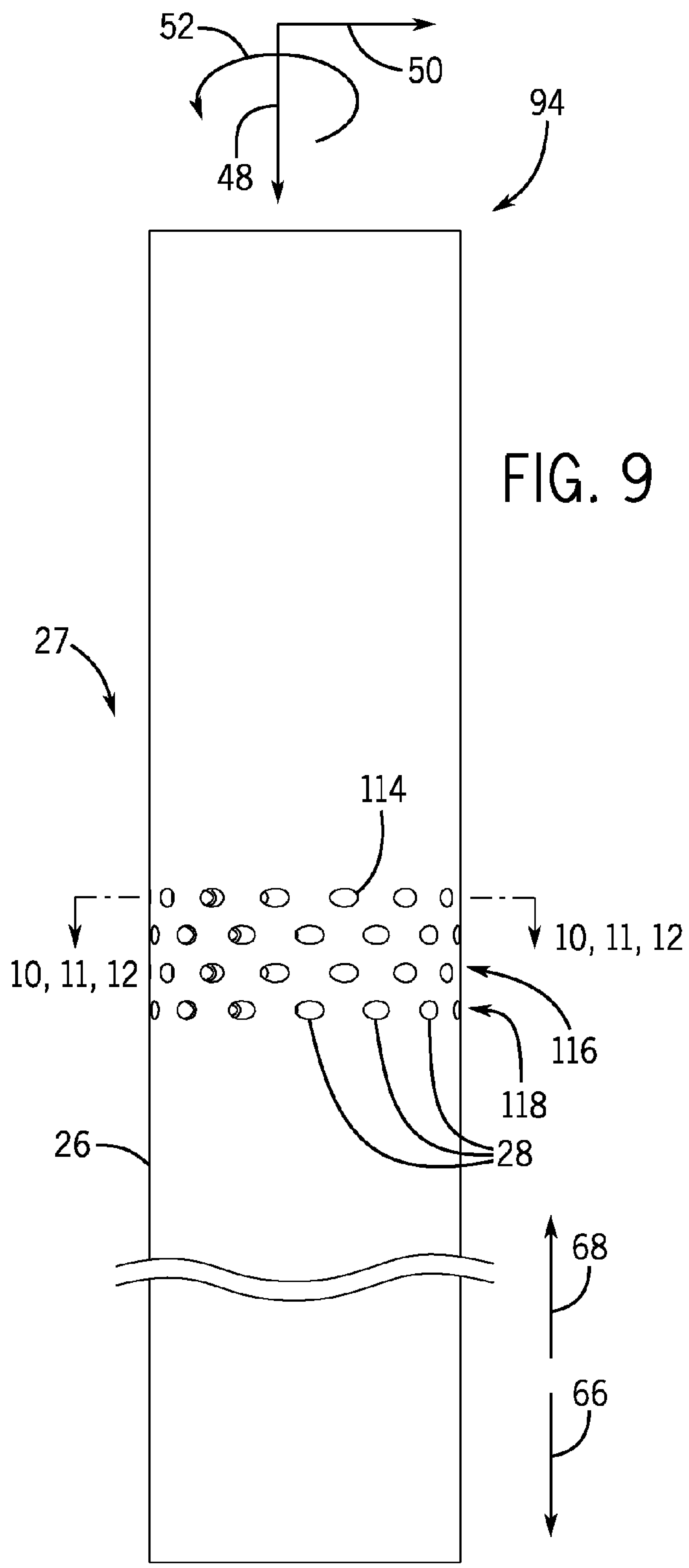

FIG. 9

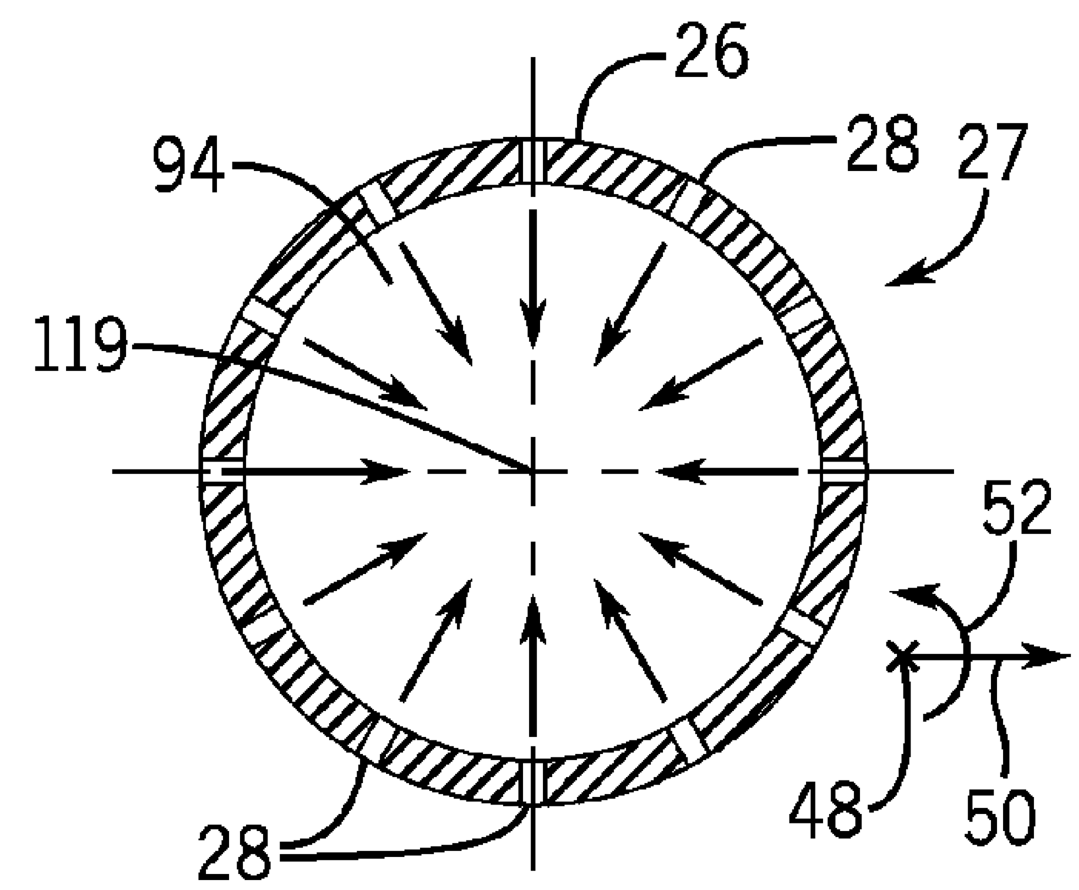

FIG. 10

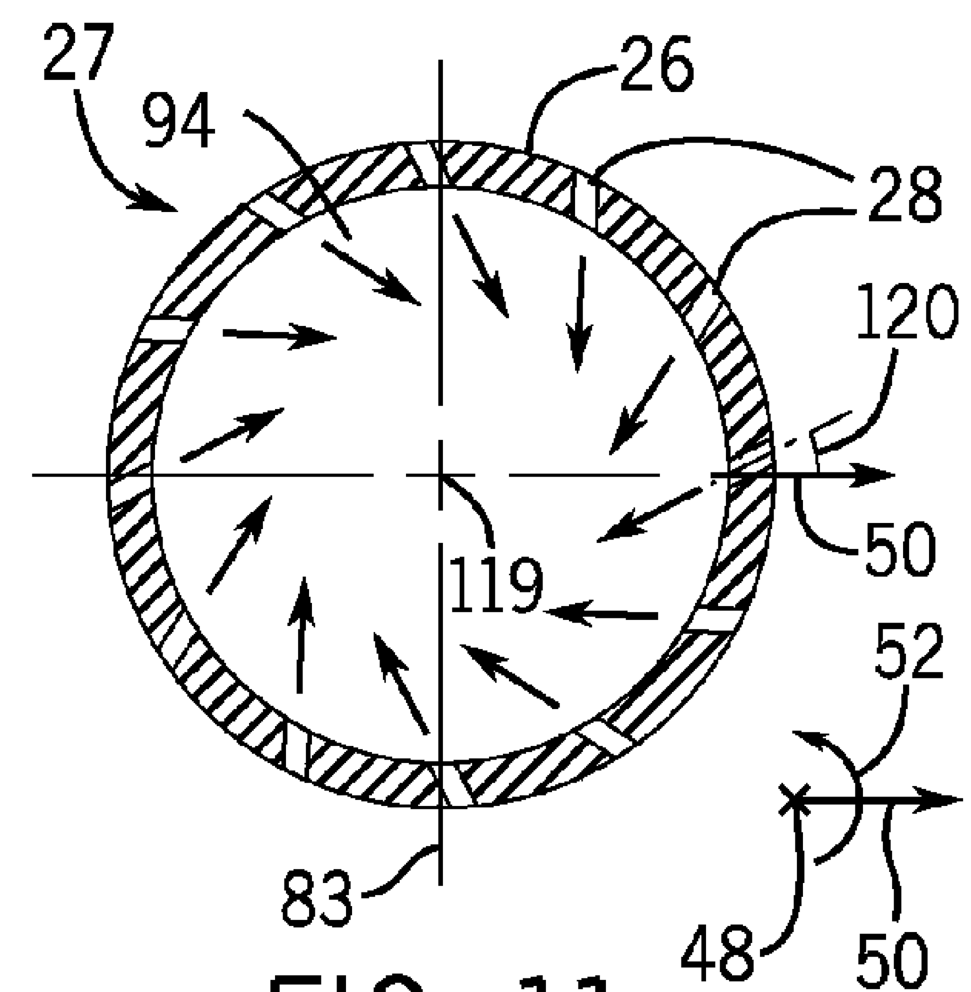

FIG. 11

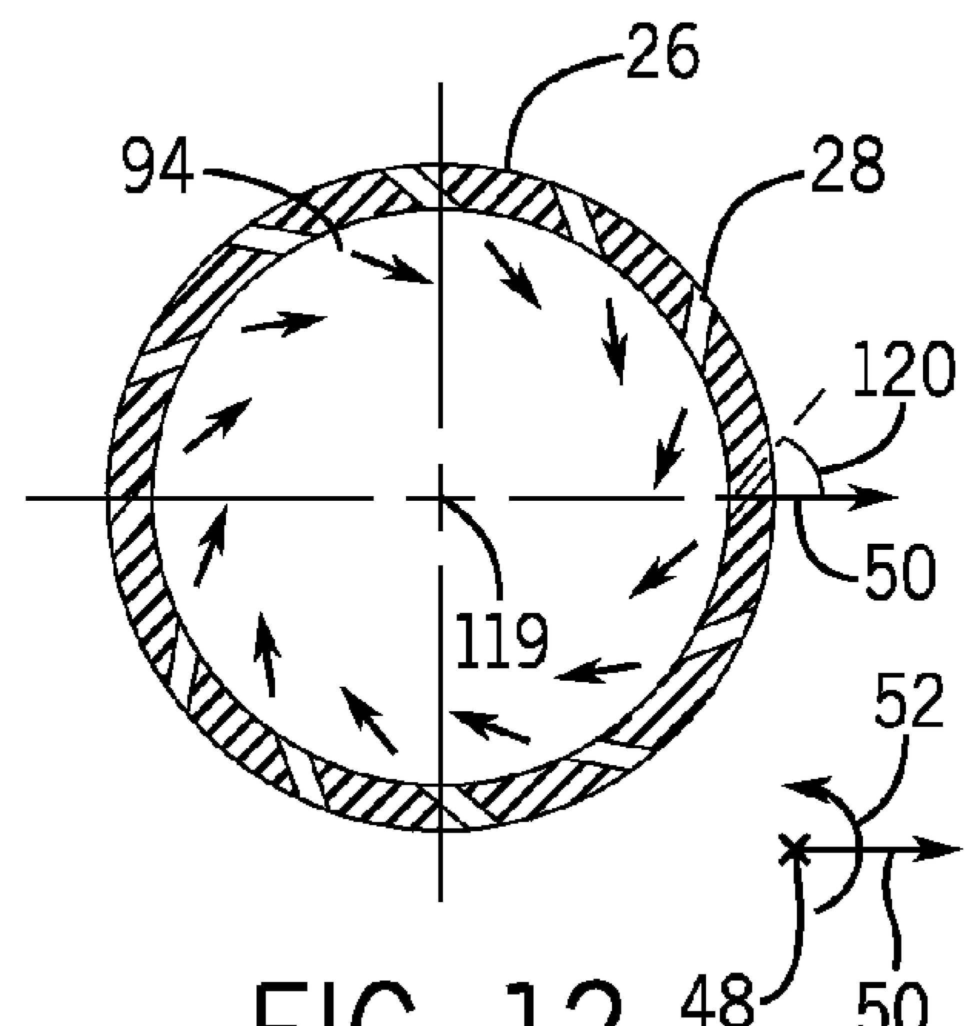

FIG. 12

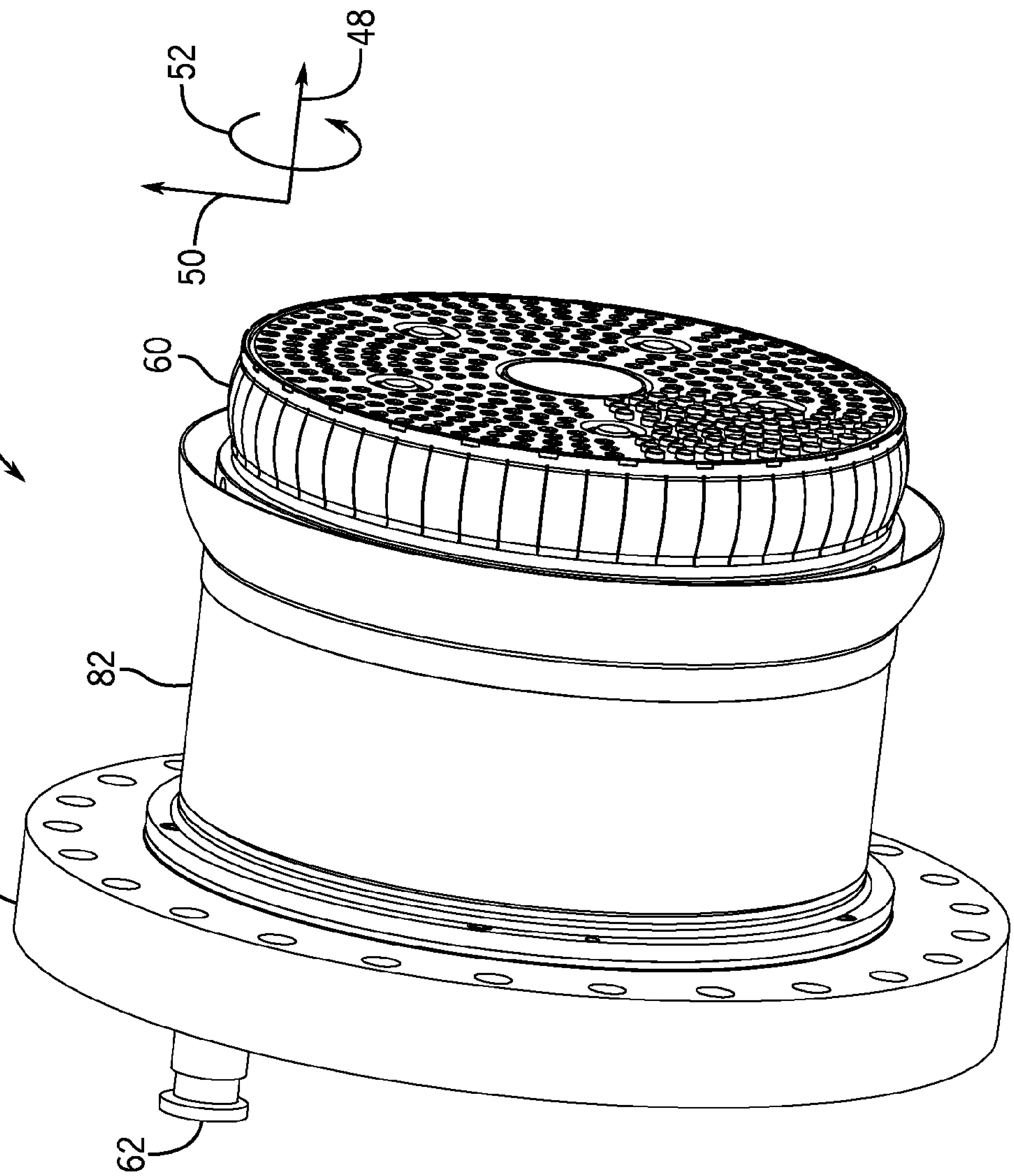

FIG. 13

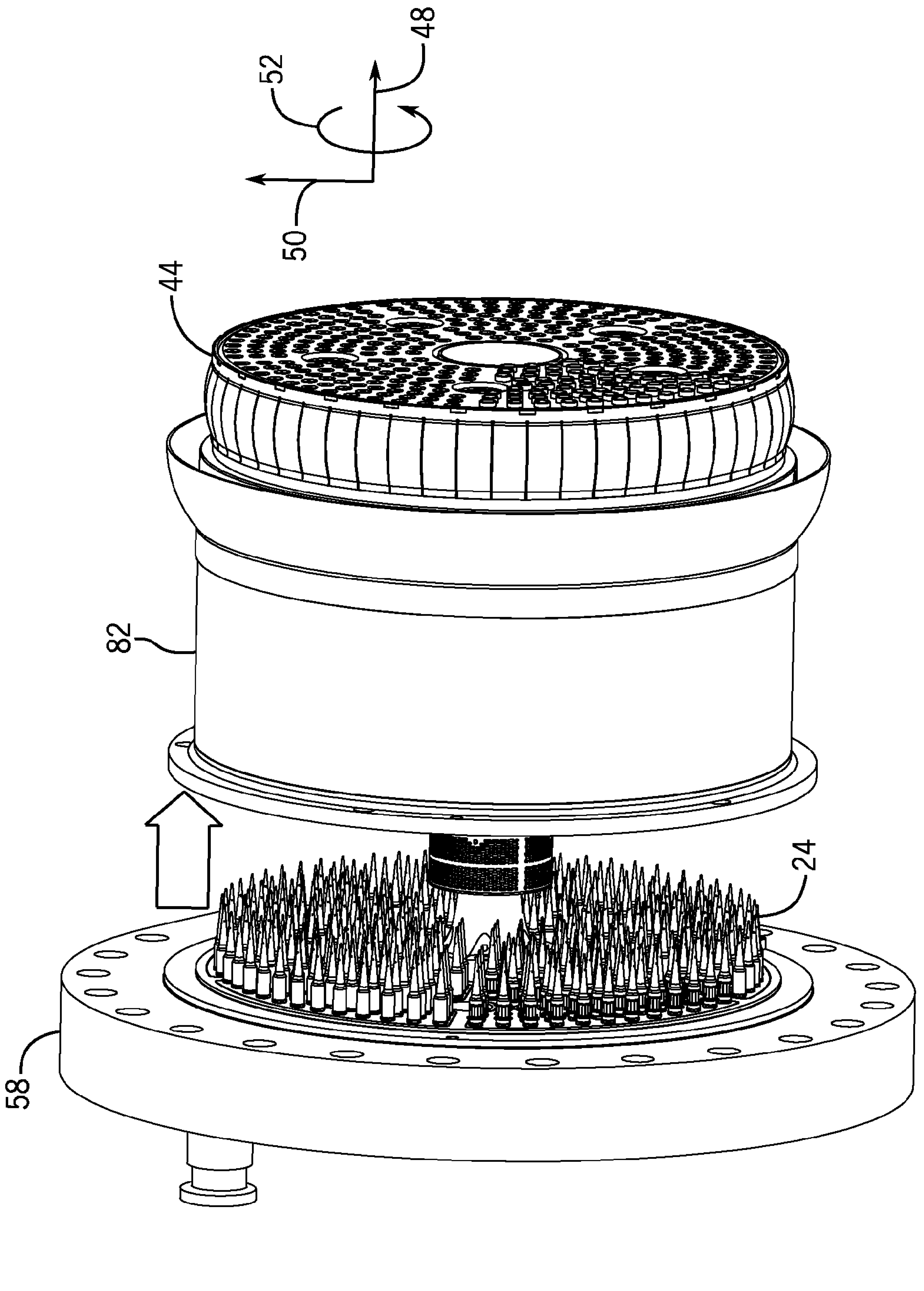

FIG. 14

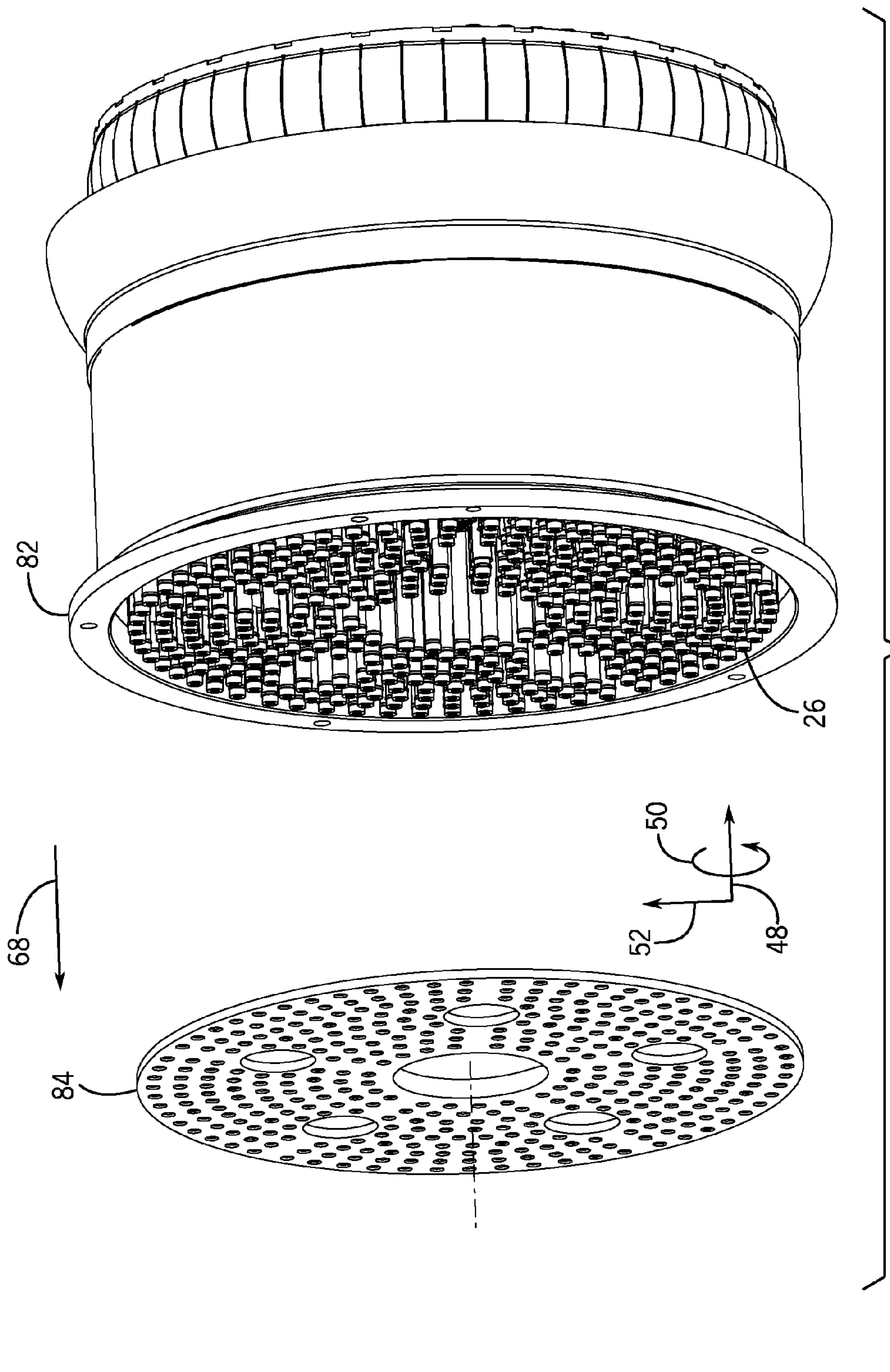

FIG. 15

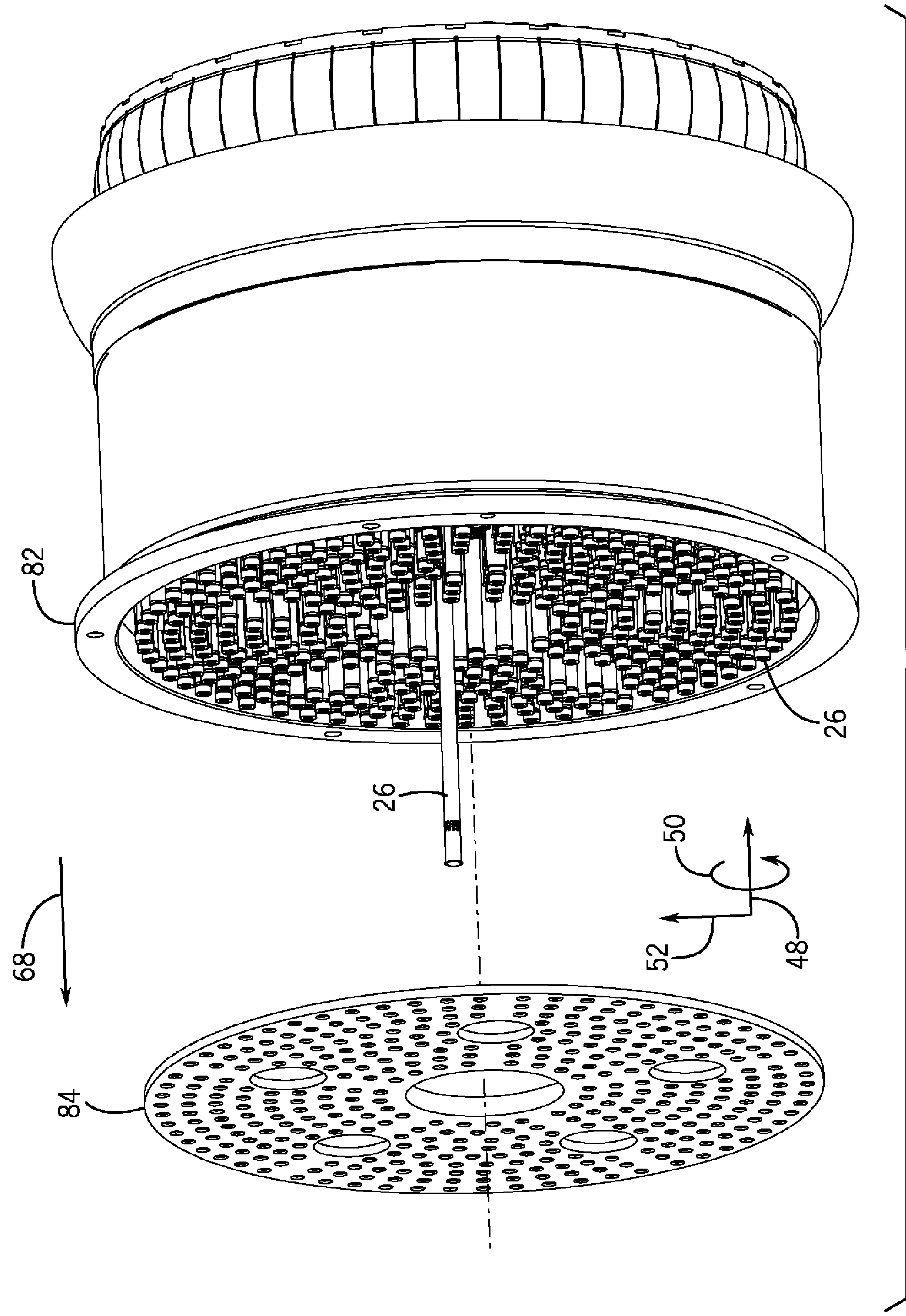

FIG. 16

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 respective 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., and 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 impingement 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 vies 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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