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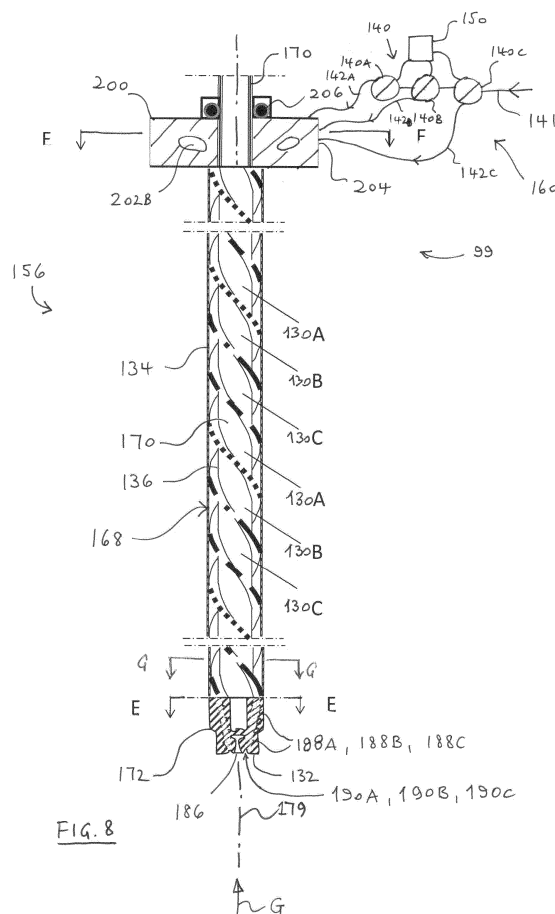
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(54) **Pilot liquid fuel lance, pilot liquid fuel system and method of use**

(57) A liquid fuel lance 156 for a burner 30 of a combustor 10 of a gas turbine combustor, a liquid fuel system incorporating the liquid fuel lance and a method of operating the liquid fuel system are disclosed. The liquid fuel lance 156 comprises an elongate liquid fuel lance body 168 and a liquid fuel tip 172. The elongate liquid fuel lance body 168 comprises a fuel flow passage 170 and at least a first air passage 130A and a second air passage 130B, 130C. A liquid fuel tip 172 defines a fuel outlet 186 and arranged about the fuel outlet 186 at least a first outlet 190A and a second outlet 190B, 190C to which air is independently supplied by the first air passage 130A and the second air passage 130B, 130C respectively, and wherein the amount of air supplied to the first air passage 130A is variable.



Description

FIELD OF INVENTION

[0001] The present invention relates to combustion equipment of a gas turbine engine and in particular a pilot liquid fuel lance and a pilot liquid fuel system for a burner arrangement of the combustion equipment, and a method of operating the pilot liquid fuel system.

BACKGROUND OF INVENTION

[0002] Gas turbines including dry low emission combustor systems can have difficulty lighting and performing over a full load range when using liquid fuels. Often this can be because of fuel placement and subsequent atomization of the fuel in mixing air flows particularly at low loads and engine start-up. Ideally, the fuel droplets need to be very small and injected into an appropriate part of the airflow entering the combustor's pre-chamber in the vicinity of a burner arrangement to burn in the correct flame location. Also the fuel droplets should not contact any wall surface but at the same time the fuel droplets need to be delivered close enough to the igniter so that the igniter can ignite the vaporised fuel particularly on start up. If the fuel droplets contact a surface this can lead to carbon deposits building up or lacquers forming and which can alter airflow characteristics or even block air and/or fuel supply holes.

[0003] The liquid pilot injection lance can have additional air assistance to aid atomisation of the liquid fuel over a range of fuel flows. This air assistance can be a supplied via a number of air outlets completely surrounding a fuel orifice or filmer. This liquid pilot injection lance is in a region prone to liquid fuel contact and as a result tends to incur carbon deposits. These carbon deposits block the air assistance holes and subsequently prevent successful atomisation of the fuel. Poor atomisation of the pilot fuel also causes problems with ignition of the fuel at start-up. The carbon deposits can even prevent the engine from restarting. Further, carbon deposits can lead to liquid fuel being injected against the combustor walls or burn in the wrong place and which can lead to burn out of components. This is a common fault with gas turbine fuel injection systems and carbon build up is a common problem. Consequently, liquid pilot injection lances are regularly replaced and are considered a consumable part. This is undesirable because such replacement is expensive, causes the gas turbine to be off-line halting supply of electricity or power for example, and can be unscheduled.

SUMMARY OF INVENTION

[0004] One objective of the present invention is to prevent carbon deposits forming on components. Another objective is to prevent carbon deposits forming on a fuel lance of a combustor. Another objective is to improve the

reliability of igniting the fuel in a combustor. Another objective is to improve the entrainment of fuel droplets in an air flow. Another objective is to improve the atomisation of liquid fuel in a combustor. Another objective is to prevent liquid fuel contacting a surface within the combustor. Another objective is to reduce or prevent scheduled or unscheduled shut down of the engine for maintenance attributed to replacing or cleaning combustor components subject to carbon deposits and particularly the liquid fuel lance. Another objective is to increase the service life of the liquid lance. It is another objective to enable the fuel lance closer to the igniter and make ignition more reliable.

[0005] For these and other objectives and advantages there is provided a liquid fuel lance for a burner of a combustor of a gas turbine combustor, the liquid fuel lance has a longitudinal axis and comprises an elongate liquid fuel lance body and a liquid fuel tip, the elongate liquid fuel lance body comprises a fuel flow passage and at least a first air passage and a second air passage, a liquid fuel tip defines a fuel outlet and arranged about the fuel outlet at least a first outlet and a second outlet to which air is independently supplied by the first air passage and the second air passage respectively, and wherein the amount of air supplied to the first air passage is variable.

[0006] The first air passage and the second air passage may extend approximately parallel to the longitudinal axis.

[0007] The first air passage and the second air passage may be helical about the longitudinal axis.

[0008] The first air passage and the second air passage may be helical about the longitudinal axis at least 180°.

[0009] The first air outlet may extend about the axis an angle in the range and including 30° and 160°.

[0010] The first air outlet may extend about the axis an angle of 120°.

[0011] The at least a first outlet and the second outlet and the first air passage and the second air passage may constitute a first air assist supply, and a second air assist supply may comprise at least first outlet and second outlet to which air is independently supplied by a first air passage and a second air passage respectively, and wherein the amount of air supplied to the first air passage of the second air assist supply is variable.

[0012] In a second embodiment of the present invention there is provided a liquid fuel system comprising the liquid fuel lance as described above and an air supply control arrangement, the air supply control arrangement having a valve means and a valve controller arranged to control the valve means, the valve means is arranged to operate at least the first air passage between a closed and an open position.

[0013] The valve means may be arranged to operate at least the second air passage between a closed and an open position.

[0014] The valve means may comprise at least a first valve arranged to vary air flow into the at least the first

air passage and a second valve arranged to operate the second air passage, wherein the first and second valves are in series with one another.

[0015] The valve means may comprise at least a first valve arranged to vary air flow into the at least the first air passage and a second valve arranged to operate the second air passage, wherein the first and second valves are in parallel with one another.

[0016] In a third aspect of the present invention there is provided a method of operating the liquid fuel system as described above wherein the method comprises the step of supplying a total air flow to the at least first air passage and second air passage, adjusting the valve means to supply the first air passage with 5% to 25% of the total air flow.

[0017] The liquid fuel system may comprise a plurality of liquid fuel injectors, the method comprises the step of adjusting the valve means to supply the first air passages with 5% to 25% of the total air flow to the plurality of liquid fuel injectors.

[0018] The method may comprise the step of adjusting the valve means to supply the first air passage with 5% to 25% of the total air flow during engine start-up or weak extinction.

[0019] The method may comprise the step of adjusting the valve means to supply the first air passage with approximately equal amounts of the total air flow during normal engine running.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] Further features, properties and advantages of the present invention will become clear from the following description of embodiments in conjunction with the accompanying drawings.

FIG. 1 is a schematic illustration of part of a turbine engine in a sectional view in which the present invention may be incorporated,

FIG. 2 shows a perspective schematic view of a section of a combustor unit of the turbine engine and in detail a burner arrangement including a pilot burner surrounded by a main burner, the pilot burner having an igniter and a conventional liquid fuel lance, however, the conventional liquid fuel lance may be replaced with a pilot fuel system including a liquid fuel lance in accordance with present invention,

FIG. 3 shows a schematic perspective and cut-away view of part of the pilot burner and in detail the conventional liquid fuel lance which may be replaced with a pilot fuel system including a liquid fuel lance in accordance with present invention,

FIG. 4 is a view along a combustor axis and onto the surface of the burner where the pilot burner is generally surrounded by the main burner having a pilot

fuel system including a liquid fuel lance in accordance with present invention,

FIG.5 and FIG.6 show sectional views of the main air flow along paths A-A and B-B respectively as shown in FIG.4 and illustrates respective distributions of fuel droplets issuing from the liquid fuel lance in accordance with the present invention,

FIG. 7 is a view on a tip of the conventional liquid fuel lance and generally along its axis showing an array of outlets arranged symmetrically around a fuel outlet; the array of outlets directs a pilot air flow to impinge on, shearing and atomizing a liquid fuel film; the pilot fuel/air vortex formed rotates clockwise,

FIG. 8 is a section through part of the liquid fuel lance in accordance with an exemplary embodiment of the present invention,

FIG.9 is a section E-E shown in FIG.8 of a tip of the liquid fuel lance and generally along its axis showing an array of air outlets arranged around a fuel outlet in accordance with the present invention,

FIG.10 is a section F-F shown in FIG.8 of an air inlet plate for guiding air into the air assist passages of the liquid fuel lance;

FIG.11 is a first schematic valve and controller arrangement of the pilot fuel system which controls the supply of air into the air assist passages of the liquid fuel lance, in this exemplary embodiment the valves are in series on a main supply pipe;

FIG.12 is a second schematic valve and controller arrangement of the pilot fuel system which controls the supply of air into the air assist passages of the liquid fuel lance, in this exemplary embodiment the valves are in parallel on a main supply pipe;

FIG.13 is a third schematic valve and controller arrangement of the pilot fuel system which controls the supply of air into the air assist passages of the liquid fuel lance, in this exemplary embodiment the valve is a pneumatic split spool valves, one of which is available from Bosch Roxroth Corporation®;

FIG.14 is a view in the direction of arrow G in FIG.8 and onto the surface of the tip of the pilot liquid fuel lance in accordance with the present invention;

FIG.15 is a view on the surface of the burner and along the burner's central axis and indicates the orientation of the liquid fuel lance relative to the main air flow from the main burner and relative to the burner's central axis and in accordance with the present invention,

FIG. 16 depicts a further embodiment of the inventive fuel lance and is an equivalent section G-G shown in FIG. 8,

FIG. 17 is a schematic view on the tip of another embodiment of the liquid fuel lance which further comprises a second air assist supply generally surrounding the first air assist supply,

FIG. 18 is a view on the tip of the liquid fuel lance in FIG. 15.

DETAILED DESCRIPTION OF INVENTION

[0021] FIG. 1 shows an example of a gas turbine engine 10 in a sectional view and generally arranged about a longitudinal axis 20. The gas turbine engine 10 comprises, in flow series, an inlet 12, a compressor section 14, a combustor section 16 and a turbine section 18 which are generally arranged in flow series and generally in the direction of the longitudinal or rotational axis 20. The gas turbine engine 10 further comprises a shaft 22 which is rotatable about the rotational axis 20 and which extends longitudinally through the gas turbine engine 10. The shaft 22 drivingly connects the turbine section 18 to the compressor section 12. The combustor section 16 comprises an annular array of combustor units 16 only one of which is shown.

[0022] In operation of the gas turbine engine 10, air 24, which is taken in through the air inlet 12 is compressed by the compressor section 14 and delivered to the combustion section or unit 16. The combustor unit 16 comprises a burner plenum 26, a pre-chamber 29, a combustion chamber 28 defined by a double walled can 27 and at least one burner 30 fixed to each combustion chamber 28. The pre-chamber 29, the combustion chamber 28 and the burner 30 are located inside the burner plenum 26. The compressed air 31 passing through the compressor 12 enters a diffuser 32 and is discharged from the diffuser 32 into the burner plenum 26 from where a portion of the air enters the burner 30 and is mixed with a gaseous and/or liquid fuel. The air/fuel mixture is then burned and the resulting combustion gas 34 or working gas from the combustion chamber is channelled via a transition duct 35 to the turbine section 18.

[0023] The turbine section 18 comprises a number of blade carrying rotor discs 36 attached to the shaft 22. In the present example, two discs 36 each carry an annular array of turbine blades 38. However, the number of blade carrying rotor discs could be different, i.e. only one disc or more than two rotor discs. In addition, guiding vanes 40, which are fixed to a stator 42 of the gas turbine engine 10, are disposed between the turbine blades 38. Between the exit of the combustion chamber 28 and the leading turbine blades 38 inlet guiding vanes 44 are provided.

[0024] The combustion gas 34 from the combustion chamber 28 enters the turbine section 18 and drives the turbine blades 38 which in turn rotates the shaft 22 to

drive the compressor section 12. The guiding vanes 40, 44 serve to optimise the angle of the combustion or working gas on to the turbine blades 38. The compressor section 12 comprises an axial series of guide vane stages 46 and rotor blade stages 48.

[0025] The terms upstream and downstream refer to the flow direction of the airflow and/or working gas flow through the engine unless otherwise stated. The terms forward and rearward refer to the general flow of gas through the engine. The terms axial, radial and circumferential are made with reference to the rotational axis 20 of the engine unless otherwise stated.

[0026] FIG. 2 is a perspective view of a part of the combustor 16 showing the burner 30, the pre-chamber 29 and part of the combustion chamber 28. The combustion chamber 28 is formed with a tubular-like shape by the double walled can 27 (shown in Fig. 1) having and extending along a combustor axis 50. The combustor 16 extends along the combustor axis 50 and comprises the pre-chamber 29 and the main combustion chamber 28, wherein the latter extends in a circumferential direction 61 around the combustor axis 50 and generally downstream, with respect to the gas flow direction, of the pre-chamber volume 29.

[0027] The burner 30 comprises a pilot burner 52 and a main burner 54. The pilot burner 52 comprises a burner body 53, a conventional liquid fuel lance 56 and an igniter 58. The main burner 54 comprises a swirler arrangement 55 having an annular array of swirler vanes 60 defining passages 62 therebetween. The annular array of swirler vanes 60 are arranged generally about a burner axis 50, which in this example is coincident with the combustor axis 50, and in conventional manner. The swirler arrangement 55 includes main fuel injection ports which are not shown, but are well known in the art. The main burner 54 defines part of the pre-chamber 29. The pilot burner 52 is located in an aperture 57 and generally radially inwardly, with respect to the burner / combustor axis 50, of the main burner 54. The pilot burner 52 has a surface 64 that defines part of an end wall of the pre-chamber 29. The end wall is further defined by the main burner 54.

[0028] The conventional liquid fuel lance 56 is at least partly housed in a first hole 66 defined in the burner body 53 of the pilot burner 52. A pilot air flow passage 69 is formed between the liquid fuel lance 56 and the walls of the first hole 66. The liquid fuel lance 56 comprises an elongate fuel lance body 86 and a liquid fuel tip 72, as shown in figure 3. The elongate fuel lance body 86 is generally cylindrical and defines a fuel flow passage 70. The liquid fuel tip 72 is mounted at one end of the elongate fuel lance body 86 and is located near to or at the surface 64. The liquid fuel lance 56 will be described in more detail with reference to Fig. 3. The igniter 58 is housed in a second passage 74 defined in the burner body 53 of the pilot burner 52. The end of the igniter 58 is located near to or at the surface 64. The igniter 58 is a well known device in the art and that requires no further description. In other combustors 16 it is possible that more than one

liquid fuel lance and/or more than one igniter may be provided.

[0029] During operation of the gas turbine engine and more particularly at engine start-up, a starter-motor cranks the engine such that the compressor 14 and turbine 16 are rotated along with the shaft 22. The compressor 14 produces a flow of compressed air 34 which is delivered to one or more of the combustor units 16. A first or major portion of the compressed air 31 is a main air flow 34A which is forced through the passages 62 of the swirler arrangement 55 where the swirler vanes 60 impart a swirl to the compressed air 31 as shown by the arrows. A second or minor portion of the compressed air 31 is a pilot air flow 34B which is forced through the pilot air flow passage 69. The pilot air flow 34B can also be referred to as an air assistance flow. Liquid fuel 76 is forced through the fuel flow passage 70 and is mixed with the pilot air flow 34B and the main air flow 34A in order to atomise the liquid fuel. Atomisation of the liquid fuel into very small droplets increases surface area to enhance subsequent vaporisation.

[0030] The main air flow 34A generally swirls around the combustor axis 50. The swirler vanes 60 impart a tangential direction component to the main air flow 34A to cause the bulk main flow 34 of combustibles to have a circumferential direction of flow. This circumferential flow aspect is in addition to the general direction of the air and fuel mixture along the combustor axis 50 from or near the surface 64 towards the transition duct 35 (see Fig.1). The fuel and air mixture passes through the pre-chamber 29 and into the combustion chamber 28. The main air flow 34A forces the pilot air flow 34B and entrained fuel near to the igniter 58, which then ignites the fuel / air mixture.

[0031] To start the engine, a starter motor rotates the shaft 22, compressor 14 and turbine 18 to a predetermined speed when the pilot fuel is supplied and ignited. Once ignited the combustor internal geometry and the air flow patterns cause a pilot flame to reignite, burn continuously and therefore exist. As the engine becomes self-powering the starter-motor can be switched off. As engine demand or load is increased from start-up, fuel is supplied to the main fuel injection ports and mixed with the main air flow 34A. A main flame is created in the combustion chamber 28 and which is radially outwardly located relative to the pilot flame.

[0032] Reference is now made to Fig.3, which shows a schematic perspective and cut-away view of part of the pilot burner 52 and in detail the conventional liquid fuel lance 56. The liquid fuel lance 56 comprises the elongate fuel lance body 86 and the liquid fuel tip 72 which are elements that can be unitary or separate. The liquid fuel tip 72 is located and captured by a narrowing 78 at an end of the first hole 66 and forms a tight fit. At the end of the fuel flow passage 70, the liquid fuel tip 72 includes a swirl plate 80 which defines an array of fuel conduits 82 having inlets and outlets. The fuel conduits 82, only one of which is shown, are angled relative to a longitudinal

or fuel lance axis 79 of the liquid fuel lance 56. Downstream of the swirl plate 80 is a fuel swirl chamber 84 and then a fuel outlet 86, which in this example is a fuel filmer. This fuel filmer 86 is divergent and produces a cone of liquid fuel. In other examples, the fuel outlet 86 can be an orifice that produces a spray of fuel or a number of orifices, each producing a spray of fuel.

[0033] The liquid fuel tip 72 forms an array of pilot air flow conduits 88 having inlets that communicate with the pilot air flow passage 69 and outlets 90 which surround the fuel filmer 86. In this exemplary embodiment, the pilot air flow conduits 88 are inclined or angled in both a circumferential sense and a radially inwardly relative to the longitudinal axis 79 of the liquid fuel lance 56. In other embodiments, the pilot air flow conduits 88 may be axially aligned, or angled in only one of the circumferential sense or radially inwardly relative to the longitudinal axis 79. In this exemplary embodiment there are 8 pilot air flow conduits 88; although in other embodiments there may be more or fewer conduits.

[0034] Pilot liquid fuel flowing in the fuel flow passage 70 enters the inlets of the fuel conduits 82 and exits the outlets imparting a swirl to the fuel in the fuel swirl chamber 84. The swirling fuel forms a thin film over the fuel filmer 86, which sheds the fuel in a relatively thin cone. Pilot air flow 34B impinges the cone of fuel and breaks the fuel into small droplets. The swirling vortex of air from the outlets 90 atomises the fuel along with the main air flow 34A.

[0035] The pilot air flow 34B is particularly useful at engine start-up and low power demands when the main air flow 34A has a relatively low mass flow compared to higher power demands and because of the lower mass flow is less able to atomise the liquid fuel. Advantageously, the pilot air flow 34B provides cooling to the pilot fuel lance and helps prevent fuel coking and carbon build up on the pilot fuel lance.

[0036] FIG.4 is a view along the combustor axis 50 and on the surface 64 of the burner 30 where the pilot burner 52 is generally surrounded by the main burner 54. A liquid fuel lance 156 and the igniter 58 are shown mounted in the burner body 53 of the pilot burner 52. The swirler arrangement 55 of the main burner 54 surrounds the surface 64 and directs the main airflow 34B via the annular array of passages 62. The annular array of swirler vanes 60 and passages 62 are arranged to impart a tangential flow component to the main air flow 34A such that when the airflow portions from each passage 62 coalesce they form a vortex 34C generally about the burner axis 50. In this embodiment, the vortex 34C rotates generally anti-clockwise as seen in Fig.4; this vortex 34C could also be said to be rotating in a clockwise direction as it travels in a direction from the surface 64 to the transition duct 35 through the pre-chamber 29 and then the combustor chamber 28.

[0037] In this exemplary embodiment, the vortex 34C is a single vortex, but in other examples the arrangements of pilot burner 52 and the main burner 54 can create a

number of vortices rotating in either the same direction or different directions and at different rotational speeds.

[0038] The positions of the liquid fuel lance 156 and the igniter 58 are arranged so that the swirling or rotating main air flow 34A passes over or around the liquid fuel lance 56 and then on to the igniter 58. As the main airflow forms a vortex 34C about the axis 50, the liquid fuel lance 156 and the igniter 58 are positioned at approximately the same radial distance from the axis 50. Thus as the fuel lance 156 injects or sprays liquid fuel into the pre-chamber 29 the main airflow 34C entrains the fuel and transports it towards the igniter 58, where ignition can take place. In other embodiments the liquid fuel lance 156 and the igniter 58 may be positioned at different radial distances from the axis 50, relative to one another, in order to accommodate different air assistance flows or swirl directions of the main and/or air assistance flows. For example the liquid fuel lance 156 is positioned nearer the axis 50 than the igniter 58 alternatively the igniter 58 is positioned nearer the axis 50 than the liquid fuel lance 156. In addition to the relative radial position of the liquid fuel lance 156 and the igniter 58, the circumferential distance between them is also important with respect to ensuring the fuel in the main airflow 34C is transported from the liquid fuel lance 156 to the igniter 58. Each application of the present invention will have its own set of parameters influenced by the airflow's swirl characteristics.

[0039] The vortex 34C has many different stream velocities within its mass flow. In this example, the portion of the vortex denoted by arrow 34Cs is travelling at a lower velocity than the portion of the vortex denoted by arrow 34Cf. Main air flow portion 34Cs is radially inwardly of main air flow portion 34Cf with respect to the axis 50. Main air flow portion 34Cs is at approximately the same radial position as the radially inner part of the pilot fuel lance 56 and the main air flow portion 34Cf is at approximately the same radial position as the radially outer part of the pilot fuel lance 156.

[0040] FIG.5 and FIG.6 show sectional views of the main air flow along paths A-A and B-B respectively as shown in FIG.4 and the distribution of fuel droplets. In FIG.4 the flow path B-B is radially outwardly of the fuel lance 156 and igniter 58 and the flow path A-A is approximately at the same radius as at least a part of the fuel lance 156 and igniter 58.

[0041] In FIG.6 the fuel lance 156 and igniter 58 are shown in dashed lines for reference purposes. As shown, each portion of main air flow exiting each passage 62 flows for a short distance immediately across the surface 64, before leaving the surface 64 and travelling away from the surface 64 and along the axis 50 as another portion of the main air flow joins from a circumferentially adjacent passage 62. Thus as can be seen the any fuel droplets 92 entrained in this portion of the main air flow long flow path B-B are quickly lifted away from the surface 64 and therefore away from the igniter 58.

[0042] In FIG.5 the main air flow 34A passes over the fuel lance 156 and on towards the igniter 58. The outlets

90, which surround the fuel filmer 86 of the fuel lance 156, direct the pilot air flow 34B to impinge on the cone of fuel exiting the fuel filmer 86 and break the fuel film into small droplets 92. The swirling vortex of pilot air, shown schematically as 94, from the outlets 90 atomises the fuel as it mixes with the main air flow 34A. The swirling vortex of pilot air 94 effectively forms a fluid buffer and causes to be formed on its leeward or downstream side a recirculation zone or a low-pressure zone 96. This recirculation zone or a low-pressure zone 96 draws the main air flow 34A towards the surface 64 between the fuel lance 156 and igniter 58. A portion of the fuel droplets 92 are also drawn towards the surface 64 and therefore close to the igniter 58 such that good ignition of the fuel / air mixture is possible.

[0043] Referring now to FIG. 7, which is a view on the tip 72 of the conventional fuel lance 56 and generally along its axis 79, the array of outlets 90 direct the pilot air flow 34B with a tangential component. When the portions of pilot air flow 34B from each outlet 90 merge they coalesce into the pilot vortex 94. The pilot vortex 94 rotates in a generally anti-clockwise direction as seen in Fig.7; this vortex 94 could also be said to be rotating in a clockwise direction as it travels in a direction from the surface of the tip 72 towards the transition duct 35 through the pre-chamber 29 and then the combustor chamber 28. In one example, there are 8 outlets 90 arranged symmetrically about the axis 79 of the fuel lance and about the fuel filmer 86. This arrangement of outlets produces, at least initially, a symmetric pilot vortex 94.

[0044] However, in service it has been found that the outlets 90 become blocked by carbon deposits formed from liquid fuel landing on the surfaces of the conventional fuel lance 56. This blocking reduces the amount of pilot air flow 34B which in turn this reduces the effectiveness of the pilot air flow 34B shearing and breaking up the fuel film. Thus it has been found that the symmetry of the pilot vortex 94 causes particular air flow characteristics that lead to liquid fuel contacting the surface of the conventional fuel lance 56 and which then forms carbon deposits that block the outlets 90. Both the direction and the strength of the air assistance jets are effected, which changes the fuel location and the atomization, potentially giving larger droplets further away from the igniter, or impinging onto combustion wall surfaces. Impingement onto the wall surfaces or fuel in the wrong place leads to the potential for combustion to occur in the wrong place and burn out components. Alternatively the vapourised fuel near the igniter is decreased and ignition is then not possible.

[0045] The present invention will now be described with reference to aspects of a pilot liquid fuel system 99 comprising a liquid fuel lance 156 and an air supply control arrangement 160 for supplying and controlling air to the liquid fuel lance 156. Both the configuration of the liquid fuel lance 156 and the air supply control arrangement 160 fulfil the object of forming an asymmetric air assist pilot vortex to prevent carbon deposits.

[0046] An exemplary embodiment of the liquid fuel lance 156 in accordance with the present invention is now described with reference to FIGS. 8, 9 and 10. Features of the conventional liquid fuel lance and its installation in the burner described with reference to the earlier figures are here given the same reference numerals plus 100 to denote like features, for example the conventional pilot fuel lance is denoted by 56 and the inventive pilot fuel lance is denoted by 156. It should be appreciated that the position of the tip 172 of the pilot fuel lance 156 is located relative to the burner as is the conventional pilot fuel lance 56.

[0047] FIG. 8 is a longitudinal section through the liquid fuel lance 156 in accordance with an exemplary embodiment of the present invention. FIG. 9 is the section E-E through the tip 172 of the liquid fuel lance 156 and generally along its axis 179 showing an array of inlets 189A, 189B, 189C arranged around the fuel outlet 186 in accordance with the present invention. The fuel outlet 186 may be a fuel filmer that produces a cone of liquid fuel or an orifice that produces a spray of fuel or a number of orifices, as described earlier. FIG. 10 is the section F-F shown in FIG. 8 of an exemplary air inlet 200 configuration for guiding air into the air assist passages 130A, 130B, 130C of the liquid fuel lance 156.

[0048] The liquid fuel lance 156 has a longitudinal axis 179 and comprises an elongate liquid fuel lance body 168 and a liquid fuel tip 172. The liquid fuel tip 172 may be threaded onto the liquid fuel lance body 168 or may be welded. The elongate liquid fuel lance body 168 comprises a fuel flow passage 170 and a first air passage 130A, a second air passage 130B and a third air passage 130C. The liquid fuel tip 172 defines a fuel outlet 186 and arranged about the fuel outlet 186 are a first air outlet 190A, a second air outlet 190B and a third air outlet 190C to which air is independently supplied by the respective first, second and third air passages 130A, 130B, 130C. The fuel passage 170 is a generally cylindrical conduit although other shapes are possible.

[0049] Here the first, second and third air passages 130A, 130B, 130C are helical in configuration and feed air into pilot air flow conduits 188A, 188B, 188C respectively that are defined in the tip 172 via inlets 189A, 189B, 189C and which terminate in respective outlets 190A, 190B and 190C in the tip surface 132. An air inlet 200 is disposed at the upstream end of the liquid fuel lance body 168 and has first, second and third inlet passages 202A, 202B, 202C arranged to feed air into the first, second and third air passages 130A, 130B, 130C respectively. The first, second and third inlet passages 202A, 202B, 202C extend from a circumferential and outer opening 204 of the inlet 200, radially inwardly towards the axis 179 where the air is turned from a radial direction to an axial direction and into the first, second and third air passages 130A, 130B, 130C. The first, second and third inlet passages 202A, 202B, 202C each subscribe a spiral or part spiral which allows a low aerodynamic loss of pressure of the air as it travels through and from the air inlet

200 to the first, second and third air passages 130A, 130B, 130C respectively. A circumferential seal 206 seals between the air inlet plate 200 and the fuel supply passage 170 are shown for illustrative purposes. Seals between the fuel lance and surrounding parts are not shown but well known from conventional designs.

[0050] The helical air passages 130A, 130B and 130C are formed between an inner wall 136 forming the fuel passage 170 and an outer wall 134 of the elongate liquid fuel lance body 168. Both the inner and outer walls are generally cylindrical and coaxial to one another. The helical air passages 130A, 130B and 130C are arranged effectively parallel to one another in a helical sense. In this embodiment, each of the helical passages 130A, 130B and 130C wraps around the fuel passage 170 twice or extends 720° about the fuel passage 170 between the air inlet 200 and the tip 172. In other embodiments, the helical passages 130A, 130B and 130C can wrap around the fuel passage 170 a minimum of 180°. The helical passages 130A, 130B and 130C wrap around the fuel passage 170 approximately three times or 1080°, but can wrap around the fuel passage 170 up to seven times.

[0051] The pilot air flow conduits 188A, 188B, 188C defined in the tip 172 are arranged about the fuel passage 170 and terminate in respective outlets 190A, 190B and 190C in the tip surface 132, themselves arranged around the fuel outlet 186. The pilot air flow conduits 188A, 188B, 188C are formed by drilling and are therefore straight passages. To create a pilot vortex, the passages are drilled at an angle such that a centre-line 207 of the pilot air flow conduit 188A has a compound direction including both axial and tangential relative to the axis 179.

[0052] The pilot air flow conduits 188A, 188B, 188C defined in the tip 172 have respective inlets 189A, 189B, 189C which allow the air in the air passages 130A, 130B and 130C to flow into the air flow conduits 188A, 188B, 188C. The angle of the centre-line 207 of the pilot air flow conduits is conveniently aligned with the helical angle of the air passages 130A, 130B and 130C so that a preferential pressure is experienced by the air entering the air flow conduits 188. The inlets 189A, 189B, 189C are formed on a surface of respective passage outlets 191A, 191B, 191C in the upstream surface 182 of the tip 172. The passage outlets 191 have dividing walls 192 therebetween to seal each of the separate air flows from one another. The passage outlets 191A, 191B, 191C and walls 192 are arranged such that each partition encloses around the outlet of air passages 130A, 130B and 130C respectively.

[0053] In FIG. 8 the pilot liquid fuel system 99 comprises a first embodiment of the air supply control arrangement 160 for supplying variable amounts of air to the air passages 130A, 130B, 130C. The air supply control arrangement 160 has a valve means 140 in the form of first, second and third valves 140A, 140B, 140C connected to a main air supply pipe 141 and each valve has respective branch pipes 142A, 142B, 142C and a valve controller 150 arranged to control the valve means 140.

The branch pipes 142A, 142B, 142C are connected to the inlet 200 and respective first, second and third inlet passages 202A, 202B, 202C. The valve means 140 is arranged to operate at least the first valve 140A to control the amount of air passing into the first air passage 130A and therefore the amount of air passing out of the outlets 190A. The valve means 140 is arranged to operate at least the first valve 140A between a fully closed and an fully open position and can control the valve 140A to pass any amount of air in between the fully closed and an fully open position. In addition, the amount of air flowing through the branch pipes 142B, 142C may also be controlled, for example, to maintain a constant air flow during the full envelope of engine operation. Alternatively, the amount of air flowing through the branch pipes 142B, 142C may also be controlled, for example, to vary the air flow during the full envelope of engine operation to create a stronger or weaker pilot vortex.

[0054] In the simplest form of the invention, only one valve 140A is provided to control the amount of air entering the first air passage 130A and directly feeds air from a main air supply pipe 141 to the second and third air passages 130B, 130C. However, in one embodiment shown here three valves 140A, 140B, 140C are provided and which are arranged in series along the one main air supply pipe 141 and the valves are therefore in series. Where only one valve 140A is provided the total mass flow of air passing along the main air supply pipe 141 will vary dependent upon the status of the valve 140A. When the valve 140A is fully open more air passes through the main supply pipe 141 than when the valve is closed or partially closed. Although this can be satisfactory the use of one or more further valves 140B, 140C can regulate the amount of air supplied to the second and third air passages 130B and 130C to keep the amount of air flow at a desired rate.

[0055] The valve controller 150 may be active or scheduled.

[0056] During start-up, the gas turbine runs through a set of automatic or predetermined steps including setting the preferable combination of air and fuel for a successful start, using only pilot fuel, switching on and off the igniter and determining when to stop trying to ignite. The step of igniting is terminated because either the start has been successful or when a limit on start attempts has been reached. The limit on the number of start attempts is set, for example, due to risk of explosion from unburnt fuel. In addition, start-up includes the step of where and/or how to inject the assist air as described herein.

[0057] Weak extinction of the combustor flame is typically detected by combustion oscillations or dynamic pressure fluctuations. These are measured continuously during operation and are part of an active pilot system. When the level of combustion oscillations increases, particularly in a certain frequency range, to a predetermined level, dependent on the burner design, weak extinction is assumed to be imminent. The control system then includes the step of preventing the flame from going out

by increasing the pilot fuel flow to make the flame more stable. At the same time, in accordance with the present invention, a step of altering where and how to inject the assist air is made and according to a predetermined schedule.

[0058] As the flame position changes or fluctuates the dynamic (acoustic) pressure signal also changes. The actual frequencies are specific to the combustion hardware but it should be appreciated that a person skilled in the art will be able to identify these critical frequencies for a given change and adjust the particular needs of the air assistance flows to suit. This could be fed into a control loop to automatically adjust the air assist delivery.

[0059] There are also operational events or issues which cannot be determined during engine running such as carbon build up. The carbon build up is due to fuel impingement on combustor surfaces and can be reduced if the liquid fuel droplets are directed into the main or bulk airflow which takes the fuel away from the surfaces. In the radial swirler, at start up for example, the central or main air flow re-circulates back towards the pilot surface 64. This recirculation is particularly strong at a given radius from the axis 50. Use of the air assistance to shape the fuel jet to prevent fuel droplets entering this recirculation region would prevent or reduce carbon build up on the pilot surface. The regions where recirculation occurs can change throughout the load range of the engine, however, the skilled person skilled can easily determine the regions and define an air assistance schedule to minimise the droplets entering this region.

[0060] Atomisation of the liquid is dependent on several factors such as film thickness of the fuel, flow-rate of the fuel, viscosity and density of the fuel and shear stresses on the fuel from the swirling air and therefore the momentum, viscosity and density of the air. The fuel and air flow rates change with engine load and ambient conditions and the amount of air assistance required therefore also changes. For example, the fuel split to the injector in question may mean that it has a higher flow-rate at lower loads and hence needs less air assistance to properly atomise the fuel. The conditions for this are specific to each combustion system and would have to be determined independently, but in accordance with the present teaching.

[0061] In view of FIG. 18, a typical example of a start up schedule comprises the steps;

- at start up; turn off air to air assist outlets AA7, AA8, AA1 in order to induce recirculation to igniter,
- after ignition turn off air to air assist outlets AA2, AA3, AA4 to put fuel into airflow to pilot flame,
- at approximately 75% load turn on air delivery to all air assist outlets to burn off any carbon deposits at or after this load,
- once the engine has started successfully, control of

the combustion system passes to automatic control based on the combustion dynamics.

[0062] In the case of a scheduled valve controller 150, the scheduling may be associated with the main engine controller such that at a demanded power level or mode of operation including start-up and weak extinction, the valve controller 150 automatically controls the valve means 140 to produce an asymmetric air assist condition. The valve controller 150 can be a standalone device or it can be a part of the main engine control system. Depending on the level of adaptation required, the assist air may be controlled by fixed or adaptive curves/lookup tables.

[0063] Referring now to FIGS. 11-13 that show a number of alternative configurations of the air supply control arrangement 160. It should be appreciated that in a gas turbine engine each combustor or burner may have one air supply control arrangement 160, alternatively one air supply control arrangement 160 may control the air supplied to all the burners or pilot fuel lances via appropriate pipe work such as a manifold that supply all burners via the same branch pipes. Which option that is chosen would depend on the size of the gas turbine and therefore size / room available to fit the air supply control arrangements but also the cost for the whole gas turbine engine. A further aspect on individual or common supply of assist air to the pilot liquid fuel lances 156 is reliability. The higher the number of components in the system inevitably the lower its reliability will be. At the same time the more adjustment possibilities available the higher the level of optimization of system performance achievable.

[0064] FIG. 11 shows a first schematic air supply control arrangement 160 of the pilot fuel system 99 which controls the supply of air into the air assist passages 130A, 130B, 130C of the liquid fuel lance 156, in this exemplary embodiment the valves 140A, 140B, 140C are in series on the main supply pipe 141. The valve controller is operable to control the valve means 140 to vary the amount of air passing through the valves and therefore the air passages 130A, 130B, 130C. This embodiment is essentially the same as that shown in FIG. 8. Valve 140C and branch pipe 142C are shown dashed because they denote optional and additional valves and branch pipes depending on the number of the air passages 130 provided in the body 168 of the pilot liquid fuel lance 156.

[0065] This arrangement may be used for both on-off or gradual/continuous control of the amount of air supplied through the first valve 140A and therefore the outlet orifice 190A. In addition a fixed restrictor 143B, 143C may be provided on either or both branch pipes 142B, 142C to help rebalance the air distribution between the branch pipes 142A, 142B and 142C or another characteristic of the system. This characteristic regards changing the air split between the different branch pipes, but that does not mean that they necessarily have to be "balanced". If for example branch pipe 142A always needs

more air than branch pipes 142B and 142C then the air escaping down branch pipes 142B and 142C is reduced. It is not possible do that by changing the valve settings due to the serial configuration.

[0066] In the situation that one sector at the lance tip 172 needed to be supplied with a high air assist flow all of the time during operation of the gas turbine and other sectors would be switch on or off or controlled continuously then the control valves associated with that sector are not required.

[0067] FIG. 12 is a second schematic air supply control arrangement 160 of the pilot fuel system 99 which controls the supply of air into the air assist passages 130A, 130B, 130C of the liquid fuel lance 156, in this exemplary embodiment the valves 140A, 140B, 140C are in parallel on the main supply pipe 141. This parallel valve configuration provides the highest degree of flexibility because the amount of air passing through each branch pipe can be controlled completely independently of the valves in the other branch pipes.

[0068] FIG. 13 is a third schematic air supply control arrangement 160 of the pilot fuel system 99 which controls the supply of air into the air assist passages 130A, 130B, 130C of the liquid fuel lance 156. In this exemplary embodiment the valve 140 is a pneumatic split spool valve, one of which is available from Bosch Rexroth Corporation®. This type of single valve can save on initial component costs, reduce the physical size and weight of valve and the number of components in the system a multifunctional valve may be used. The split spool configuration is particularly useful if the switching of the delivery of air to the air passages 130A, 130B, 130C are required instantly and from one desired air flow amount to another rather than gradually or continuously.

[0069] It should be appreciated that the air supply control arrangement 160 will have a certain flow characteristic such that here more than one branch pipe can be flowing at the same time. In other words, this is a parallel arrangement, but with no gradual control. As before, the flow split between the branch pipes during e.g. commissioning or service, by way of using fixed orifices.

[0070] Depending on the number of branches in the configuration it may be advantageous to combine more than one for the arrangements above. To modify these characteristics over the full load range of the turbine engine it may, for example, be favorable to have individual air supply control arrangement 160 as shown in figure 13 with multiple valves as described with reference to FIGS. 11 and 12.

[0071] The method of operating the pilot liquid fuel system 99 comprises the air supply control arrangement 160 supplying a total air flow to the first air passage 130A and second air passage 130B and adjusting the valve means 140 to supply the first air passage 130A with 5% to 25% of the total air flow. In the exemplary embodiment described above, the total air flow supplied to the first air passage 130A, second air passage 130B and third air passage 130C adjusting the valve means 160 to supply

the first air passage 130A with 5% to 25% of the total air flow. It should be appreciated that where the branch pipes 142A, 142B, 142C are manifolds supplying air to all the pilot fuel lances 156 of the gas turbine engine the method of operating the pilot liquid fuel system includes opening the valve means 140 to supply the first air passages 130A with 5% to 25% of the total air flow to the plurality of liquid fuel injectors 156.

[0072] Once the engine is self propelling or during normal engine running and there is a stable combustor flame, the method further includes the step of opening the valve means 140 to supply the first air passage 130A with approximately equal amount of the total air flow compared to the other air flow passages 130B, 130C.

[0073] The pilot air flow conduits 188A, 188B, 188C and outlets 190A, 190B, 190C direct the pilot air flow 34B with a tangential component to form a pilot vortex 94. During engine start up and weak extinction of the combustion flame, an asymmetric air flow through the pilot air flow conduits 188A, 188B, 188C and in combination with the main swirler vortex to help prevent liquid fuel contacting the surfaces and later giving rise to carbon deposits. An asymmetric air flow is created by supplying only a fraction of the total air flow to one of the air passages 130. As mentioned above the fraction of the total air flow can be zero, although it is practical to supply approximately 5% of the total air flow to prevent hot gases being ingested into the outlets 190A.

[0074] Referring now to FIG.14 which shows a view along arrow G shown in FIG.8 and onto the surface 132 of the tip 172 of the liquid fuel lance 156. As previously mentioned one objective is to create an asymmetric air assist delivery, which in turn creates an asymmetric pilot vortex of air and fuel. This is achieved by controlling the flow of air to at least one of the air passages and in this example air passage 130A. As mentioned earlier, each air passage 130A, 130B and 130C supplies air to respective pilot air flow conduits 189A, 189B and 189C which exits the tip 172 via outlets 190A, 190B and 190C. As can be seen in FIG.14 there are three groups of three outlets. A group of outlets has so far been referred to with reference numbers 190A, 190B and 190C. In this example, each 'outlet' comprises three outlets referred to outlet 190A, 190B and 190C, because the term outlet can refer to one or a number of outlets. Indeed, FIG. 14 shows three sectors A, B and C within which the one or number of each outlet 190A, 190B and 190C is located. In this example, sector A is the controlled or varied air flow sector A where a reduced or lower air flow, at the desired engine operating condition, is provided and which is preferably in the range 5-15% of the total air flow passing through the air passages. As described earlier, the amount of air flow passing through all three groups of outlets can be controlled, however, the term 'controlled air flow sector A' will be used to denote sector A.

[0075] The extent of the controlled air flow sector A is defined by an angle θ about the fuel lance's axis 79 as shown in FIG.14. In general, the outlets 190 are regularly

or evenly spaced about the axis 179, and the lines denoting angle θ are approximately mid-way between outlets in adjacent sectors A, B, C. In this example the angle θ is approximately 120° and for other examples, the angle θ can be between and including 30° and 160° . It should be appreciated that one, two, three or more outlets 190 may be defined in each sector A, B, C. A centre-line 100 is shown in FIG.8 and which is the centre-line or bisector of the blank sector 98 to define the orientation of the fuel lance 56 and controlled air flow sector A relative to the combustor chamber axis 50.

[0076] This arrangement creates an asymmetric pilot air flow 34B delivery and hence an asymmetric pilot vortex 94. This asymmetric pilot vortex 94 has the effect of keeping the fuel lance 156 free from liquid fuel landing on its surfaces and subsequent carbon deposits by creating an air flow regime around the pilot lance that shields the pilot lance 56 from droplets 92. This has the benefit that the pilot air flow outlets 190 do not block during use and therefore the quality of the fuel spray and atomization is maintained. Consequently, ignition at start-up is also improved. In addition, the pilot air flow or 'air assistance' being asymmetric increases the local turbulence and improves the shear on the droplets 92, aiding their atomization and pushing the droplets 92 away from the outlets 190, preventing any carbon build up due to the liquid fuel coming into contact with the injector surface.

[0077] The asymmetric pilot air flow 34B delivery and the asymmetric pilot vortex 94 remain strong enough to effectively form the fluid buffer 94 and cause to be formed on its leeward or downstream side, the recirculation zone 96 or low-pressure zone 96. Thus the recirculation zone 96 or low-pressure zone 96 still draws the main air flow 34A towards the surface 64 between the fuel lance 156 and igniter 58. A portion of the fuel droplets 92 are also drawn towards the surface 64 and therefore close to the igniter 58 such that good ignition of the fuel / air mixture remains equally possible.

[0078] It has been found that the asymmetric pilot vortex 94 is able to prevent or substantially prevent liquid droplets 92 contacting the surfaces of the fuel lance 156 whatever the orientation of the centre-line 100. However, there is only a significant benefit to the delivery of fuel droplets 92 in the main flow to the igniter 58, as described above, if the orientation of the centre-line 100 is in a particular orientation compared to the vortex 34C or relative to the combustor chamber axis 50.

[0079] Referring to FIG.15 which is a view on the surface 64 of the burner 30 and along the axis 50 and from which a radial line 102 emanates and passes through the axis 78 of the fuel lance 56. The fuel lance 56 and igniter 58 are shown along with main airflow arrows 34A issuing from the main air flow passages 62. As described earlier, the portion of the vortex denoted by arrow 34Cf is travelling at a generally higher velocity than the portion of the vortex denoted by arrow 34Cs. The relatively slower flow is generally radially inward of the faster velocity air.

[0080] The fuel lance 156 as previously described is

at least partly housed within the burner body 53 of the burner 30 and the outlets 190 and the fuel filmer 186 are located at or near to the surface 64. In this example, the outlets 190 and the fuel filmer 86 are located below the surface 64 in the burner body 53. The igniter 58 is also at least partly housed within the burner body 53 and has an end face 59, located just below the surface 64, but could be at or near to the surface 64.

[0081] The burner 30 further includes an array of gas injection ports 122 generally formed in a radially outward part of the burner 30 and under a circumferential lip 124 as shown in FIG.2. These gas injection ports 122 can supply a pilot gas-fuel as is known in the art.

[0082] The terms clockwise and anticlockwise are with respect to the view on the surface 64 of the burner 30 as seen in FIG.15.

[0083] In this exemplary embodiment, the centre-line 100 of the controlled air flow sector A and is angled at approximately 0° relative to the radial line 102 extending from the combustor chamber axis 50 to the fuel lance axis 78. Furthermore, the main air flow passages are tangentially angled relative to the burner axis 50 to create an anticlockwise swirl direction of the main air flow 34A and the air passages 188 are tangentially angled relative to the fuel lance axis 179 to create an anticlockwise swirl direction of the pilot air flow 34B. However, in this first embodiment the range of angles which provide at least some of the desired advantages of the present invention is between and including $+60^\circ$ and -60° . The most advantageous range of angles is between and including $+30^\circ$ and -10° .

[0084] To prevent carbon build up during normal operation the centre of the blocked holes should be between 120° and 200° to direct the flow into an airstream which takes the droplets to the combustion region and not back towards the pilot face. However, these angles are only for a single embodiment of the design, the purpose of the design is to direct the liquid droplets into a preferential position which will be different for different combustion systems.

[0085] In a second embodiment, the main air flow passages are tangentially angled relative to the burner axis 50 to create an anticlockwise swirl direction of the main air flow 34A and the air passages 188 are tangentially angled relative to the fuel lance axis 179 to create a clockwise swirl direction of the pilot air flow 34B. In this second embodiment the range of angles which provide at least some of the desired advantages of the present invention is between and including $+120^\circ$ and 0° .

[0086] In a third embodiment, the main air flow passages are tangentially angled relative to the burner axis 50 to create a clockwise swirl direction of the main air flow 34A and the air passages 188 are tangentially angled relative to the fuel lance axis 179 to create an anticlockwise swirl direction of the pilot air flow 34B. In this third embodiment the range of angles which provide at least some of the desired advantages of the present invention is between and including 0° and -120° .

[0087] Thus overall, the centre-line 100 of the controlled air flow sector A and can be angled between $+120^\circ$ and -120° from a radial line 102 from the axis 50 and passing through the fuel lance 156. In all embodiments, the igniter 58 is positioned downstream of the fuel lance 156 with respect to the clockwise or anticlockwise direction of the main air flow 34A.

[0088] The orientation of the fuel lance 156 as described above is advantageous in that the outlets 190 are kept free of carbon deposits and therefore good atomisation of the fuel film and good start-up ignition is maintained. During ignition it is important that fuel washes over the igniter 58 to ensure reliable ignition. However, during other engine conditions such as weak extinction, part-load or maximum load other orientations of the controlled air flow sector A are even more beneficial. During normal engine running, at engine speed or power above ignition or start up, it is desirable to avoid the fuel contacting or washing over the igniter 58 because it may form carbon deposits. Thus at ignition the condition described with reference to FIG.5 is desirable where the fuel droplets wash over or very close to the injector; and during normal engine running it is desirable that the condition described with reference to FIG.6 is desirable where the fuel droplets are generally carried away from the igniter.

[0089] Thus a method of operating the burner 30 in accordance with the present invention comprises the step of rotating the fuel lance between a start-up condition and a second condition. The second condition can be any one of the conditions such as weak extinction, part-load or maximum load. In particular, weak extinction is a condition where the flame can extinguish if there is further decrease in fuel supply without changes in the path the fuel takes during combustion and is related to flame stability. The weak extinction does not depend on the fuel / air ratio only but also for example the air temperature as well as the rate of change in fuel / air ratio or changes in fuel composition. Typically a lower air temperature and /or a faster rate of change have a negative impact on flame stability. For the same fuel / air ratio with a lower weak extinction, the flame is less likely to extinguish.

[0090] Referring back to FIG. 8 and its description, the controlled air flow sector A has the centre-line 100 angled or orientated relative to the radial line 102; at engine start-up condition the blank sector 98 is angled between $+120^\circ$ and -120° from the radial line 102 and at the second condition the liquid fuel lance 56 is rotated about its own axis 79 such that the blank sector 98 is angled between $+240^\circ$ and -360° from the radial line 102. Thus in one example, at start-up the centre-line 102 is angled at approximately 0° from the radial line 102 and a high-power condition, the liquid fuel lance 56 is rotated by approximately -120° as viewed in FIG.14.

[0091] FIG.16 depicts a further embodiment of the inventive fuel lance 156. FIG.16 is an equivalent section G-G shown in FIG.8. In this exemplary embodiment only an approximately 120 degree sector (9) at the tip of the

lance is arranged to release assist air. This sector is provided with two subsectors, a first subsector 130A of approximately 90 degrees and a second subsector 130B of approximately 30 degree. The majority of the air assist can be supplied to one of these subsectors 130A, 130B and which one will depend on the operating conditions of the engine or combustor. In one example, it is preferable to supply air through the second subsector 130B during the ignition phase or engine start up. In variations of this embodiment, the subsectors 130A, 130B can be each 90 degrees in extent and can be opposite one another rather than immediate next to one another.

[0092] FIG. 17 is a schematic view on the tip of another embodiment of the liquid fuel lance 156 and having a second air assist supply generally surrounding the first air assist supply as described above. The inner wall 136 defines the fuel passage 186 and the outer wall 134 bounds the air passages 130A, B, C and which via air flow conduits 188A, 188B, 188C feed the outlets 190 of the first air assist supply. Surrounding the outer wall 134 the first air assist supply is a further outer wall 135 which bounds further air passages 130D, E, F feeding air via air flow conduits 188D, 188E, 188F to outlets 190 D, E, F (not shown but similar to those shown in FIG.8). The walls 136, 134, 135 are generally cylindrical and coaxial to one another.

[0093] In this embodiment the air via air flow conduits 188D, 188E, 188F and outlets 190 D, E, F are arranged to direct the air assist in a circumferential flow direction opposite to the first air supply. This embodiment caters for a further optimisation of the flow field surrounding the fuel jet at different operation conditions. Thus the first air assist supply and the second air assist supply are arranged to form counter rotating vortices to further enhance mixing and asymmetric air assist delivery to improve ignition. The second air assist supply is arranged similarly to the first air assist supply and has the same functionality and therefore no further description is required. In use the second air assist supply is varied in accordance with the first air assist supply or may be supplied.

[0094] Whereas the above exemplary liquid fuel lance 156, liquid fuel system 160 and method of operation has been described with reference to a pilot liquid fuel system, the fuel system is equally applicable to a main liquid fuel system.

Claims

1. A liquid fuel lance (156) for a burner (30) of a combustor (16) of a gas turbine combustor (16), the liquid fuel lance (156) has a longitudinal axis (179) and comprises an elongate liquid fuel lance body (168) and a liquid fuel tip (172), the elongate liquid fuel lance body (168) comprises a fuel flow passage (170) and at least a first air pas-

sage (130A) and a second air passage (130B, 130C), a liquid fuel tip (172) defines a fuel outlet (186) and arranged about the fuel outlet (186) at least a first outlet (190A) and a second outlet (190B, 190C) to which air is independently supplied by the first air passage (130A) and the second air passage (130B, 130C) respectively, and wherein the amount of air supplied to the first air passage (130A) is variable.

2. A liquid fuel lance (156) as claimed in claim 1 wherein the first air passage (130A) and the second air passage (130B, 130C) extend approximately parallel to the longitudinal axis (79).
3. A liquid fuel lance (156) as claimed in claim 1 wherein the first air passage (130A) and the second air passage (130B, 130C) are helical about the longitudinal axis (79).
4. A liquid fuel lance (156) as claimed in claim 3 wherein the first air passage (130A) and the second air passage (130B, 130C) are helical about the longitudinal axis (79) at least 180°.
5. A liquid fuel lance (156) as claimed in any one of claims 1-4 wherein the first air outlet (130A) extends about the axis an angle in the range and including 30° and 160°.
6. A liquid fuel lance (156) as claimed in any one of claims 1-4 wherein the first air outlet (130A) extends about the axis an angle of 120°.
7. A liquid fuel lance (156) as claimed in any one of claims 1-6 wherein the at least a first outlet (190A) and the second outlet (190B, 190C) and the first air passage (130A) and the second air passage (130B, 130C) constitute a first air assist supply, and a second air assist supply comprises at least first outlet (190D) and second outlet (190E, 190F) to which air is independently supplied by a first air passage (130D) and a second air passage (130E, 130F) respectively, and wherein the amount of air supplied to the first air passage (130D) of the second air assist supply is variable.
8. A liquid fuel system (160) comprising the liquid fuel lance (156) as claimed in any one of claims 1-7 and an air supply control arrangement (140), the air supply control arrangement (140) having a valve means (140) and a valve controller (150) arranged to control the valve means (140), the valve means (140) is arranged to operate at least the first air passage (130A) between a closed and an open position.

9. A liquid fuel system (160) as claimed in claim 8 wherein the valve means (140) is arranged to operate at least the second air passage (130B, 130C) between a closed and an open position. 5
10. A liquid fuel system (160) as claimed in claim 9 wherein the valve means (140) comprises at least a first valve (140A) arranged to vary air flow into the at least the first air passage (130A) and a second valve (140B, 140C) arranged to operate the second air passage (130B, 130C), 10
wherein the first and second valves are in series with one another.
11. A liquid fuel system (160) as claimed in claim 9 15
wherein the valve means (140) comprises at least a first valve (140A) arranged to vary air flow into the at least the first air passage (140B) and a second valve (140B, 140C) arranged to operate the second air passage (130B, 130C), 20
wherein the first and second valves are in parallel with one another.
12. A method of operating the liquid fuel system (160) as claimed in any one of claims 8-11 wherein the method comprises the step of 25
supplying a total air flow to the at least first air passage (130A) and second air passage (130B, 130C) adjusting the valve means (140) to supply the first air passage (130A) with 5% to 25% of the total air flow. 30
13. A method of operating the liquid fuel system (160) as claimed in claim 12 wherein the liquid fuel system comprises a plurality of liquid fuel injectors (156), the method comprises the step of 35
adjusting the valve means (140) to supply the first air passages (130A) with 5% to 25% of the total air flow to the plurality of liquid fuel injectors (156). 40
14. A method of operating the liquid fuel system (160) as claimed in any one of claims 12-13 comprising the step of 45
adjusting the valve means (140) to supply the first air passage (130A) with 5% to 25% of the total air flow during engine start-up or weak extinction.
15. A method of operating the liquid fuel system (160) as claimed in any one of claims 2-14 comprising the step of 50
adjusting the valve means (140) to supply the first air passage (130A) with approximately equal amounts of the total air flow during normal engine running. 55

FIG 1

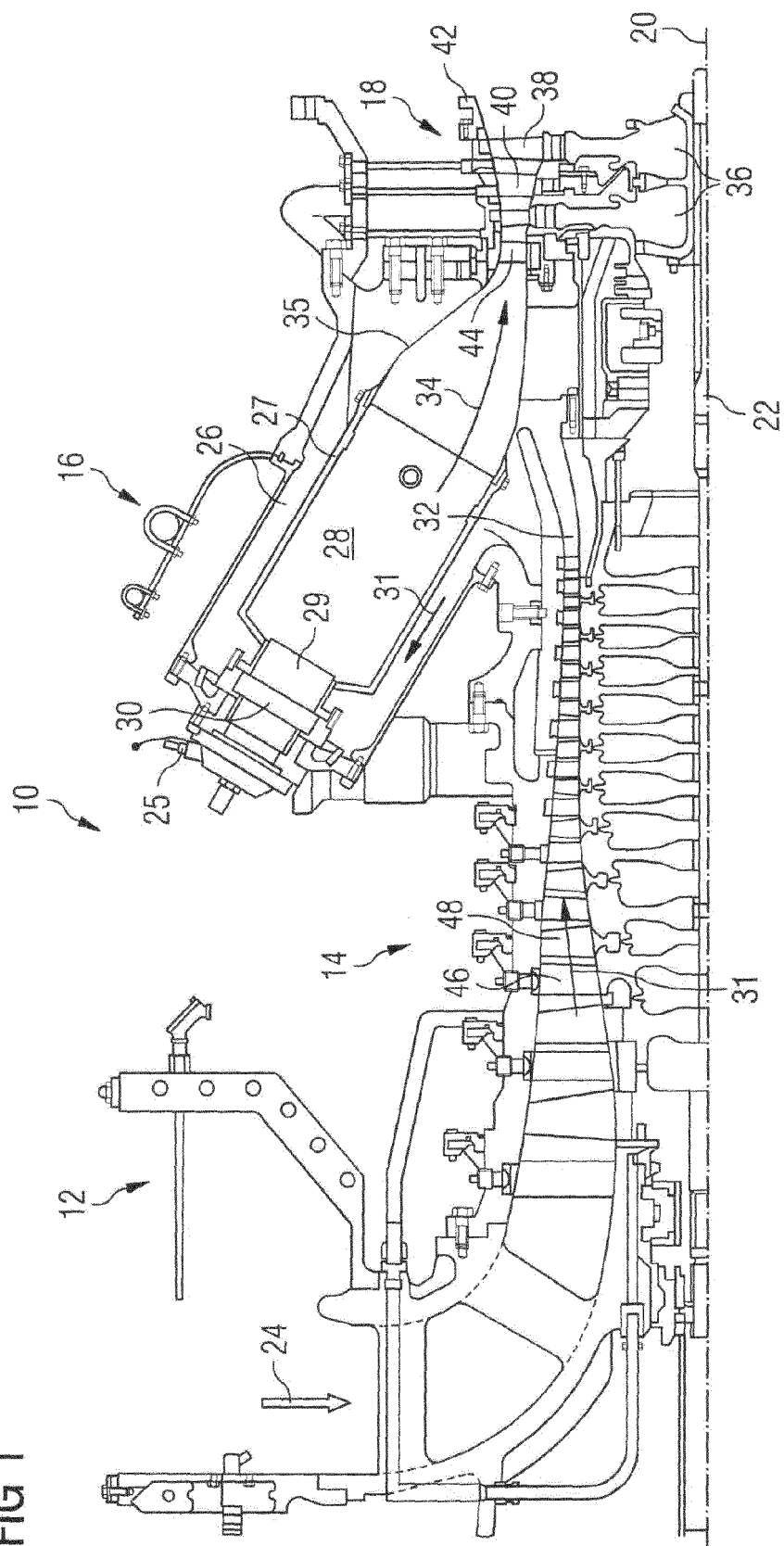


FIG 2

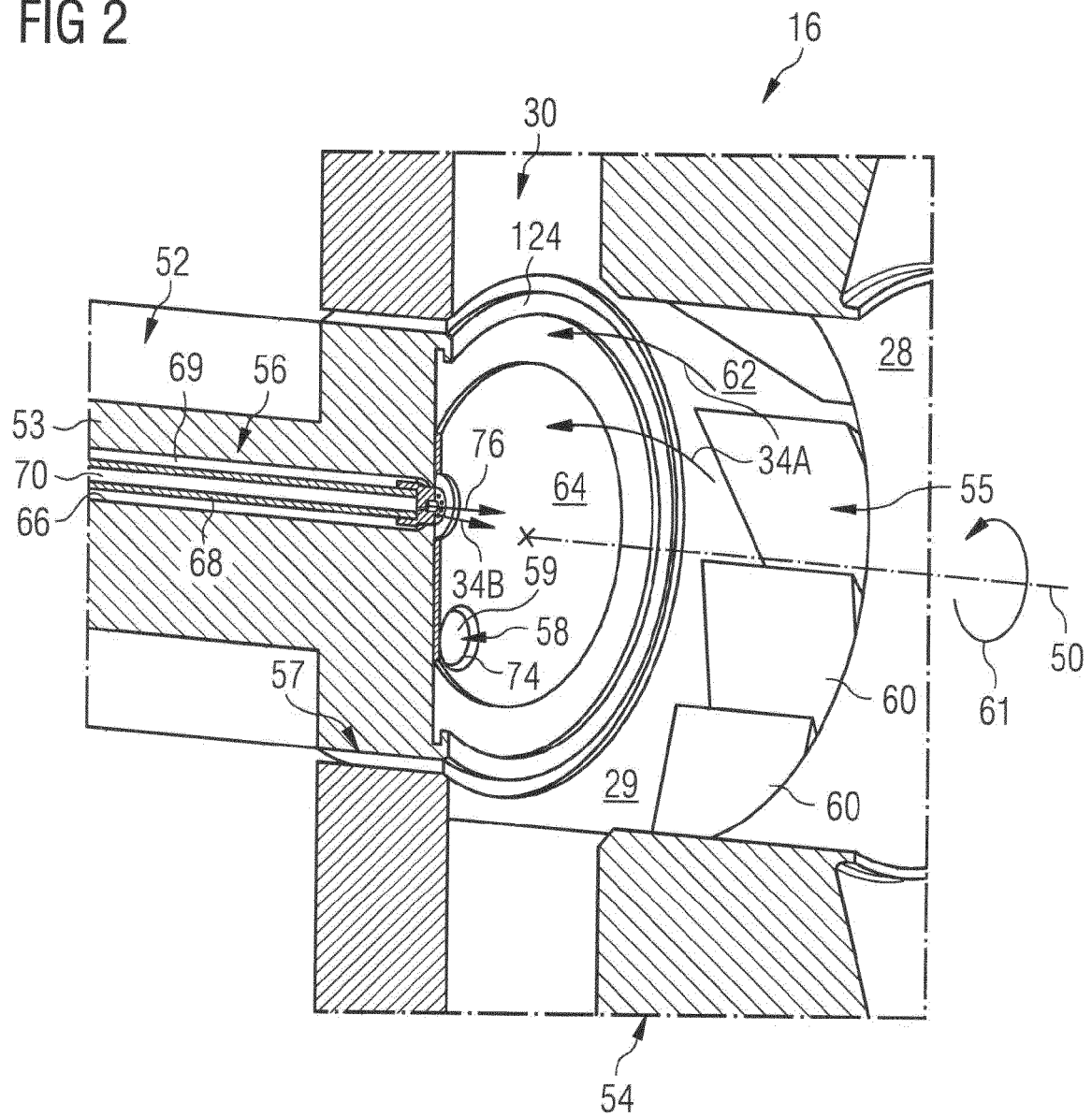


FIG 3

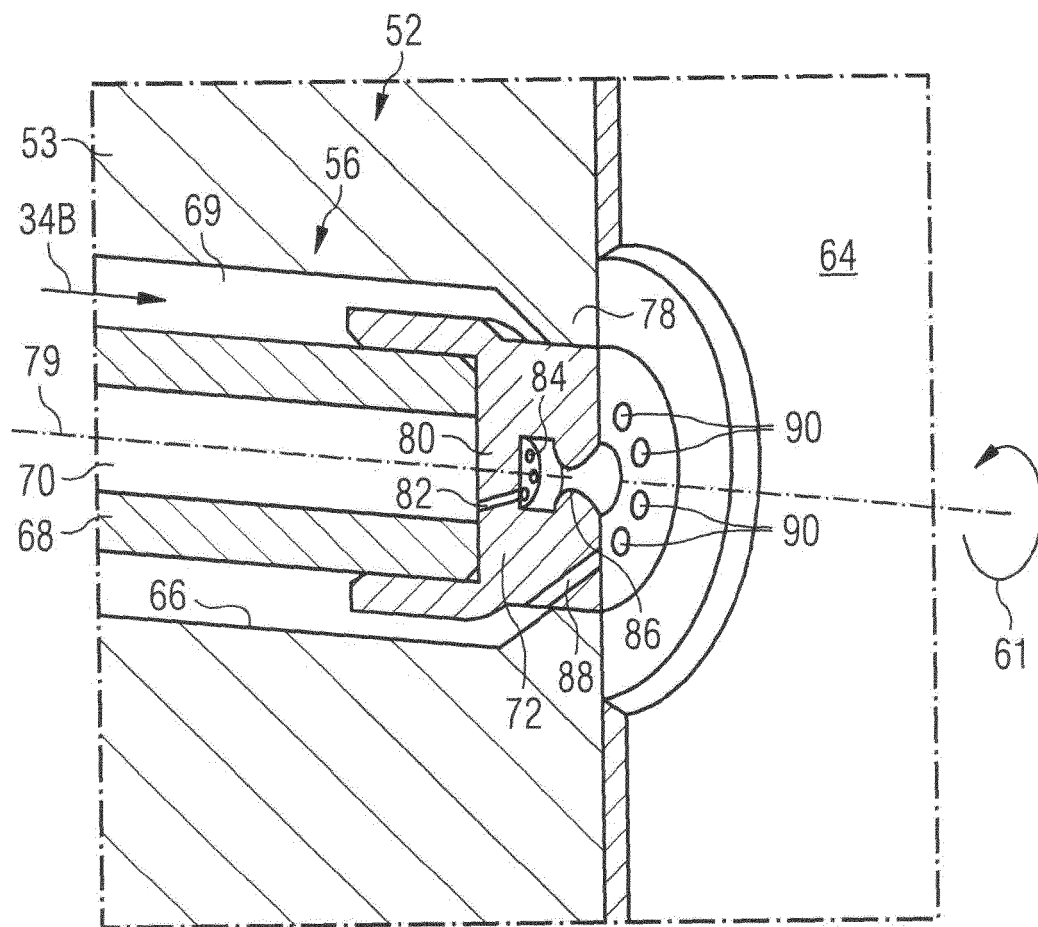


FIG 4

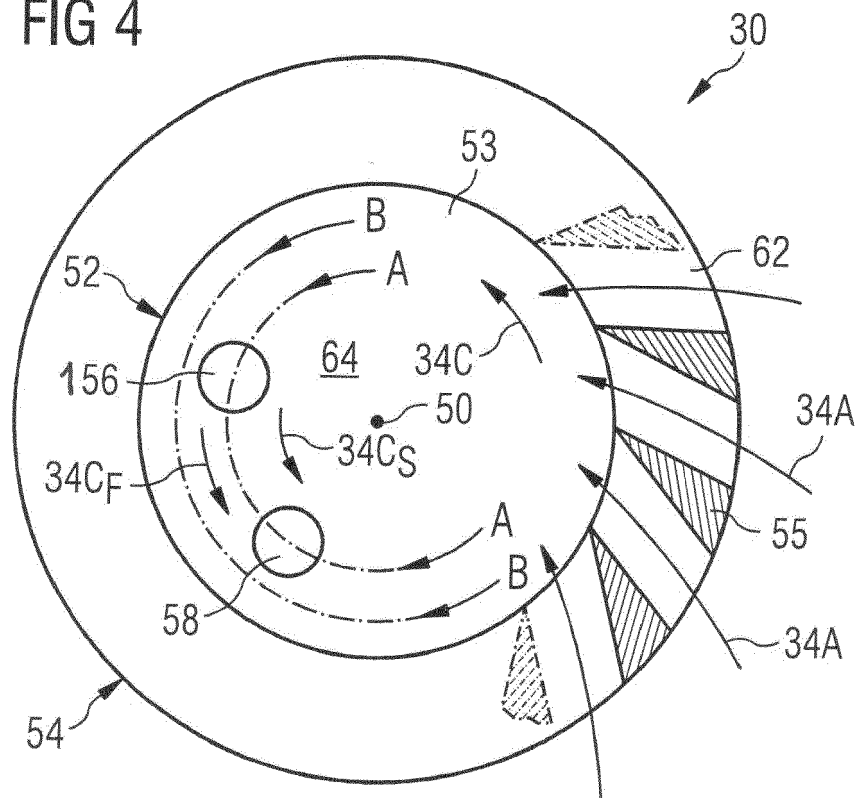


FIG 7

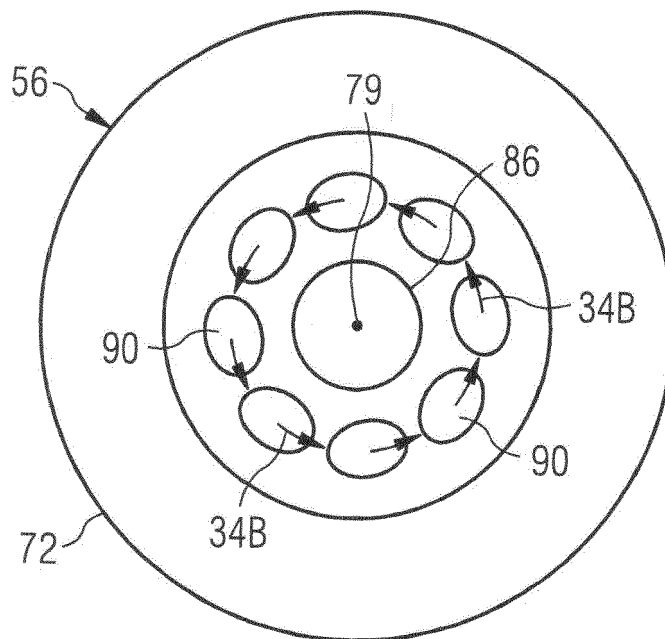


FIG 5

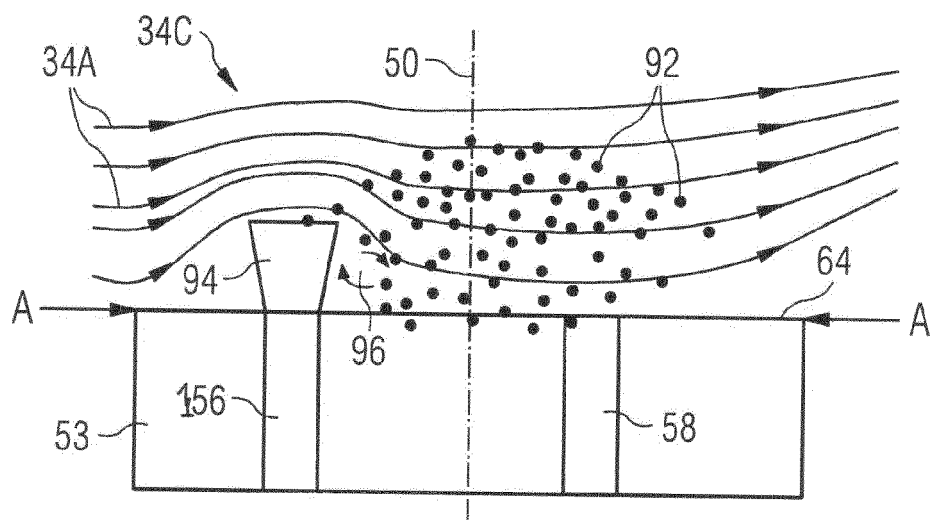
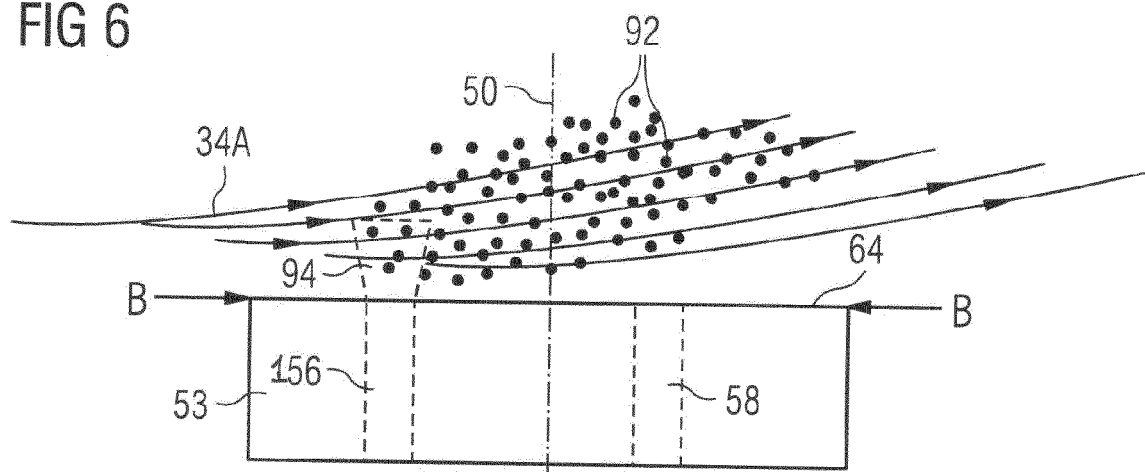
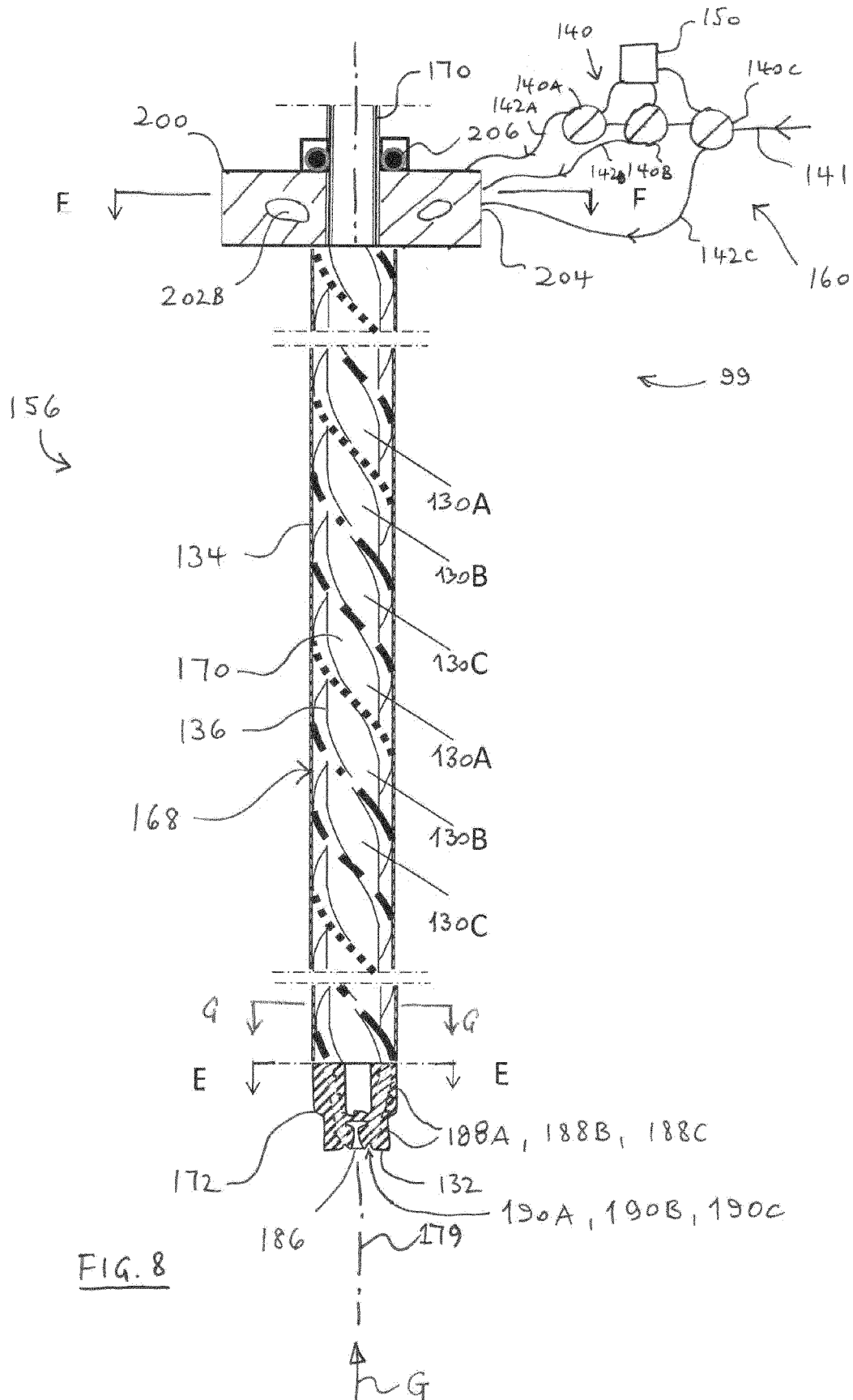


FIG 6





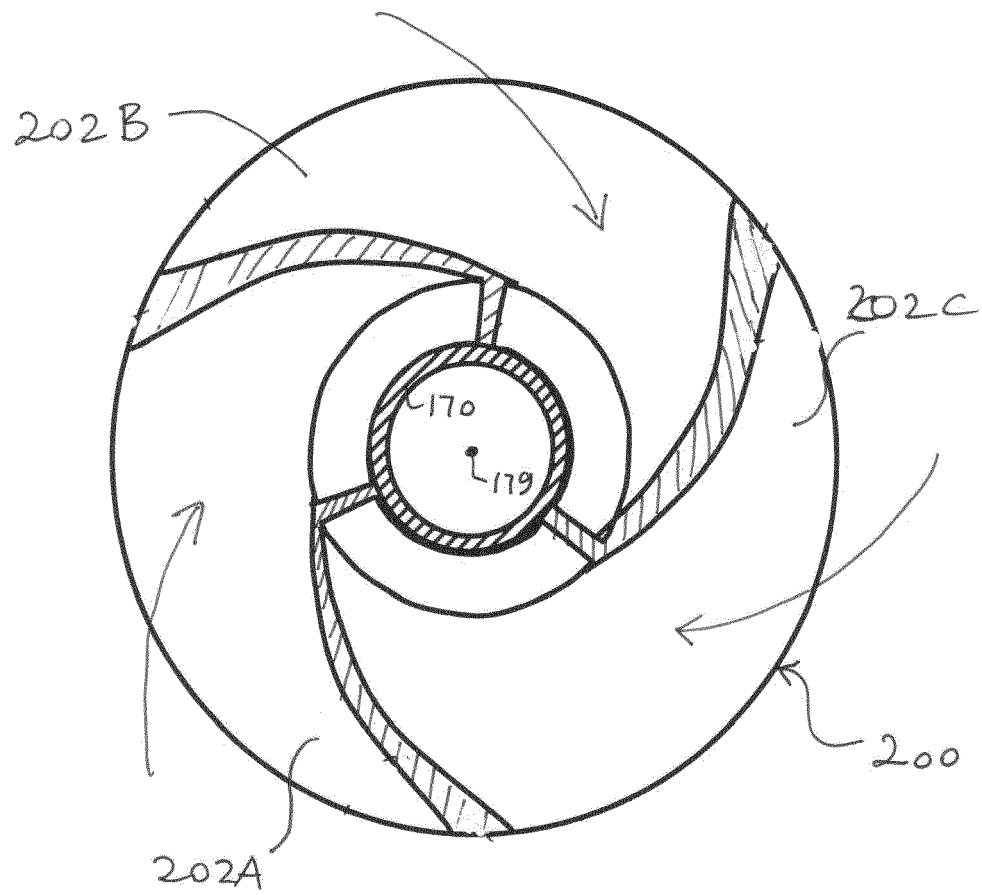


Figure 10 (view F-F)

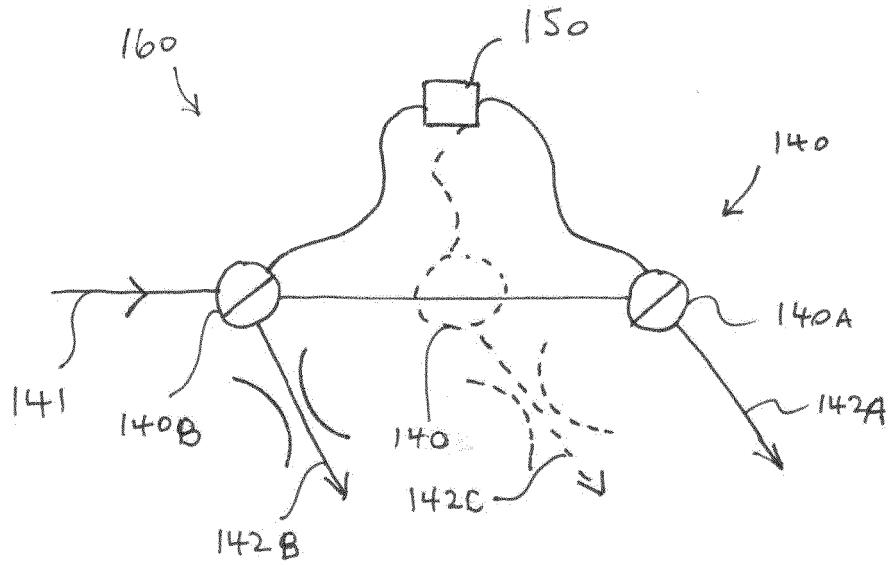


FIG. 11

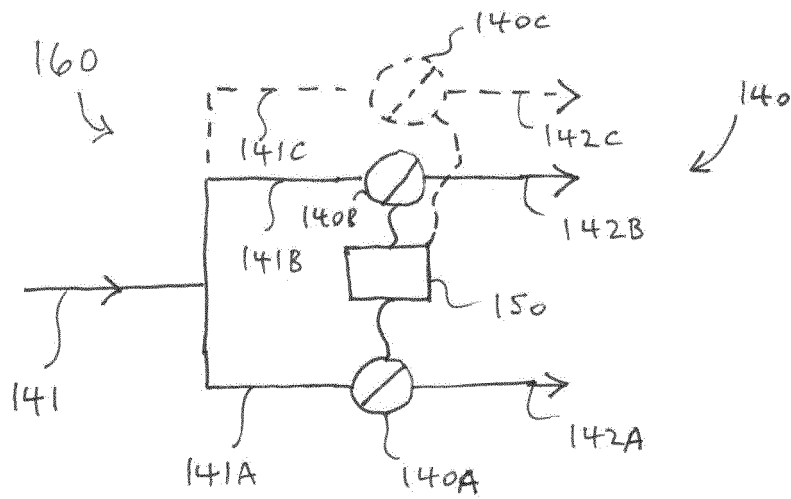


FIG. 12.

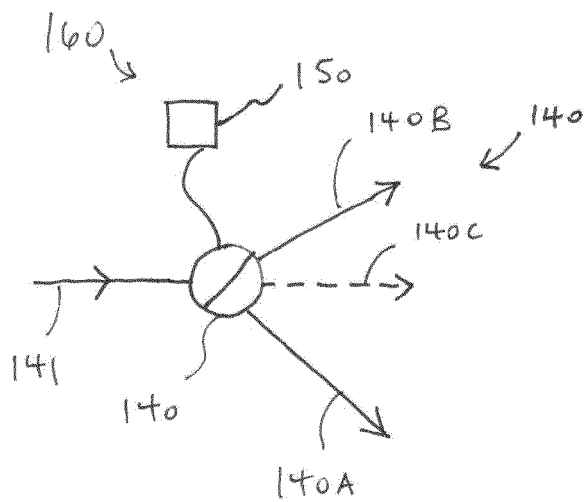


FIG. 13

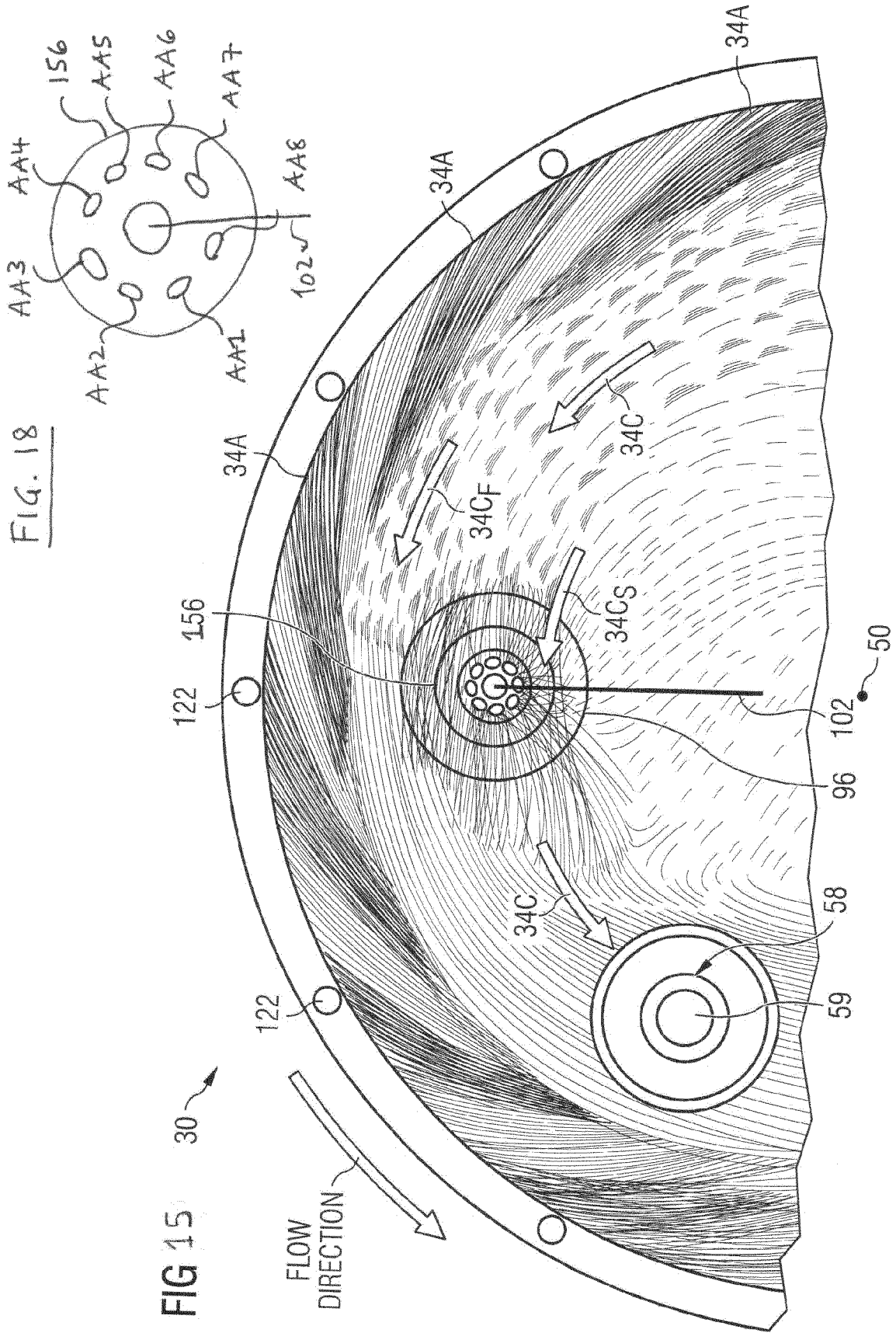


FIG. 16

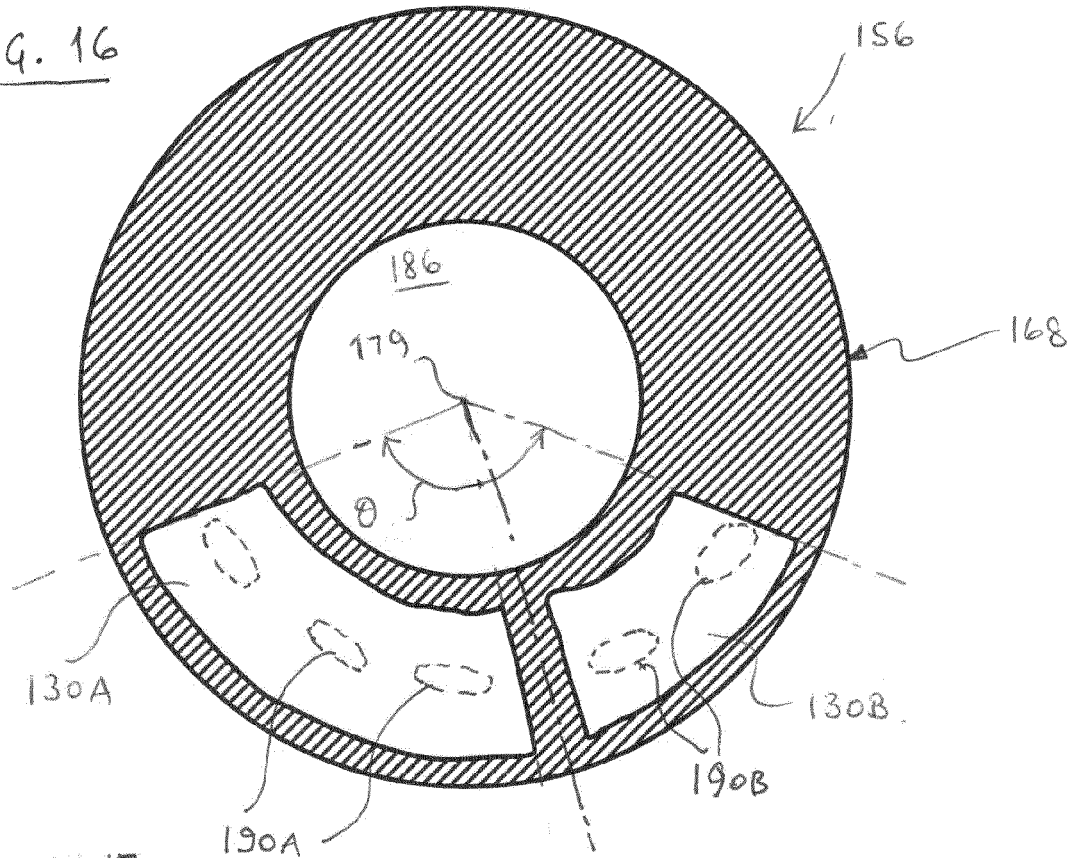
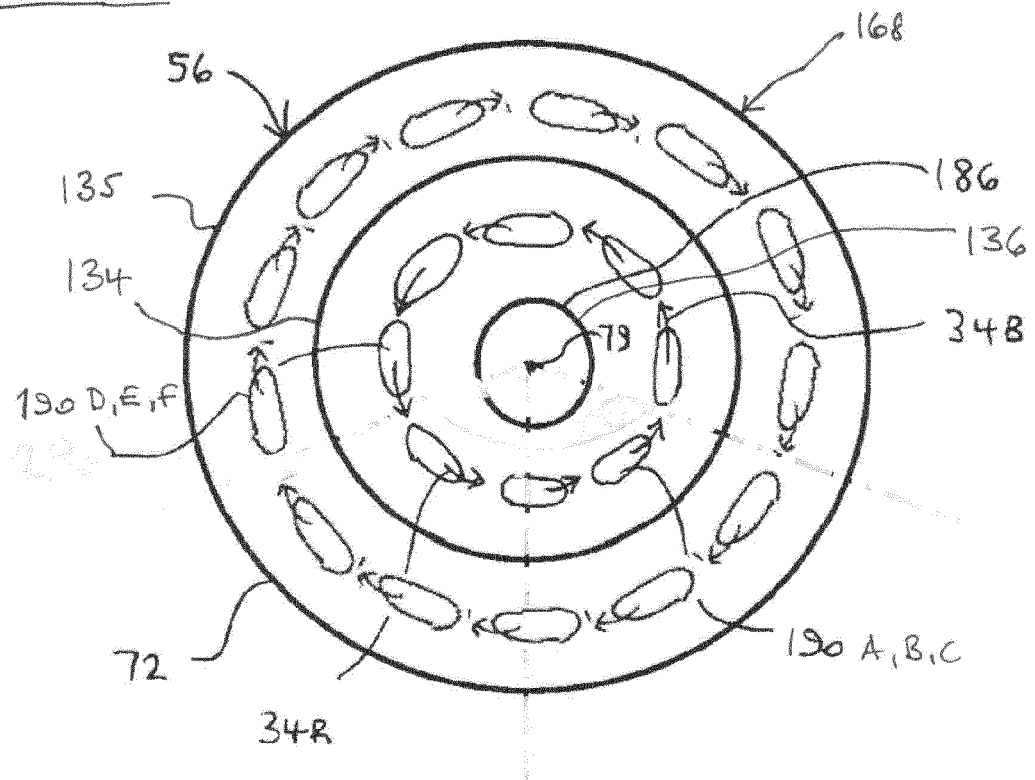


FIG. 17





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