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(54) TOROIDAL RING MANIFOLD FOR SECONDARY FUEL NOZZLE OF A DLN GAS TURBINE

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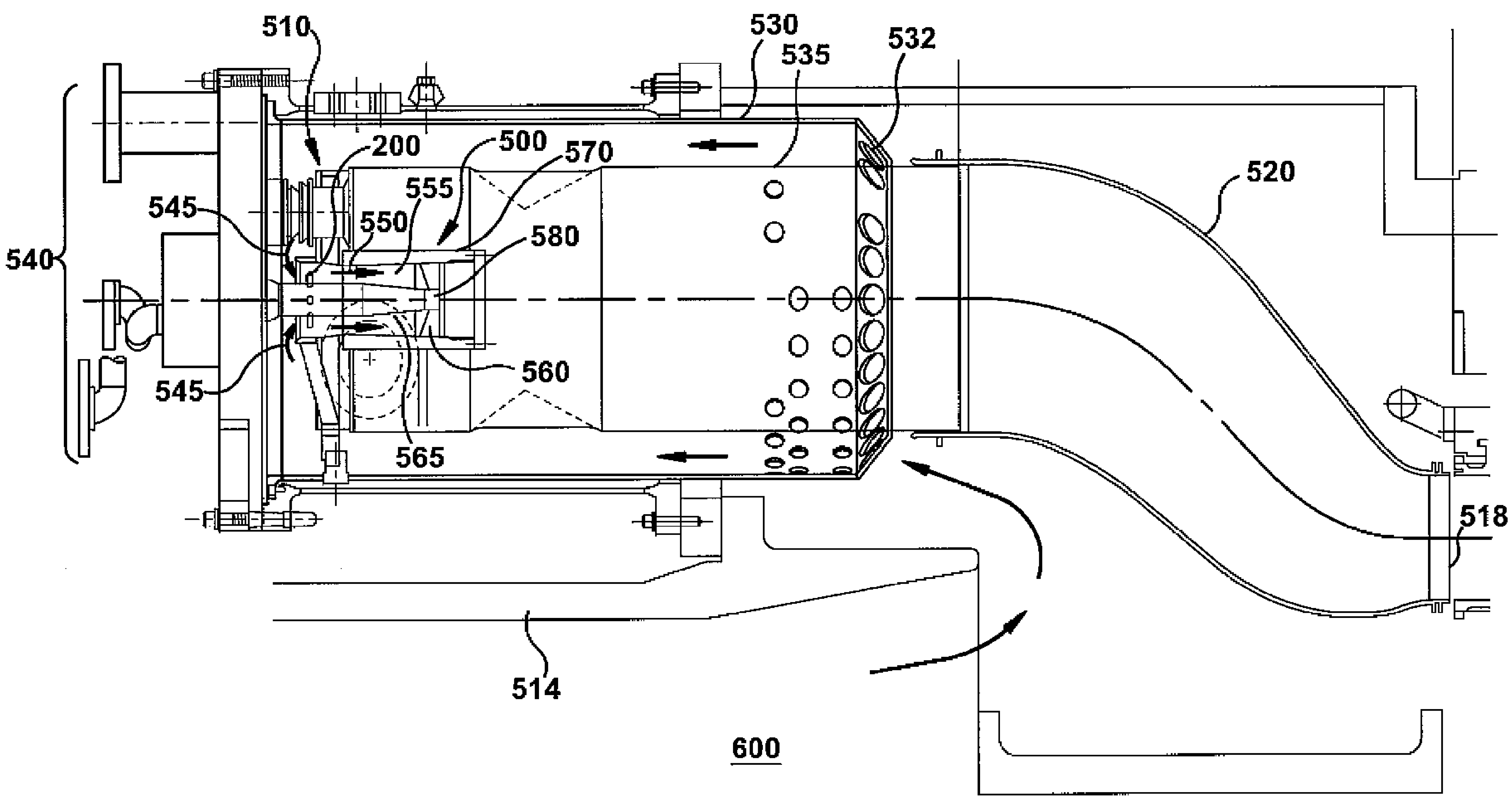
(57) ABSTRACT

A toroidal ring manifold for effectively dispersing premixing fuel with air in the secondary fuel nozzle of a combustor for a Dry Low NO_x (DLN) gas turbine, thereby providing stable combustion with low nitrogen oxide (NO_x) emissions. The toroidal ring manifold is centered around a centerbody hub of a secondary fuel nozzle assembly in a premixing volume between the nozzle centerbody hub body and a centerbody cap. The ring manifold receives fuel from the nozzle body and dispenses premix fuel from a plurality of rows of individual holes on its downstream surface into an axial airstream. The number and location of the rows, the number, size and spacing of holes in each row, and the radial position of the toroidal ring manifold within the premixing volume are optimized to promote premixing.



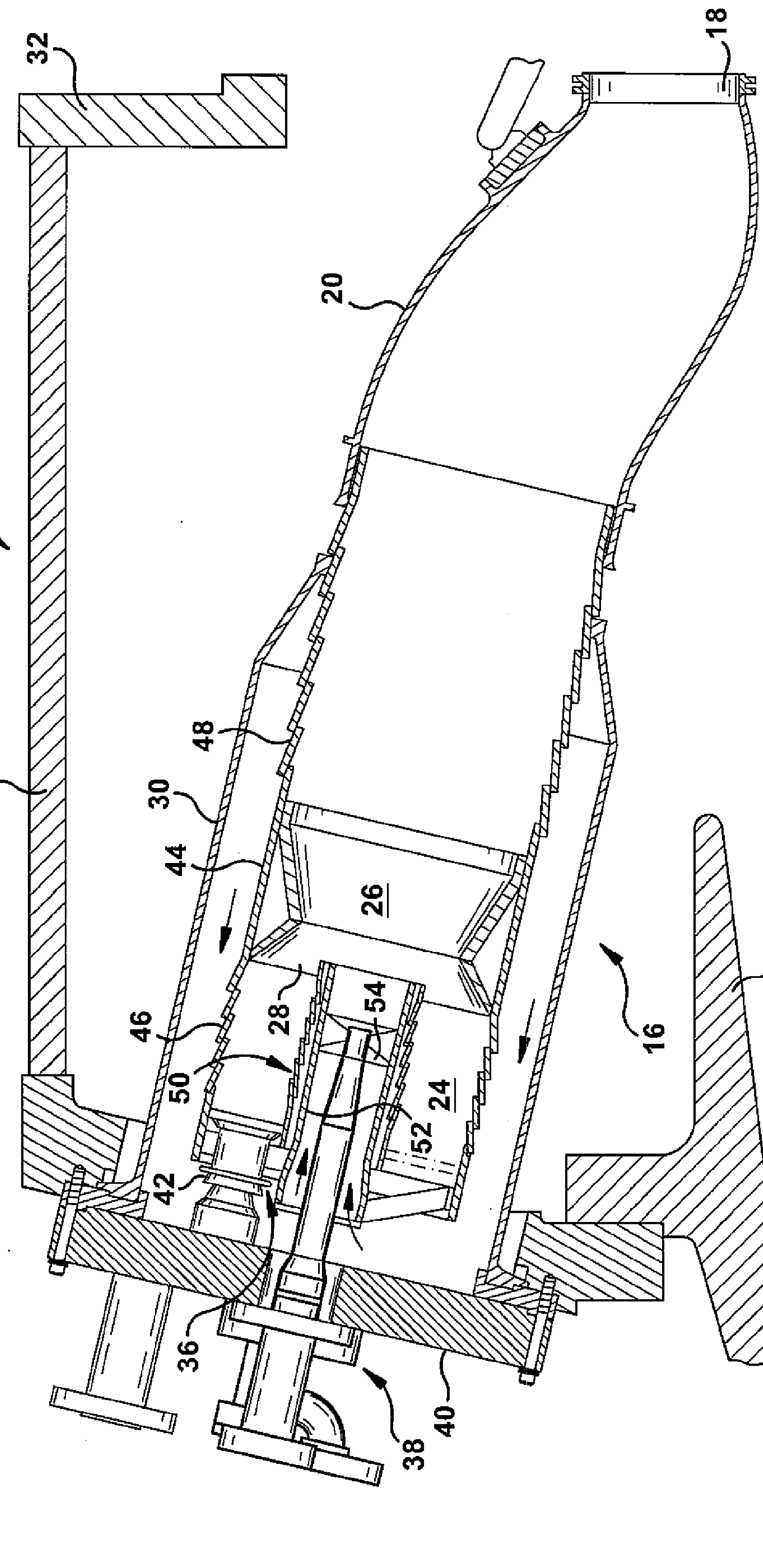
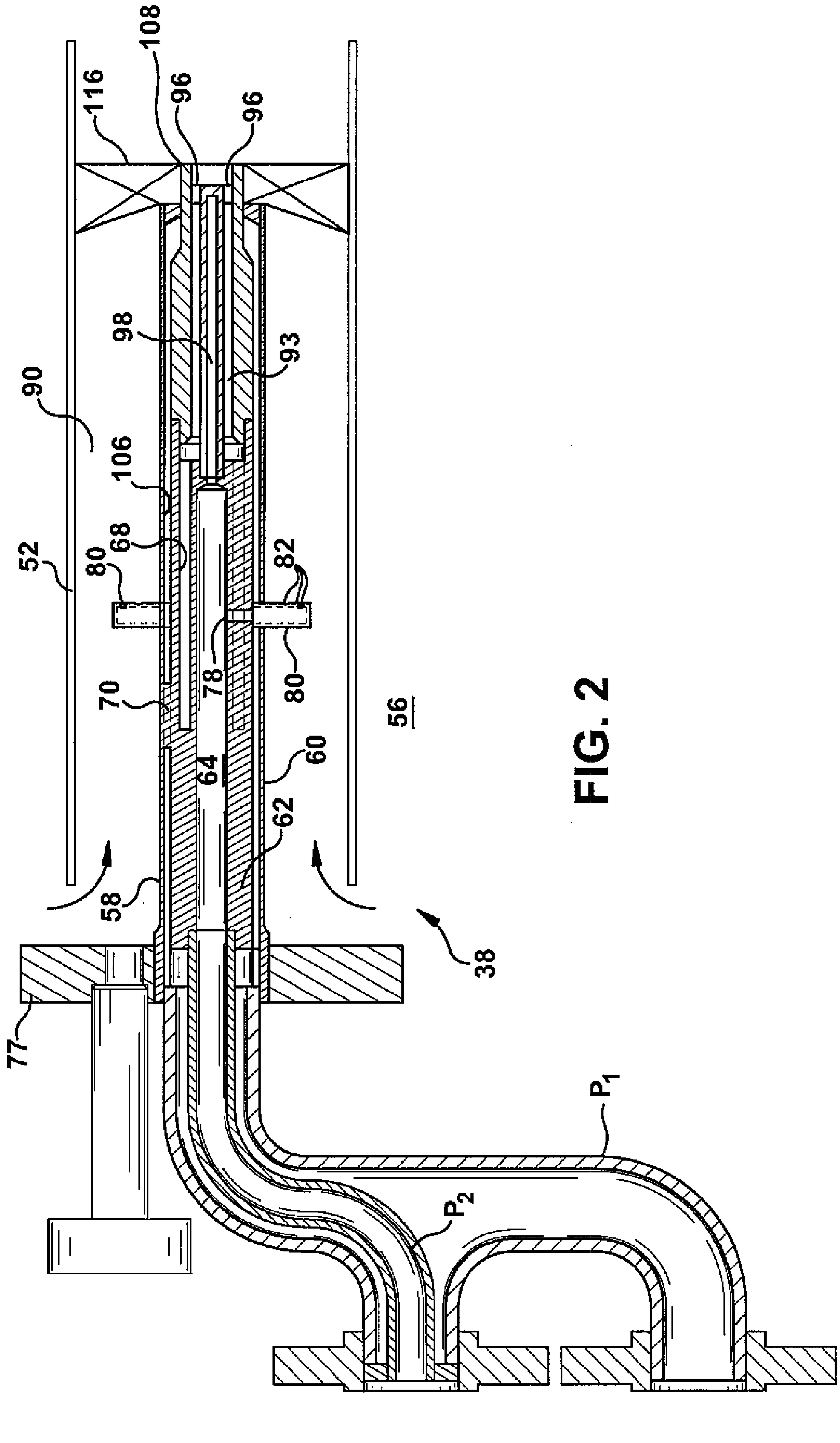


FIG. 1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108
96
96
98
93
90
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68
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56
64
60
62
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77
P_1
P_2

FIG. 2

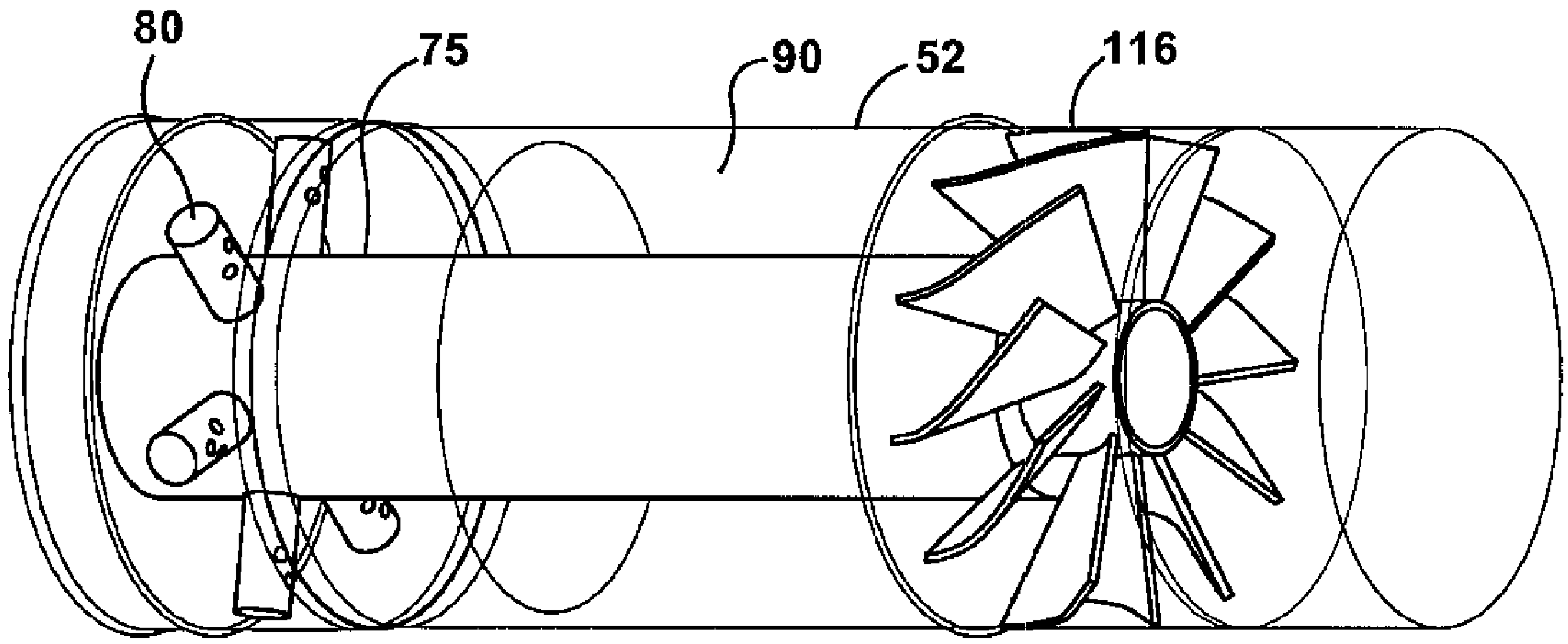


FIG. 3A

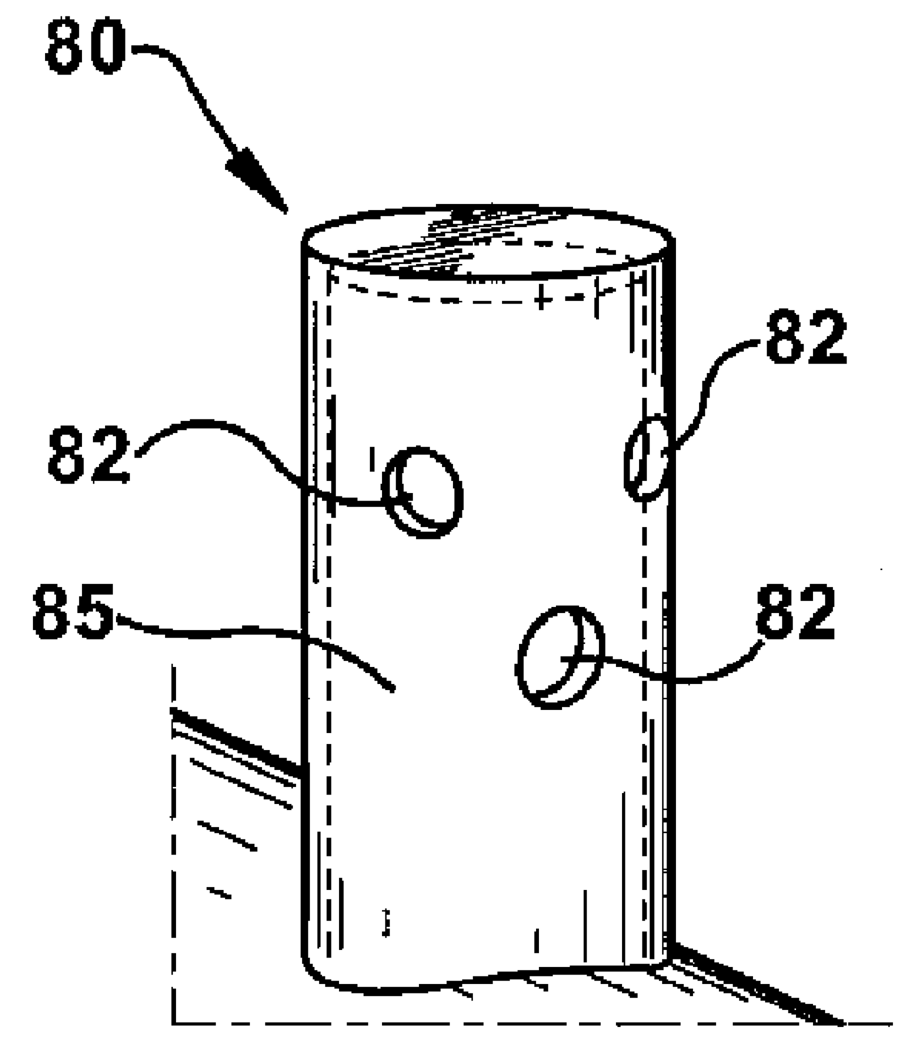


FIG. 3B

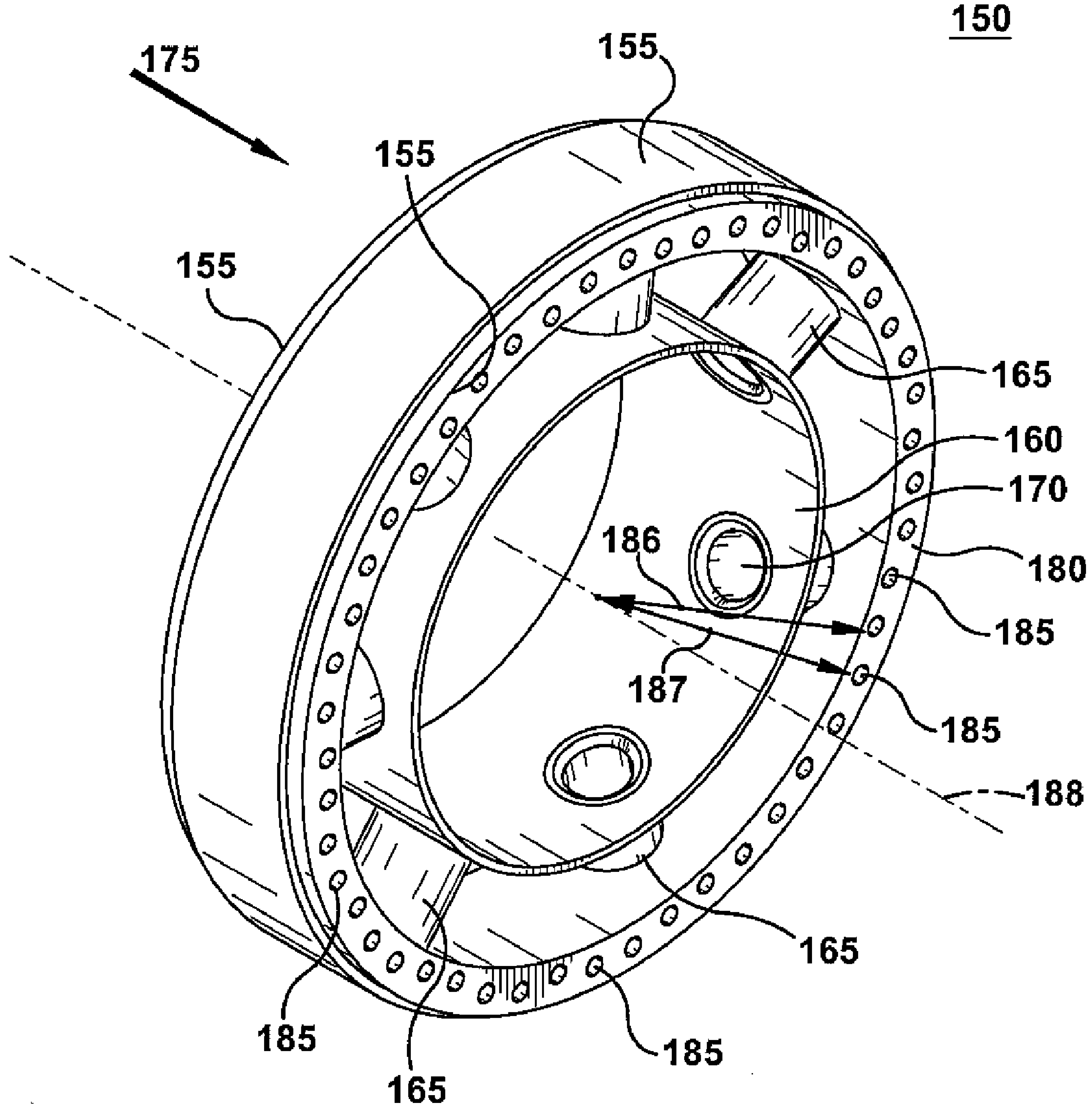

150
175
155
155
155
165
160
170
186
180
185
187
185
188
165
185
165
185

FIG. 4

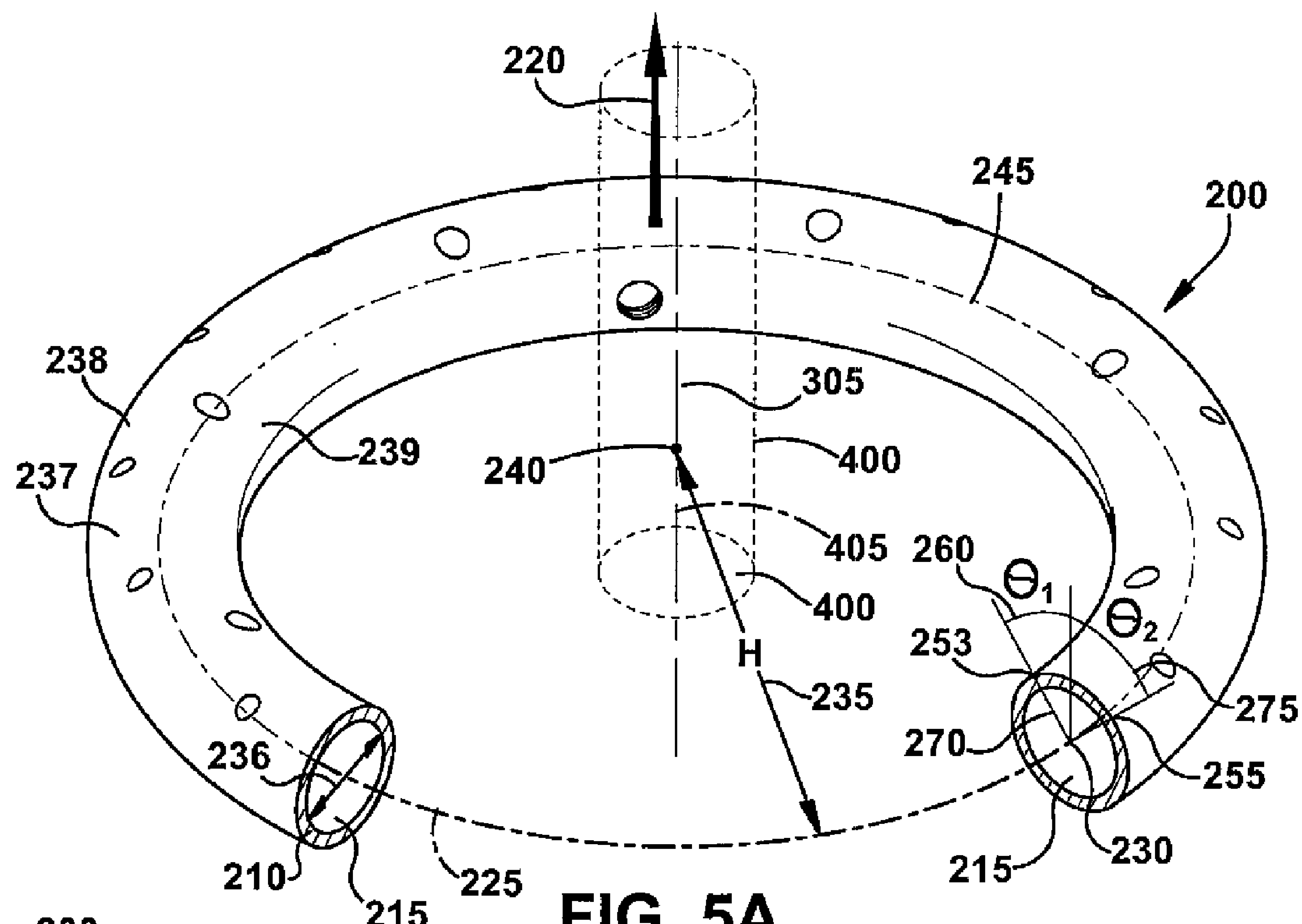


FIG. 5A

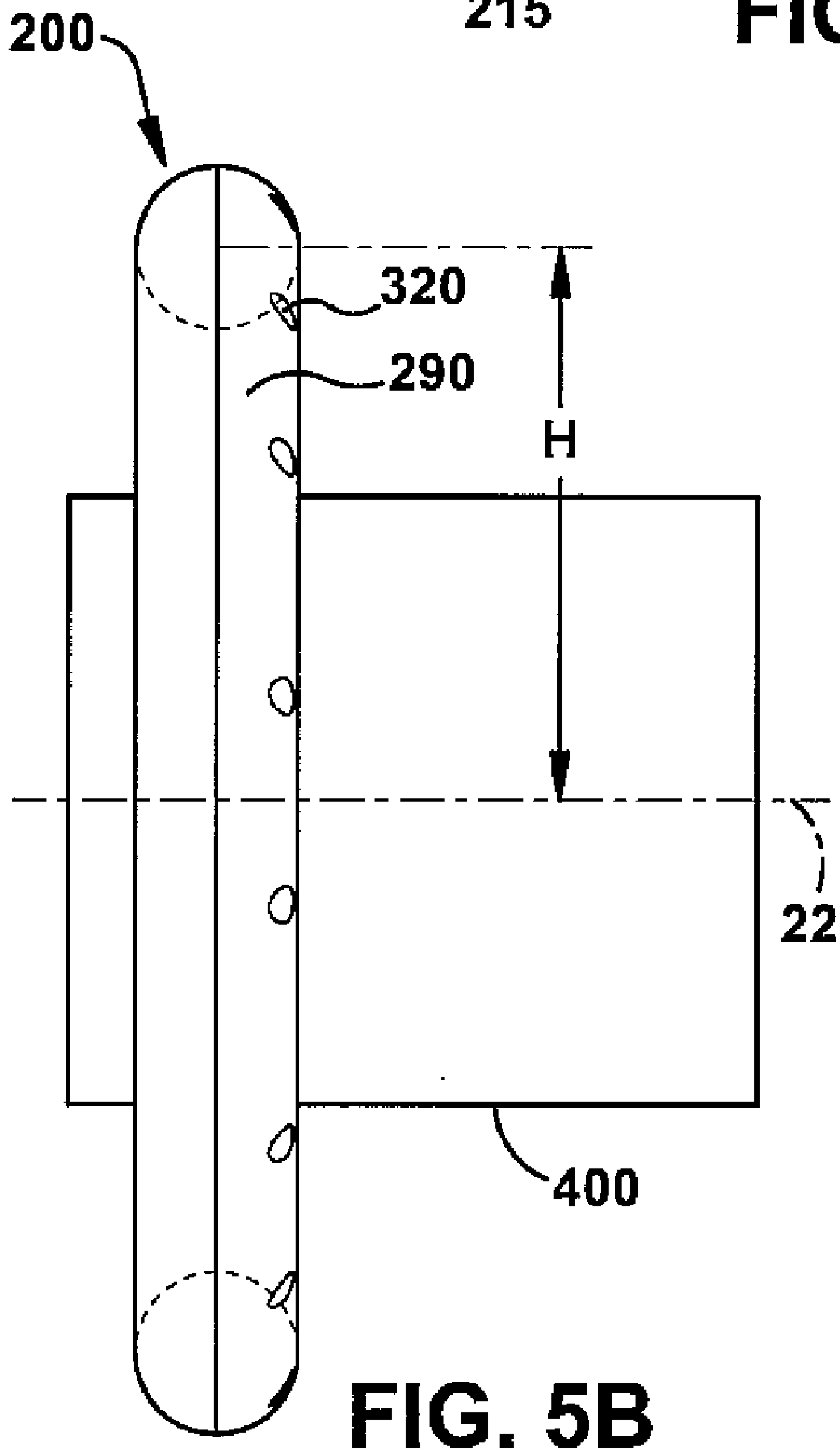


FIG. 5B

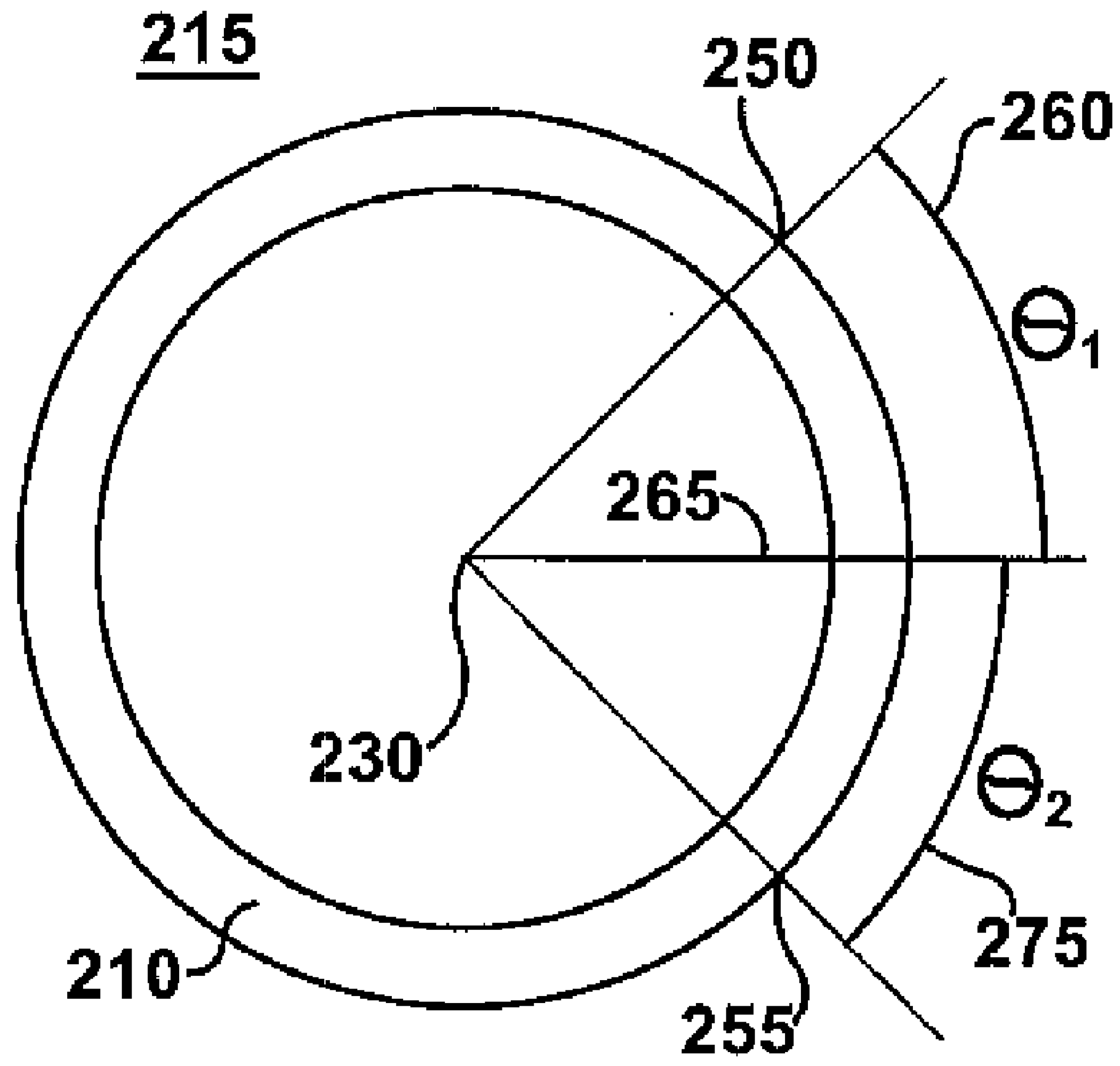
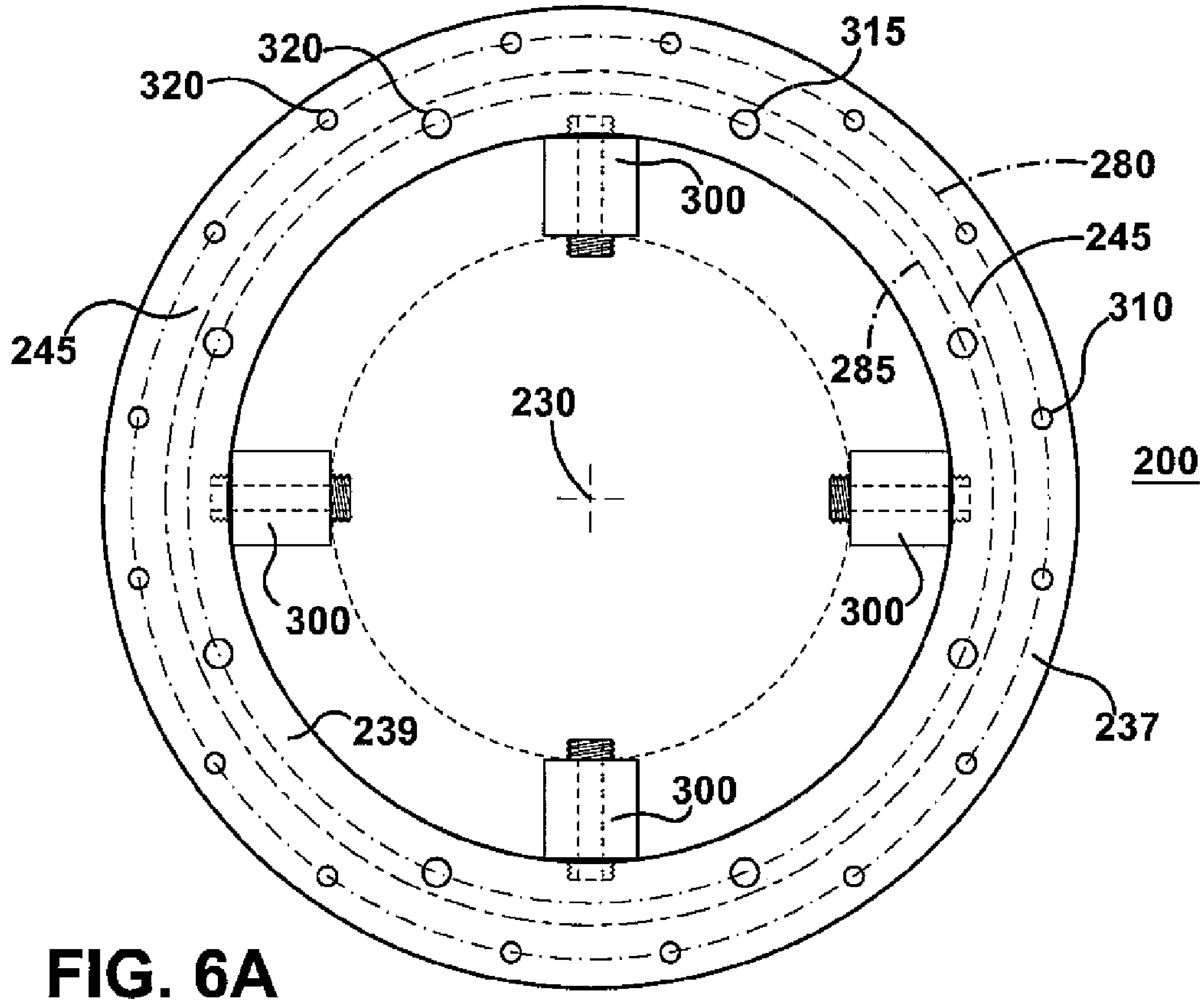


FIG. 5C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320
315
280
300
245
310
245
285
230
200
300
300
237
239
300

FIG. 6A

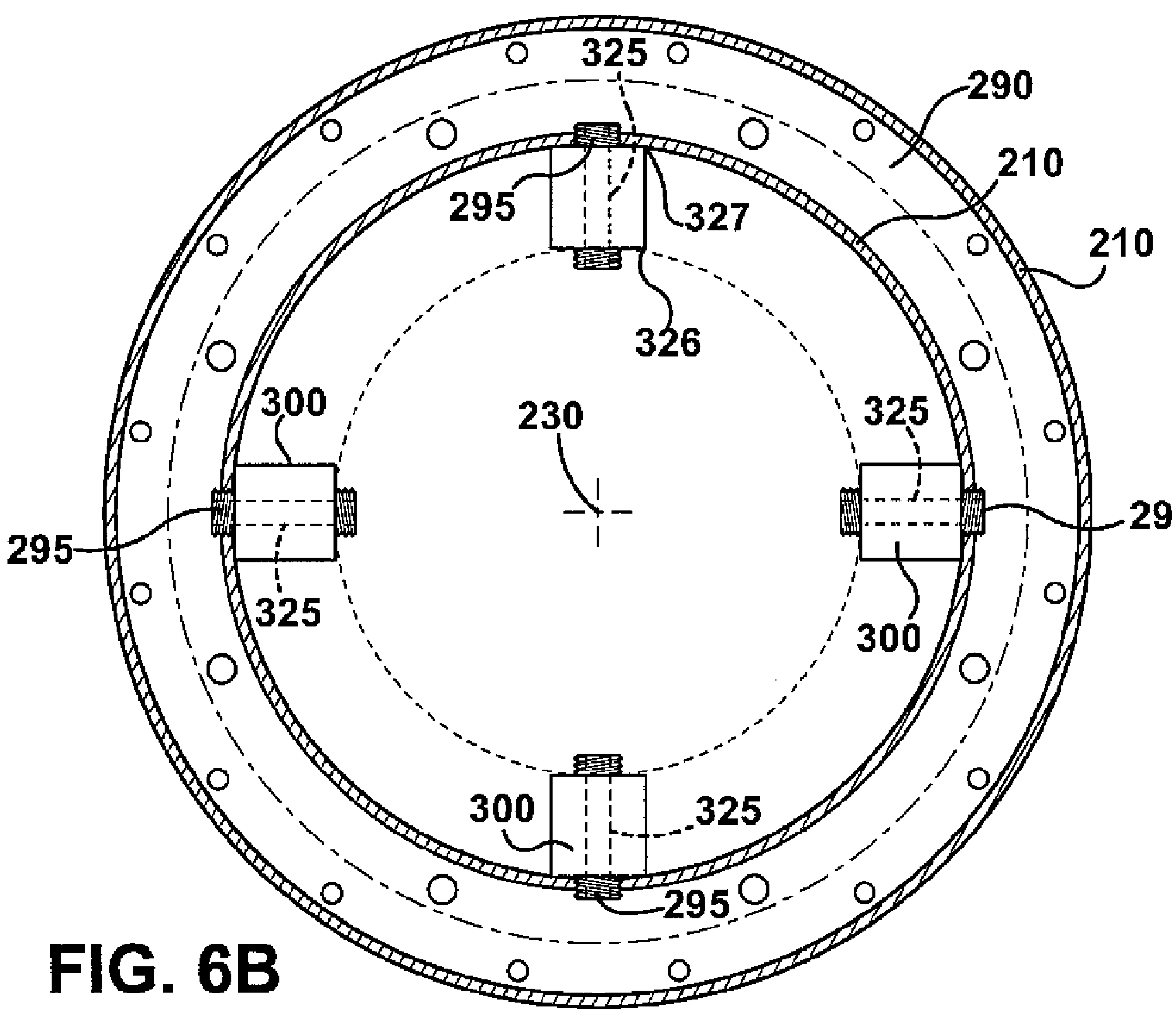
325
290
210
295
327
210
326
300
230
325
295
295
325
300
300
325
295

FIG. 6B

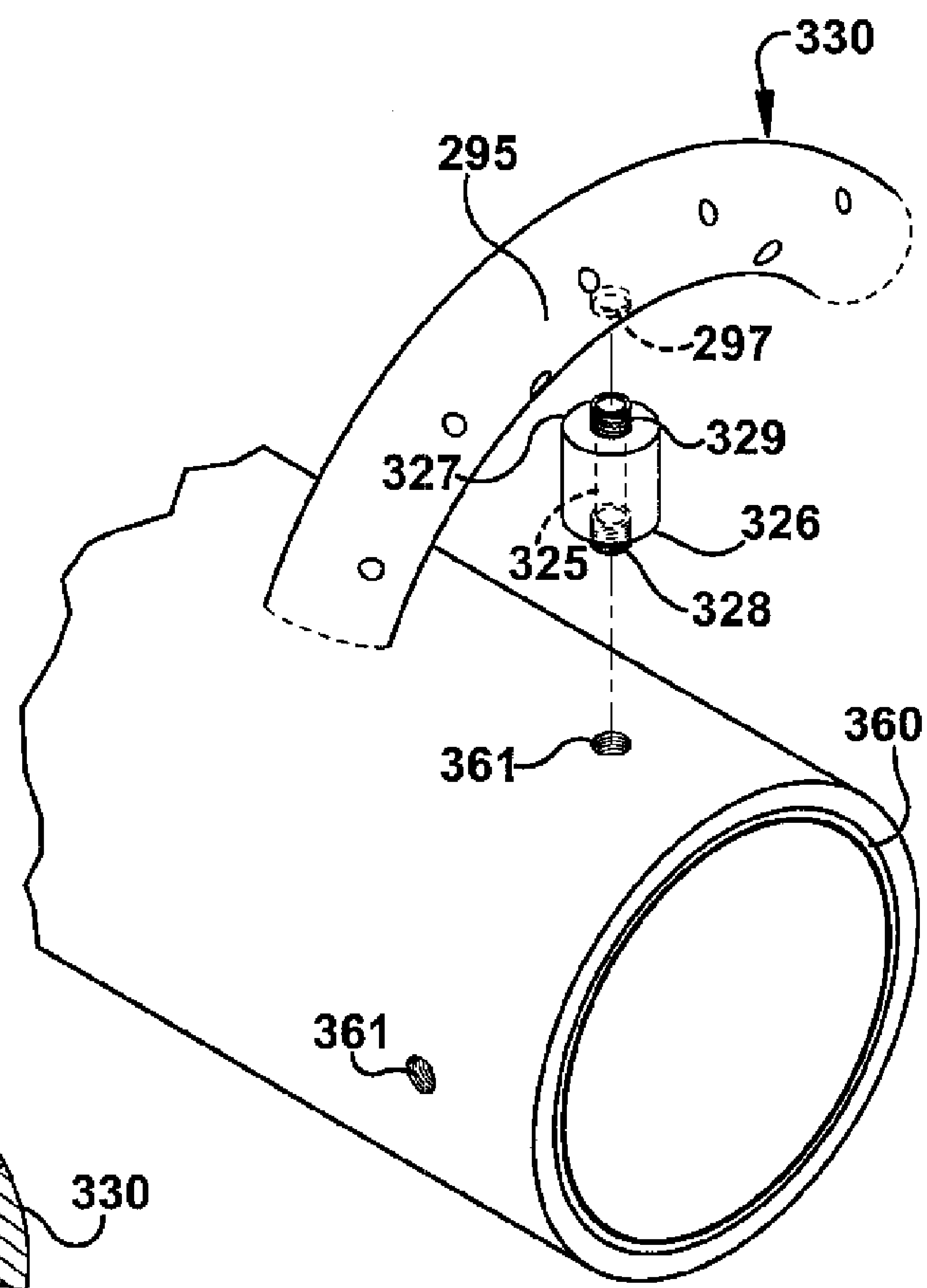
330
295
297
329
327
326
325
328
360
361
361

FIG. 7A

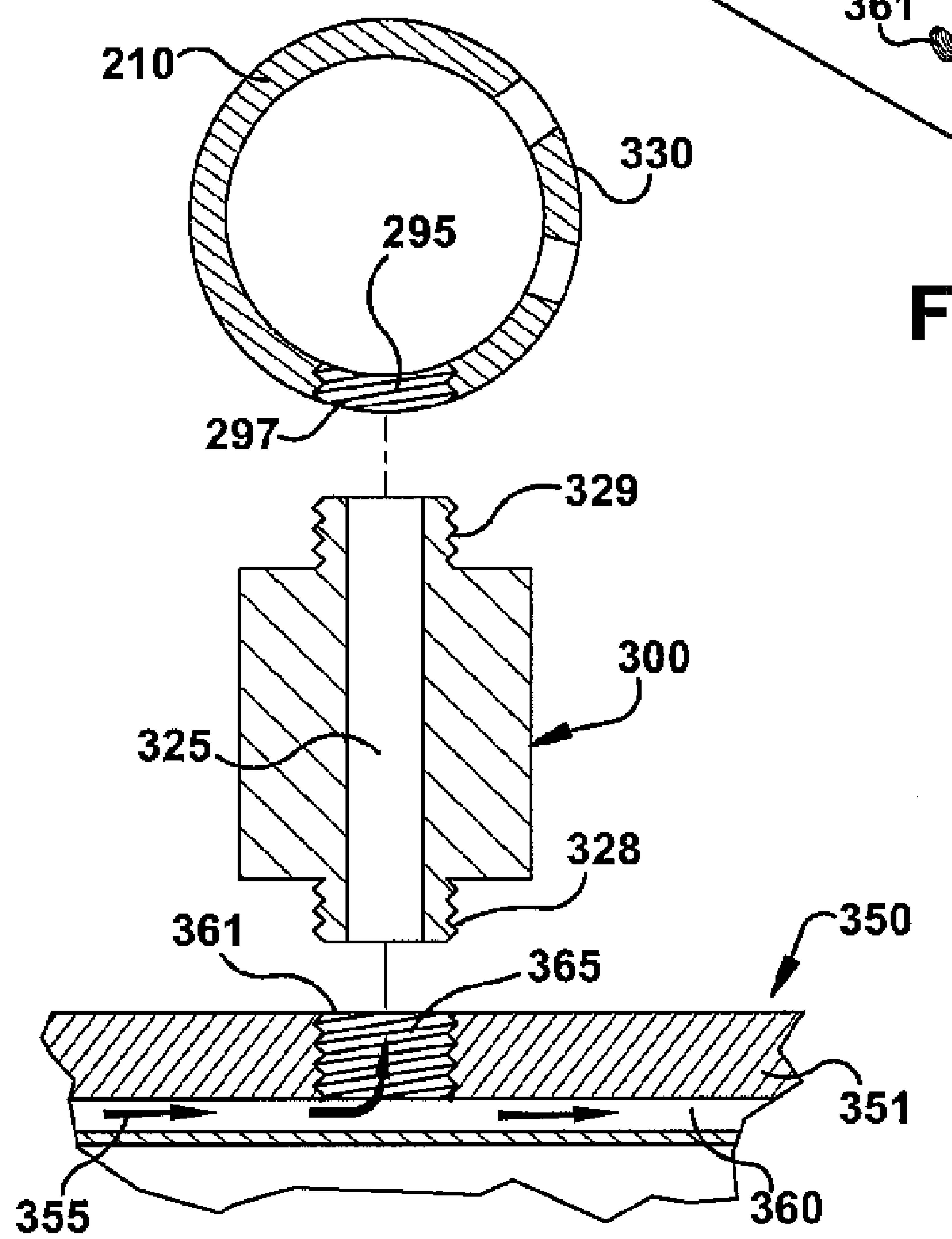
210
330
295
297
329
300
325
328
361
365
350
351
355
360

FIG. 7B

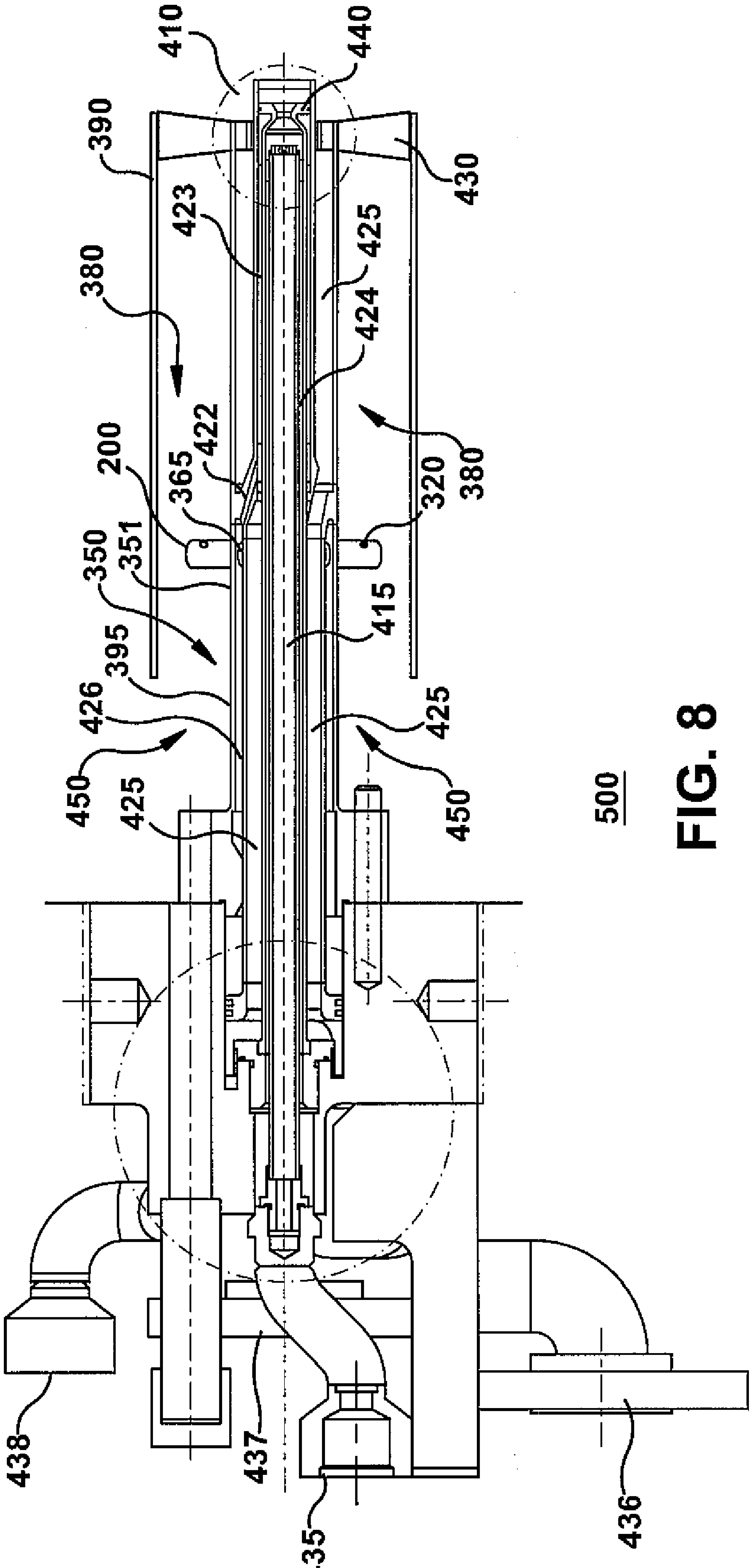
410
440
390
430
423
425
380
424
422
200
365
320
380
350
351
415
395
426
425
450
425
450
500
438
437
435
436

FIG. 8

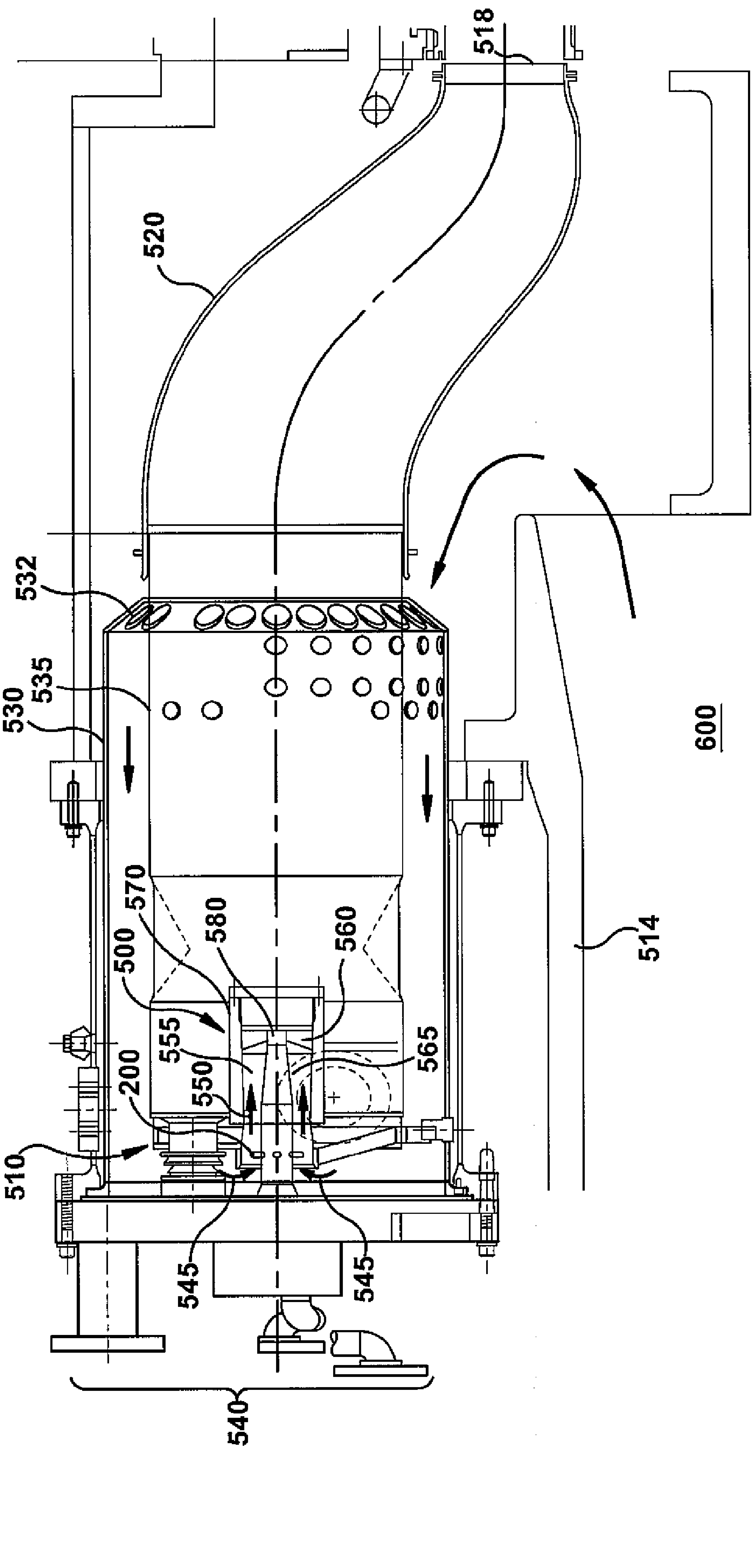
518
520
532
535
530
570
580
560
500
555
565
200
550
510
545
545
540
514
600

FIG. 9

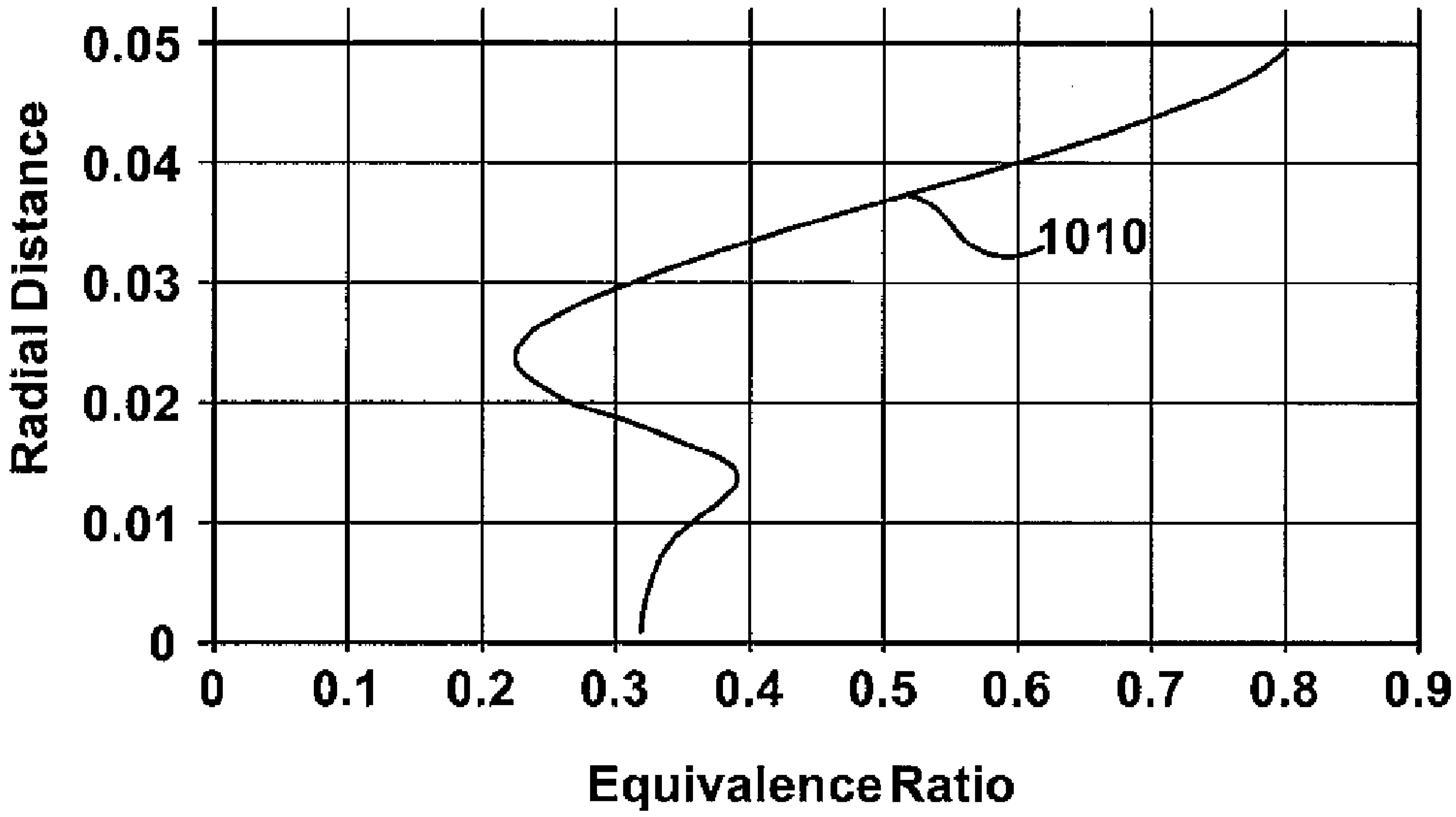

FIG. 10A

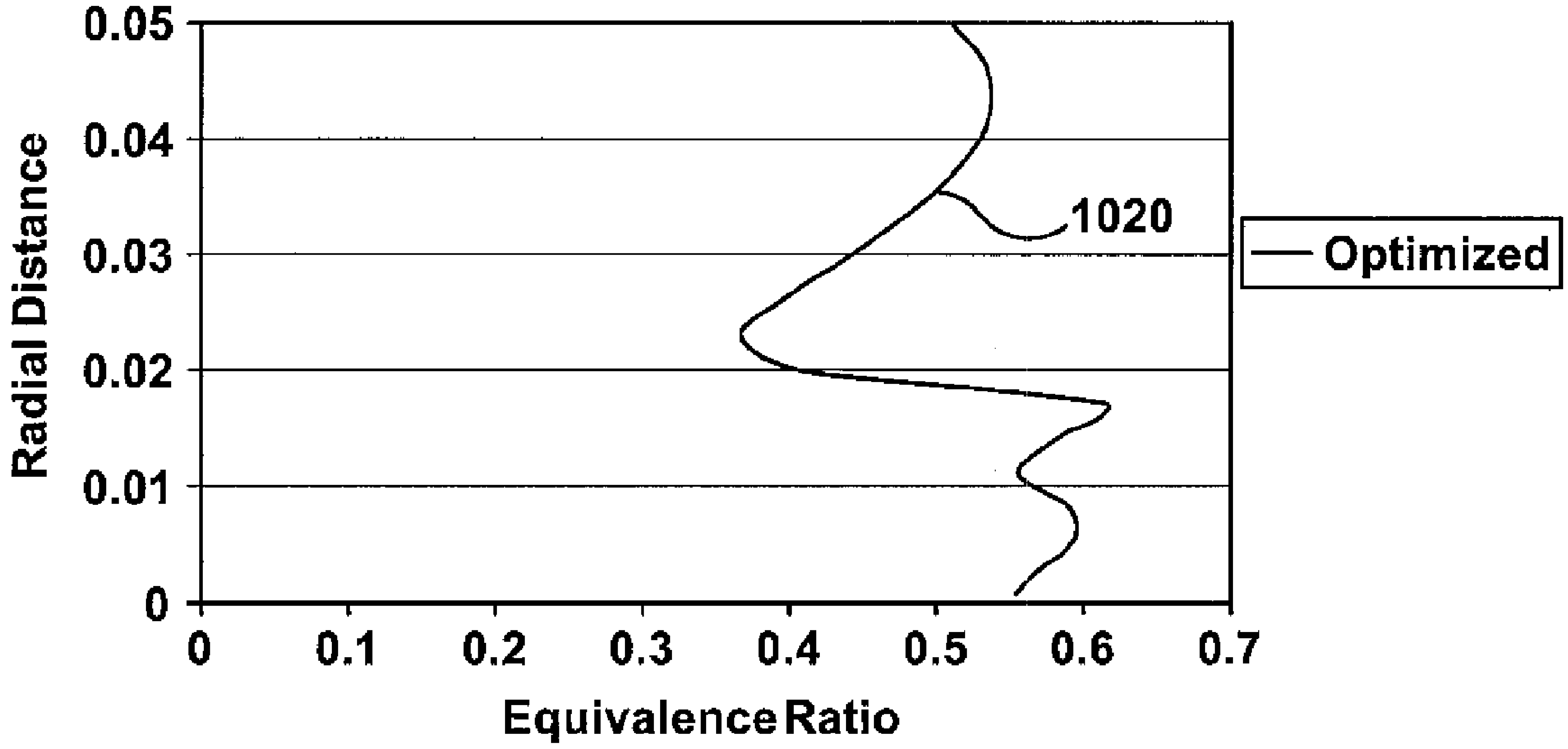

FIG. 10B

TOROIDAL RING MANIFOLD FOR SECONDARY FUEL NOZZLE OF A DLN GAS TURBINE

BACKGROUND OF THE INVENTION

[0001] The invention relates generally to a secondary fuel nozzle for a gas turbine combustor and more specifically to a toroidal ring manifold for fuel premixing in the secondary fuel nozzle of a Dry Low NOx (DLN) gas turbine.

[0002] FIG. **1** illustrates a prior art combustor for a gas turbine **12**, which includes a compressor **14** (partially shown), a plurality of combustors **16** (one shown for convenience and clarity), and a turbine represented by a single blade **18**. Although not specifically shown, the turbine **16** is drivingly connected to the compressor **14** along a common axis. The compressor **14** pressurizes inlet air, which is then reverse flowed to the combustor **14** where it is used to cool the combustor **16** and to provide air to the combustion process. Although only one combustor **14** is shown, the gas turbine **10** includes a plurality of combustors **16** located about the periphery thereof. A transition duct **20** connects the outlet end of each combustor **16** with the inlet end of the turbine **18** to deliver the hot products of combustion to the turbine **18**.

[0003] Each combustor **16** comprises a primary or upstream combustion chamber **24** and a secondary of downstream combustion chamber **26** separated by a venturi throat region **28**. The combustor **16** is surrounded by a combustor flow sleeve **30**, which channels compressor discharge air flow to the combustor. The combustor is further surrounded by an outer casing **31**, which is bolted to the turbine casing **32**.

[0004] Primary nozzles **36** provide fuel delivery to the upstream combustion chamber **24** and are arranged in an annular array around a central secondary nozzle **38**. Each of the primary nozzles **36** protrudes into the primary combustion chamber **24** through a rear wall **40**. Secondary nozzle **38** extends from a rear wall **40** to the throat region **28** in order to introduce fuel into the secondary combustion chamber **26**. Fuel is delivered to the primary nozzles **36** through fuel lines (not shown) in a manner well known in the art.

[0005] Combustion air is introduced into the fuel stage through air swirlers **42** positioned adjacent the outlet ends of nozzles **36**. The swirlers **42** introduce swirling combustion air, which mixes with the fuel from nozzles **36** and provides an ignitable mixture for combustion on startup, in chamber **24**. Combustion air for the swirlers **42** is derived from the compressor **14** and the routing of air between the combustion flow sleeve **30** and the wall **44** of the combustion chamber. The cylindrical wall **44** of the combustor is provided with slots or louvers **46** in the primary combustion chamber **24**, and similar slots or louvers **48** downstream of the secondary combustion chamber **26** for cooling purposes, and for introducing dilution air into the combustion zones to prevent substantial rises in flame temperature. The secondary nozzle **38** is located within a centerbody **50** and extends through a liner **52** provided with a swirler **54** through which combustion air is introduced for mixing with fuel from the secondary nozzle.

[0006] Referring now to FIG. **2**, a gas-only secondary fuel nozzle assembly **56** is illustrated. Fuel is supplied to sustain a flame by diffusion pipe P_1 and to sustain a premixed flame by pipe P_2 which, at the inlet to the secondary fuel nozzle assembly **56**, are arranged concentrically relative to each other.

[0007] The following will primarily describe the premix fuel secondary nozzle assembly **56**. A rearward component, or gas body, **58** includes an outer sleeve portion **60** and an inner hollow core portion **62** provided with a central bore **94** forming a premix fuel passage **64**. A plurality of axial air passages **68** are formed in a forward half of the rearward component **58** in surrounding relationship to the premix passage **64**. A like number of radial wall portions (e.g., four) are arranged about the end of sleeve portion **60** and each includes an inclined, radial aperture **70** for permitting air within the liner **52** to enter a corresponding air passage **68**. The rearward end of component **58** is adapted to receive the fuel pipes P_1, P_2, respectively, as shown in FIG. **2**, within a mounting flange **77**.

[0008] A plurality of radial holes **78** are provided about the circumference of the forward portion of component **58**, permitting a like number of radial gas injector tubes (pegs) **80** to be received therein to thereby establish communication with the premix passage **64**. Each peg **80** is provided with a plurality of apertures or orifices **82** so that fuel from the premix passage **64** may be discharged into a premixing area **90** between the secondary nozzle assembly **56** and liner **52** for mixing with combustion air within the liner. The pegs **80** are designed to distribute fuel into the airflow. Good mixing of fuel and air in the premixing area **90** is necessary to minimize nitrogen-oxide (NO_x) emissions. A flame holding swirler **116** which may or may not be integral with the nozzle is located at the forward end of the secondary nozzle, extending radially between the reduced diameter forward end **108** and the liner **52** for swirling the premixed fuel/air flowing within the liner. Combustion air will enter the secondary nozzle assembly **56** via holes **70** and will flow through a premix passage defined by passage **64**, pilot bore **98** and pilot orifice **100**. This fuel, along with air from swirler slots **96**, provides a diffusion flame sub-pilot. At the same time, a majority of the fuel supplied to the premix passage will flow into the gas injectors **80** for discharge from orifices **82** toward the liner **52** where it is mixed with air.

[0009] As illustrated in FIG. **3**A-**3**B, premixing of fuel with air as performed in prior art secondary fuel nozzles may include the plurality of pegs **80**, equally spaced around the periphery of the secondary nozzle body **75** in the premixing volume **40**. Each peg **80** may include a central cavity **85** running the length of the peg. The inner end of each peg may be attached to the nozzle body at the location of the radial fuel holes, thereby establishing communication between the fuel cavity in the nozzle body and the central cavity of the peg, as previously described with respect to FIG. **2**. Along a downstream surface of the peg **80**, a plurality of the fuel discharge holes **82** are provided from the central internal cavity, thereby providing for discharge of premix fuel into the airflow between the secondary nozzle body **75** and the liner **52**. Three radially-located fuel discharge holes **82** are provided along the downstream side of the peg **80**. Positioning of the hole location along the row of holes was varied. In this prior art secondary nozzle, six pegs are evenly distributed around the circumference of the secondary nozzle body **75**, with three orifices for fuel dispersal along the downstream side of the peg. However, the effective mixing of fuel and air is not complete. More complete mixing of the fuel and air can lead to lower NO_x emissions and more stable combustion.

[0010] The above described nozzle construction provides for the premixed mode of operation via a diffusion flame and, once in the premixed mode, operates to turn off the diffusion flame and start the premixing flame, for sustained operation. However, elevated emissions from a gas turbine is the result of insufficient mixing of air and fuel prior to burning in the combustion chamber. The existing peg design, described above, is not able to mix fuel and air properly to obtain the requisite degree of mixing for low emissions. Attempts to change the location of holes in the pegs have not been able to achieve satisfactory fuel and air mixing.

[0011] FIG. **4** illustrates a fuel distribution device **150** for a secondary fuel nozzle as described in U.S. Pat. No. 6,446,439 and U.S. Pat. No. 6,282,904 by Kraft et al. An annular fuel manifold **155** is mounted to a support sleeve **160** through support cylinders **165**. The manifold **155** presents a rectangular cross-section. The support sleeve **160** is affixed to the body of a secondary fuel nozzle (not shown) by welding. Fuel in the body of the secondary nozzle, passes through holes **170** in the support sleeve and through the support cylinders **165** into the hollow annular fuel manifold **155**. The annular fuel manifold **155** is positioned in an airstream **175** around secondary nozzle body (not shown). Fuel is distributed from the downstream face **180** of the annular fuel manifold through an array of apertures **185**. The apertures **185** may be at a first radial distance **186** or a second radial distance **187** within the airstream from a central axis. The direction of the apertures **185** with respect to the airflow may be collinear or at an angle. However, the rectangular-shaped annulus limits the angles of the apertures may make with respect to the direction of the airstream.

[0012] The cylindrical-shaped annular cylindrical fuel manifold **155** for fuel premix distribution may provide for radial and circumferential fuel distribution over the peg arrangement. However the annular manifold has limitations on mixing, stemming from the limited flow angles that may be created within respect to the airflow, and particularly with respect to the radial distribution of fuel into the airstream.

[0013] Accordingly, there is a need to provide an alternate structure to improve the fuel-air premixing in the secondary nozzle to promote lower emissions and improved combustion dynamics.

BRIEF DESCRIPTION OF THE INVENTION

[0014] The present invention relates to a toroidal ring manifold for effectively dispersing premixing fuel with air in the secondary nozzle of a combustor for a DLN gas turbine, thereby providing stable combustion with low nitrogen oxide (NO_x) emissions.

[0015] Briefly in accordance with one aspect of the present invention, a toroidal ring manifold for dispersing fuel into a premixing zone of a secondary fuel nozzle for a DLN gas turbine combustor is provided. The toroidal ring manifold includes a toroidal ring manifold shell of a generally toroidal shape, with a cavity within the shell. A plurality of radial penetrations on an inner toroidal surface of the toroidal ring manifold shell extend into the shell cavity, each of the plurality of radial penetrations being located in a predetermined arrangement on the inner toroidal surface.

[0016] A plurality of support arms extend inward radially from the inner toroidal surface of the toroidal ring manifold shell. One support arm of the plurality of support arms may be attached to the toroidal ring manifold shell at each of the plurality of radial penetrations and extend inward radially from the inner surface of the toroidal ring manifold shell. The support arm further includes an axial internal cavity for transporting premix fuel from an inner radial end to an outer radial end at the toroidal ring manifold shell. A plurality of penetrations through one poloidal surface of the toroidal ring manifold shell for dispersing premix fuel are also provided and located according to a predetermined arrangement.

[0017] In accordance with another aspect of the present invention, a secondary fuel nozzle assembly for a gas turbine combustor is provided. The secondary fuel nozzle assembly includes a premix fuel connection at the rearward end of the secondary fuel nozzle assembly and a nozzle body connected at a rearward end to the premix fuel connection. A toroidal ring manifold is centered radially around the nozzle body for distributing fuel from the nozzle body into an axial airflow path around the nozzle body. A support structure is provided for supporting the toroidal ring manifold. Further, a communication path is provided for fuel from the nozzle body to the toroidal ring manifold.

[0018] In accordance with a third aspect of the present invention, a combustor for a DLN gas turbine is provided. The combustor includes a secondary fuel nozzle assembly with a fuel connection at the rearward end and a nozzle body connected at a rearward end to the fuel connection. A toroidal ring manifold may be centered radially around the nozzle body for distributing fuel from the nozzle body into an axial airflow path around the nozzle body. A support structure is provided for the toroidal ring manifold. A communication path is provided for fuel from the nozzle body to the toroidal ring manifold. A liner circumferentially surrounds the secondary nozzle assembly, including a penetration at the rearward end for admitting airflow to a premixing volume. The premixing volume encompasses a generally annular shape defined between the secondary nozzle assembly and an inner wall of the liner. A swirler may be mounted at the forward end of the secondary nozzle assembly.

BRIEF DESCRIPTION OF THE DRAWING

[0019] 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 pails throughout the drawings, wherein:

[0020] FIG. **1** is a partial cross-sectional view of a prior art known dry low NO_x combustor;

[0021] FIG. **2**A is a partial cross sectional view of a prior art secondary premixed/diffusion fuel nozzle;

[0022] FIG. **2**B is an exploded cross-sectional view of the prior art secondary fuel nozzle illustrated in FIG. **2**;

[0023] FIG. **3**A illustrates a peg arrangement for the prior art secondary fuel nozzle;

[0024] FIG. **3**B illustrates the arrangement of fuel discharge holes in the peg of the prior art secondary nozzle;

[0025] FIG. **4** illustrates a prior art manifold for fuel premix.

[0026] FIG. **5**A illustrates a cross-section of an inventive toroidal shell;

[0027] FIG. **5**B illustrates a side view of a toroidal ring manifold around a nozzle body;

[0028] FIG. **5**C illustrates a toroidal ring manifold cross section illustrating row angles for fuel mixing holes on the downstream surface;

[0029] FIG. **6**A illustrates an external view of a downstream side for a preferred embodiment of the inventive toroidal ring manifold;

[0030] FIG. **6**B illustrates an internal view of the downstream side for a preferred embodiment of the inventive toroidal ring manifold;

[0031] FIG. **7**A illustrates an isometric view of assembly arrangements for the inventive toroidal ring manifold to a secondary fuel nozzle body.

[0032] FIG. **7**B illustrates a sectional view of the inventive toroidal ring manifold through a secondary fuel nozzle, support arm and manifold shell;

[0033] FIG. **8** illustrates a secondary fuel assembly for a gas turbine incorporating an embodiment of the inventive toroidal ring manifold;

[0034] FIG. **9** illustrates a combustor for a gas turbine incorporating the inventive toroidal ring manifold.

[0035] FIG. **10**A illustrates a radial profile of calculated unmixedness for the prior art peg secondary fuel nozzle; and

[0036] FIG. **10**B illustrates a radial profile of calculated unmixedness for the secondary fuel nozzle with an embodiment of the inventive toroidal ring manifold.

DETAILED DESCRIPTION OF THE INVENTION

[0037] The following embodiments of the present invention have many advantages, including effectively dispersing premixing fuel with air in the secondary nozzle of a combustor for a Dry Low NO_x (DLN) gas turbine, thereby providing stable combustion with low nitrogen oxide (NO_x) emissions.

[0038] According to one aspect of the present invention a toroidal ring manifold is provided to disperse fuel into the premixing volume between a secondary nozzle body and the finer. FIG. **5**A illustrates a cross-section of a toroidal shell. A toroidal ring manifold **200** may comprise a generally toroidal-shaped shell **210**, with a circular ring cross section **215**. The toroidal-shaped shell **210** is centered on a poloidal axis **220**. When the toroidal ring manifold **200** is united with a nozzle body **400** (partially shown) as part of a secondary fuel assembly, the poloidal axis may be coincident with a longitudinal axis **305** of the nozzle body **400**. A toroidal axis **225** runs through the center **230** of circular ring cross-section **215**. The toroidal ring manifold **200** includes a ring height H **235**, defined between the center **240** of the toroidal ring manifold on the poloidal axis **220** and the center **230** of the circular ring cross-section **215** on toroidal axis **225**. Setting of the ring height H **235** and a cross-section diameter **236** adjusts the positioning of the ring outer surface **237** relative to a premixing space (not shown) around the body of the secondary nozzle. The outer surface **237** of the toroidal ring manifold **200** may be divided into an upper surface **238** and a lower surface **239** by an equator of the ring.

[0039] A locus of points forming a row circumferentially around the toroidal ring manifold (for example first point **250** on the surface of the circular cross-sections **215**) may be defined by row angle θ_1 **260** formed between a line running parallel to the poloidal axis **220** through the center **230** of the ring cross-section **215** and a line **270** between center **230** of the ring-cross section **215** and the point on the surface **250**. For convention, angle θ_1 (toward the poloidal axis) is defined as positive. A second row angle θ_2 **275** describes point **255** and an associated locus of centers for a second row, also on the outer surface of the toroidal ring manifold **200**.

[0040] FIG. **5**B illustrates a side view of a toroidal ring manifold **200** around a nozzle body **400**. Toroidal ring manifold **200** includes fuel mixing holes **320** on a downstream surface **290**. Height H **235** of the toroidal ring manifold establishes positioning of the manifold and hence of the fuel mixing holes **320** relative to the nozzle body **400**. FIG. **5**C illustrates a toroidal ring manifold cross section illustrating row angles for fuel mixing holes on the downstream surface. The row angles θ_1 **260** and θ_2 **275** may define the locus of centers for fuel mixing holes **320** (described in greater detail below).

[0041] FIG. **6**A illustrates a downstream elevation view of the toroidal ring manifold. FIG. **6**B illustrates an internal elevation view of the downstream surface of the toroidal ring manifold. The toroidal ring manifold **200**, centered on the poloidal axis **230** includes a central cavity **290** within the manifold shell **210**. The central cavity **290** may also be toroidal-shaped. A plurality of radial penetrations **295** may be provided through the outer surface **237** of the toroidal manifold shell **210**, where the penetrations **295** extend into the central cavity **290**, according to a predetermined arrangement. The toroidal ring manifold **210** may also include a plurality of support arms **300** extending inward radially from the lower surface **239** of the manifold shell **210**. In one aspect of the inventive manifold, four support arms **300** and the corresponding radial penetrations **295** may be evenly distributed about the lower surface **239** of manifold shell **210**.

[0042] The plurality of support arms **300** may each include an axial internal cavity **325** for fuel delivery, where the internal cavity **325** extends from an inner radial end **326** to an outer radial end **327** of the support arm **300**. The outer radial end **327** may be connected to the toroidal ring manifold **200** at the location of one of the corresponding radial penetrations **295** of manifold shell **210**, thereby providing a communication path for fuel through the support arms **300** and into the central cavity **290** of the toroidal ring manifold **200**.

[0043] FIG. **7**A illustrates an isometric view of assembly arrangements for the inventive toroidal ring manifold to a secondary fuel nozzle body. FIG. **7**B illustrates a sectional view through a secondary fuel nozzle body **350**, support arm **300** and manifold shell **210**. The manifold shell **210** may be comprised of four shells section **330**. Each shell section **330** includes a radial penetration **295** for accepting the outer radial end **327** of the support arm **300**. The support arm **300** includes threaded connections **328** on inner radial end **326** and threaded connections **329** on the outer radial end **327**. The radial penetration **295** on the manifold shell **210** includes threads **297** to mate with threads **329** to join the outer radial end **327** of support arm **300** to the shell section **330**. Further radial holes **361** may penetrate wall **351** of nozzle body **350** extending to the premix fuel passage **360**, thereunder. Radial holes **361** may include threads **365** to permit mating with threads **328** on the inner end **326** of support arm **300** for attaching the support arm **300** to the secondary fuel nozzle body **350**. A flow path **355** for premix fuel is thereby provided from premix fuel passage **360** in the secondary fuel nozzle body **350**, through radial holes **361**, through cavity **325** in the support arms, and radial penetrations **295** in the shell section **330**. Shell sections **330** may be connected to form toroidal ring manifold **200** by welding or other suitable connection means.

[0044] Referring again to FIG. **6**A-**6**B, a plurality of penetrations, through the downstream poloidal surface of the toroidal ring manifold shell **210** and into the shell cavity **290** may be located according to a predetermined arrangement. The predetermined arrangement of penetrations are optimized to provide from mixing of fuel from the cavity **290** of the shell **210** with air flow surrounding the manifold shell **210**. The predetermined arrangement may include at least one row of holes. Loci for the centers of individual holes in a row (ring) **280**, **285** of holes may be set at an individual predetermined angle with respect to the ring cross-section. It is preferred that the individual holes **310**, **315** within a row of holes **280**, **285** be evenly spaced circumferentially around the locus of centers for a specific row. Further it is preferred that the individual holes within each row be of the same diameter. Holes for separate rows of holes may be of the same diameter or a different diameter. It is also preferred that the toroidal ring manifold shell include two rows of holes.

[0045] A preferred embodiment may include two rows or rings (a first row **280** and a second row **285**) of holes in a downstream poloidal surface of the toroidal ring manifold shell. It is further preferred that the locus of centers for individual holes **310** for the first row **280** be at a predetermined positive angle θ_1 **260** (FIG. **5**C), with respect to the ring cross-section **215** and the locus of centers for individual holes **315** of the second row **285** be at a predetermined negative angle θ_2 **275** (FIG. **5**C) with respect to the ring cross-section **215**. Further, it is preferred that the diameter size of the individual holes **310** of the first row **280** be smaller than the diameter size of the individual holes **315** of the second row **285**. In a preferred embodiment of the inventive manifold, the individual holes **310** of the first row **280** may include diameters of about 0.082 inch and the individual holes **315** of the second row **285** may include diameters of about 0.116 inch.

[0046] The number of individual holes of a first row of holes may equal or not equal the number of individual holes of other rows. In a preferred embodiment of the inventive manifold with two rows of holes, the first row **280** may include 16 individual holes **310** and the second row **285** may include 8 individual holes **315**. Further, it is preferred that the individual holes **310** of the first row **280** and the individual holes **315** of the second row **285** be evenly spaced relative to each other so as to promote an evenly distributed circumferential fuel-air (F/A ratio) in the premix volume.

[0047] Another aspect of the present invention provides a secondary fuel nozzle assembly **500** for a gas turbine combustor including an embodiment of the inventive toroidal ring manifold **200** (of FIGS. **5-7**) is illustrated in FIG. **8**. FIG. **8** illustrates the inventive toroidal ring manifold **200** mounted to the nozzle centerbody **350**. The toroidal ring manifold **200** is positioned in the premixing volume **380** for distributing secondary premix fuel around the centerbody hub **395** and within the centerbody cap **390**. A fuel oil connection **435**, a secondary gas connection **436**, a tertiary gas connection **437** and a water connection **438** may be provided at the rearward end of the secondary fuel nozzle assembly **500**. The toroidal ring manifold **200** is centered radially around the nozzle centerbody **350** for distributing premix fuel from the nozzle centerbody **350** into an axial airflow path **450** around the nozzle centerbody. A support structure is provided for supporting the manifold ling shell from the centerbody hub **395**.

[0048] Within the nozzle centerbody hub **395** of the secondary fuel nozzle assembly **500**, a plurality of internal fuel cavities (passages) are provided for supplying different fuel types to the premixing volume **380** and to the tip **410** of the nozzle. Fuel oil may be provided to the tip **410** through fuel oil cavity **415**. Secondary gas fuel cavity **426** connects the secondary gas fuel for premixing to a plurality of radial holes **365** through the outer wall **351** of centerbody hub **395**. The plurality of radial holes **365** are arranged in a predetermined distribution around the circumference of the centerbody hub **395**. The predetermined distribution of radial holes **365** are arranged to match and align with the support arms (not shown) of the toroidal ring manifold to provide a communication path for the premix fuel through the cavities of the support arm and into the shell cavity of the toroidal ring manifold **200**, as previously described. The secondary fuel may further be distributed through secondary fuel passages **422** and **423** to pilot holes **440** at the nozzle tip **410** for a gas pilot flame. Tertiary gas fuel may be supplied through tertiary gas passages **425** to the nozzle tip **410**. An injection water passage **424** for water injection at the nozzle tip **410** may further be provided.

[0049] Secondary gas fuel, released through the fuel mixing holes **320** into airstream **450**, mixes with the air in premixing volume **380**. The secondary gas fuel is further mixed with the airstream **450** by swirler **430** at the tip **410** of the nozzle.

[0050] The structure of the inventive toroidal ring manifold, its support arms, and the attachment to the centerbody hub have previously been described with respect to FIGS. **4-8**. The secondary fuel nozzle assembly **500** includes these described elements of the toroidal ring manifold. Further, while the inventive toroidal ring manifold **200** is shown with one secondary fuel nozzle assembly **500**, it should be understood that various embodiments of the inventive toroidal ring manifold may be combined with secondary fuel nozzles that include different arrangements and combinations of fuel sources and fuel passage arrangements.

[0051] A combustor **600** for a DLN gas turbine is also provided under another aspect of the present invention. The combustor **600** may include the secondary fuel nozzle assembly **500**, including the toroidal ring manifold **200**, as previously described. The combustor **600** may also a plurality of primary fuel nozzle assemblies **510** surrounding the secondary fuel nozzle assembly. Fuel connections **540** may be provided at the rear end of the combustor.

[0052] FIG. **9** illustrates an embodiment of the inventive combustor. A compressor **514** (partially shown) is mounted to the combustor **600** and provides compressed air to the combustor. A flow sleeve **530** surrounding the primary fuel nozzle assemblies **510** and secondary fuel nozzle assembly **500** accepts air from the compressor **514** through flow holes **532**. Air flow between the flow sleeve **530** and combustion liner **535** is directed to the rear of the primary fuel nozzle assemblies **510** and secondary fuel assembly **500**. Airflow **545** enters the rear end of the secondary fuel nozzle assembly **500** and flows around the toroidal ring manifold **200** between centerbody hub **565** and centerbody cap (liner) **570**. The toroidal ring manifold **200** disperses fuel into the airstream from the fuel mixing holes **320** (FIG. **8**) on its downstream surface. Air and secondary gas fuel mix **550** in premix volume **555** and may flow through swirler **560** situated between the forward end of nozzle tip **580** and the center body cap **570**.

[0053] The structure of the inventive toroidal ring manifold, its support arms, and the attachment to the centerbody hub have previously been described with respect to FIGS. **4-8**. The combustor **600** includes these described elements of the toroidal ring manifold **200**. Further, while the inventive toroidal ring manifold **200** is shown with one combustor, it should be understood that various embodiments of the invention may be combined with secondary fuel nozzles that include different arrangements and combinations of airflow paths, fuel sources and fuel passage arrangements.

[0054] As previously described, the toroidal ring manifold shell further includes a radius being set to a predetermined height to align the at least one row of holes radially within the premixing volume between the secondary fuel nozzle assembly and the liner. The predetermined arrangement for the plurality of penetrations through a downstream poloidal surface of the toroidal ring manifold shell preferentially includes two rows of holes, with a locus for the centers of the holes for each row being set at an individual predetermined angle with respect to the ring cross-section, including a first row of holes with a locus for the centers of the holes for the first row being set at a predetermined positive angle with respect to the ring cross-section and a second row of holes, with a locus for the centers of the holes for the row being set at a predetermined negative angle with respect to the ring cross-section. The diameter for the individual holes within first row of holes may be smaller than the diameter for the individual holes within the second row of holes, and the centers for the individual holes within first row of holes may be staggered circumferentially with respect to centers for the individual holes within the second row of holes.

[0055] While the inventive toroidal ring manifold is shown with one combustor arrangement, it should be understood that various embodiments of the invention may be combined with other combustor embodiments that include different arrangements and combinations of fuel, air and water sources, flow paths and discharge.

[0056] The objective of the above-described design is to establish a constant fuel-air (F/A) ratio in the premix volume downstream of the toroidal ring manifold. It is desired to reduce both the circumferential F/A ratio variation and the radial F/A ratio variation in the premix volume and particularly at the exit of the swirler. The number of individual holes in a row of holes may be used to reduce the circumferential F/A ratio variation. The ring height and the row angles for the locus of centers of the rows of holes may be used to reduce the radial variation in F/A ratio and control the exit radial F/A profile downstream of the swirler.

[0057] A parameter representing unmixedness has been defined for comparing the relative performance of different cases with varied values for embodiments of the inventive design and the prior art. Unmixedness=$\Sigma A_i(\Phi_I-\Phi_{global})^2/\Sigma A_i$, where Ai=area of a cell, Φ_I=cell equivalence ratio and Φ_{global}=global equivalence ratio (0.4828). Unmixedness was computed for an existing peg design for the secondary fuel nozzle to be 0.06642. A design space was employed to evaluate the effect of individual hole locations and ring height on premixedness at the exit of the swirler. A calculation of unmixedness was performed for ranges of the following parameters, as follows: ring diameter (0.35-0.45 inch); ring height (1.2-1.7 inch); angle θ_1 (0-120 degrees); angle θ_2 (0-120 degrees).

[0058] Due to strong linearity in the responses, a reliable transfer function was difficult to obtain. Optimization of parameters was done with sampling and meta-model methods. Unnixedness was calculated at the exit of the swirler for the above-described cases. Ring height and row angle parameters were optimized to minimize the unmixedness, yielding: ring height approximately 1.35 inch, angle θ_1 approximately 58.7 degrees and angle θ_2 approximately 1.7 degrees. With the parameters optimized, unmixedness at the swirler exit was calculated as 0.01, considerably below the unmixedness of 0.06642 of the existing peg design.

[0059] Further, the toroidal ring manifold cross-section provides presents an aerodynamic design with respect to the airstream flowing between the liner and the nozzle body, superior to other less aerodynamic arrangements in prior art. For example, the inventive toroidal ring manifold presents a pressure drop roughly equivalent to the prior art peg design, thereby continuing to allow adequate fuel flow and air flow through the premixing volume and swirler while providing superior mixing.

[0060] FIG. **10**A illustrates a radial profile of calculated unmixedness for the prior art peg secondary fuel nozzle. FIG. **10**B illustrates a radial profile of calculated unmixedness for the secondary fuel nozzle with an embodiment of the inventive toroidal ring manifold. Together FIGS. **10**A and **10**B illustrate the relative unmixedness of fuel and air on a plane at the discharge of the swirler utilizing the prior art pegs and inventive toroidal ring manifold, respectively. The vertical axis represents distance within the premixing volume from the outside of the secondary fuel nozzle to the finer. The horizontal axis represents the equivalence ratio at specific radial distances from center points. For the peg design, the calculated equivalence ratio **1010** varies from 0.22 to 0.8 over the radial distance. For the inventive toroidal ring manifold design, the calculated equivalence **1020** ratio varies from 0.35 to 0.63 over the radial distance, indicating a much more even radial F/A ratio, thereby promoting more even downstream combustion, with the resulting reduction in combustion dynamics and in NO_x emissions.

[0061] While various embodiments are described herein, it will be appreciated from the specification that various combinations of elements, variations or improvements therein may be made, and are within the scope of the invention.

1. A toroidal ring manifold for dispensing fuel into a premixing zone of a secondary fuel nozzle for a Dry Low NO_x (DLN) gas turbine combustor, the toroidal ring manifold comprising:
- a toroidal ring manifold shell of a generally toroidal shape, including a central cavity within the shell;
- a plurality of radial penetrations on an inner surface of the toroidal ring manifold shell, each penetration of the plurality of penetrations extending into the central cavity and being located in a predetermined arrangement on the inner surface;
- a plurality of support arms extending inward radially from the inner surface of the toroidal ring manifold shell, one support arm of the plurality of support arms being attached to the toroidal ring manifold shell at each of the plurality of radial penetrations and extending inward radially from the inner surface of the toroidal ring manifold shell, wherein the support arm further includes an axial internal cavity for transporting fuel from an inner radial end to an outer radial end at the toroidal ring manifold shell; and
- a plurality of penetrations through one poloidal surface of the toroidal ring manifold shell, the plurality of penetrations being located according to a predetermined arrangement.

2. The toroidal ring manifold according to claim **1**, each support arm of the plurality of support arms each comprising:
- a means at the inner radial end for attaching the support arm to a fuel source and a means at the outer radial end for attaching the support arm to the toroidal ring manifold, wherein the means may include a threaded connection.

3. The toroidal ring manifold according to claim **1**, wherein the predetermined arrangement for the plurality of penetrations through one poloidal surface of the toroidal ring manifold shell comprises:
- at least one row of holes, with a locus for centers of holes for each row being set at an individual predetermined angle with respect to a ring cross-section.

4. The toroidal ring manifold according to claim **3** wherein individual holes within each row of the at least one row of holes are evenly spaced circumferentially along the locus for the centers of the holes for each row.

5. The toroidal ring manifold according to claim **4**, wherein:

individual holes within each row of the at least one row of holes are of the same diameter;

the holes within separate rows of the at least one row of holes may be at least one of a same diameter and a different diameter; and

a toroidal radius of the toroidal ring manifold shell is set to a predetermined size for positioning the at least one row of holes with respect to the poloidal axis.

6. The toroidal ring manifold according to claim **3**, wherein the predetermined arrangement for the plurality of penetrations through one poloidal surface of the toroidal ring manifold shell comprises:

two rows of holes, with a locus for the centers of the holes for each row being set at an individual predetermined angle with respect to the ring cross-section.

7. The toroidal ring manifold according to claim **6**, wherein the two rows of holes, with a locus for the centers of the holes for each row being set at an individual predetermined angle with respect to the ring cross-section; comprises:

a first row of holes, with a locus for the centers of the holes for the first row being set at a predetermined positive angle with respect to the ring cross-section; and

a second row of holes, with a locus for the centers of the holes for the row being set at a predetermined negative angle with respect to the ring cross-section.

8. The toroidal ring manifold according to claim **7**, wherein a diameter for the individual holes within first row of holes are smaller than a diameter for the individual holes within the second row of holes.

9. The toroidal ring manifold according to claim **7**, wherein centers for the individual holes within first row of holes are staggered circumferentially with respect to centers for the individual holes within the second row of holes.

10. A secondary fuel nozzle assembly for a Dry Low NO_x (DLN) gas turbine combustor, the secondary fuel nozzle assembly comprising:

a fuel supply at a rearward end of the secondary fuel nozzle assembly;

a nozzle body connected at the rearward end to the fuel supply;

a liner axially surrounding the nozzle body;

a toroidal ring manifold centered radially around the nozzle body for distributing fuel from the nozzle body into an axial airflow path around the nozzle body;

a premixing volume between the nozzle body and the liner;

a support structure for the toroidal ring manifold; and

a communication path for fuel from the nozzle body to the toroidal ring manifold.

11. The secondary fuel nozzle assembly for a gas turbine combustor; the secondary fuel nozzle assembly further comprising:

an internal fuel cavity within the nozzle body for delivering fuel from the fuel supply;

a plurality of radial passages from the internal fuel cavity arranged in a predetermined distribution around a circumference of the nozzle body;

a plurality of penetrations on an inner toroidal surface of the toroidal ring manifold, the plurality of radial penetrations being equal to the plurality of radial passages from the internal fuel cavity wherein the plurality of radial penetrations are arranged axially and circumferentially to align with the predetermined distribution of radial passages from the internal fuel cavity;

a plurality of radial support arms equal in number to the plurality of radial passages from the internal fuel cavity, each support arm including an internal passage between an inner radial end and an outer radial end, the inner radial end being attached to the nozzle body at the location of one of the plurality of radial passages from the internal fuel cavity and the outer radial end being attached to the toroidal ring manifold at the location of the penetrations of the inner toroidal surface; and

a predetermined arrangement for a plurality of penetrations through a downstream poloidal surface of the toroidal ring manifold shell including at least one row of holes, with a locus for centers of holes for each row being set at an individual predetermined angle with respect to a ring cross-section of the toroidal ring manifold.

12. The secondary fuel nozzle assembly according to claim **11**, wherein the predetermined arrangement for the plurality of penetrations through one poloidal surface of the toroidal ring manifold shell comprises:

individual holes, within each row of the at least one row of holes, being evenly spaced circumferentially around the locus for centers.

13. The secondary fuel nozzle assembly according to claim **12**, wherein:

individual holes within each row of the at least one row of holes are of the same diameter;

the individual holes within separate rows of the at least one row of holes may include at least one of a same diameter and a different diameter; and,

a toroidal radius of the toroidal ring manifold shell may include a predetermined size for positioning the at least one row of holes with respect to the poloidal axis.

14. The secondary fuel nozzle assembly according to claim **13**, wherein the predetermined arrangement for the plurality of penetrations through a downstream poloidal surface of the toroidal ring manifold shell comprises:

two rows of holes, with a locus for the centers of the holes for each row being set at an individual predetermined angle with respect to the ring cross-section, including a first row of holes with a locus for the centers of the holes for the first row being set at a predetermined positive angle with respect to the ring cross-section and a second row of holes, with a locus for the centers of the holes for the row being set at a predetermined negative angle with respect to the ring cross-section.

15. The secondary fuel nozzle assembly according to claim **14**, wherein the diameter for the individual holes within first row of holes are larger than the diameter for the individual holes within the second row of holes.

16. The secondary fuel nozzle assembly according to claim **15**, wherein centers for the individual holes within first row of holes are staggered circumferentially with respect to centers for the individual holes within the second row of holes.

17. A combustor for a Dry Low NO_x (DLN) gas turbine, the combustor comprising:

a secondary fuel nozzle assembly including a premix fuel connection at the rearward end of the secondary fuel nozzle assembly; a nozzle body connected at a rearward end to the fuel connection; a toroidal ring manifold centered radially around the nozzle body for distributing fuel from the nozzle body into an axial airflow path around the nozzle body; a support structure for the toroidal ring manifold; and a communication path for fuel from the nozzle body to the toroidal ring manifold;

a liner circumferentially surrounding the secondary fuel nozzle assembly, including a penetration at the rearward end for admitting airflow to a premixing volume;

the premixing volume of a generally annular shape defined between the secondary fuel nozzle assembly and an inner wall of the liner; and

a swirler mounted at the forward end of the secondary fuel nozzle assembly.

18. The combustor for a DLN gas turbine according to claim **17**, the secondary fuel nozzle assembly further comprising:

an internal fuel cavity within the nozzle body for delivering premix fuel from the fuel connection;

a plurality of radial passages from the internal fuel cavity arranged in a predetermined distribution around a circumference of the nozzle body,

a plurality of penetrations on an inner toroidal surface of the toroidal ring manifold, the plurality of radial penetrations being equal to the plurality of radial passages from the internal fuel cavity wherein the plurality of radial penetrations are arranged axially and circumferentially to align with the predetermined distribution of radial passages from the internal fuel cavity;

a plurality of radial support arms equal in number to the plurality of radial passages from the internal fuel cavity, each support arm including an internal passage between an inner radial end and an outer radial end, the inner radial end being attached to the nozzle body at the location of one of the plurality of radial passages from the internal fuel cavity and the outer radial end being attached to the toroidal ring manifold at the location of the penetrations of the inner toroidal surface;

a predetermined arrangement for a plurality of penetrations through a downstream poloidal surface of the toroidal ring manifold shell including at least one row of holes, with a locus for centers of holes for each row being set at an individual predetermined angle with respect to a ring cross-section of the toroidal ring manifold; and

a toroidal radius of the toroidal ring manifold shell being set to a predetermined value to align the at least one row of holes radially within the premixing volume between the secondary fuel nozzle assembly and the liner.

19. The combustor for a DLN gas turbine according to claim **18**, wherein the predetermined arrangement for the plurality of penetrations through a downstream poloidal surface of the toroidal ring manifold shell comprises:

two rows of holes, with a locus for the centers of the holes for each row being set at an individual predetermined angle with respect to the ring cross-section, including a first row of holes with a locus for the centers of the holes for the first row being set at a predetermined positive angle with respect to the ring cross-section and a second row of holes, with a locus for the centers of the holes for the row being set at a predetermined negative angle with respect to the ring cross-section.

20. The combustor for a DLN gas turbine according to claim **19**, wherein the diameter for the individual holes within first row of holes are larger than the diameter for the individual holes within the second row of holes, and the centers for the individual holes within first row of holes are staggered circumferentially with respect to centers for the individual holes within the second row of holes.

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