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(54) Pulse detonation cleaning apparatus

(57) The burning of fuel (e.g., coal) in industrial equipment generates an exhaust flow containing airborne particulate. The flow is passed through a rotary heat exchanger (50) to preheat inlet air. The heat exchanger element is subject to fouling and is cleaned by a pulsed combustion device (222,223). The device is operated by introducing a fuel and oxidizer charge to at least one conduit (224) and initiating combustion of the charge. The combustion generates a shock wave to which the element is exposed, dislodging and/or otherwise removing the deposits.

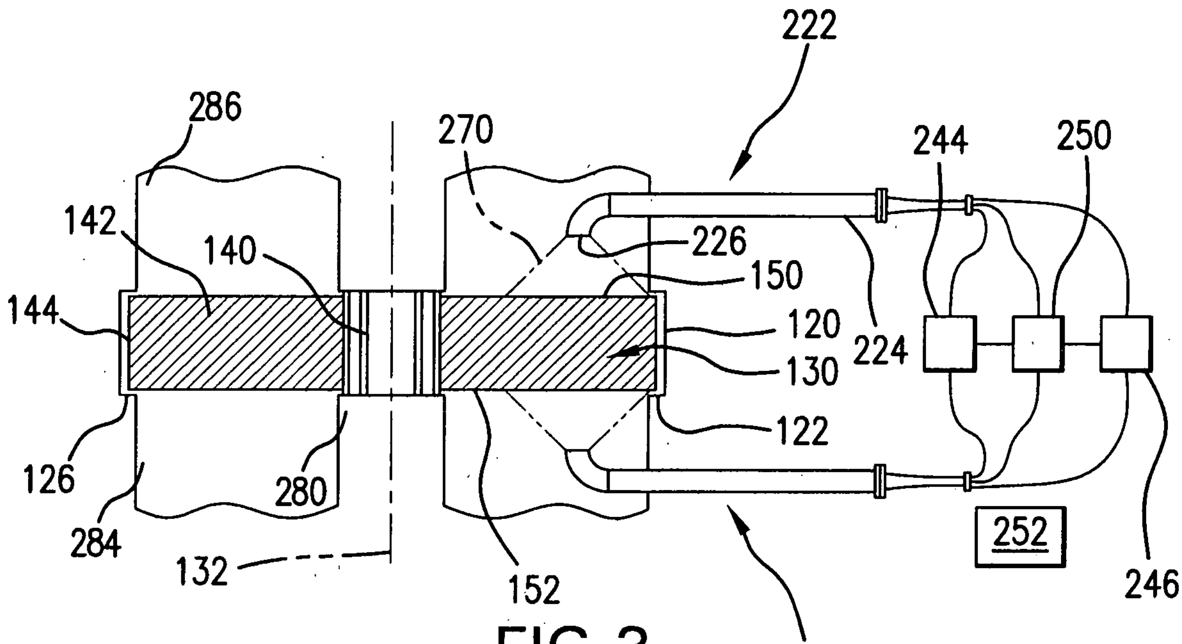

FIG.3

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Description

BACKGROUND

[0001] The disclosure relates to coal-fired industrial equipment. More particularly, the disclosure relates to the cleaning of from coal-fired industrial equipment such as pulverized coal-fired utility boilers.

[0002] One feature of many pieces of such equipment is the use of a rotary heat exchanger to pre-heat inlet air by transferring heat from the exhaust flow. Exemplary rotary heat exchangers are found in US Patents 4487252 and 5950707. In an exemplary axial rotary heat exchanger, the exhaust and inlet flows pass along respective angular sectors of the heat exchanger. The flows pass through a rotating core of the heat exchanger. The core has plates or other features that absorb heat when in the exhaust flowpath and then lose that heat while passing through the inlet air flow. Steam or air purges may be used to clean the core plates.

[0003] Within equipment such as boilers, sootblowers have been used to clean surfaces such as boiler tubes. Steam lance sootblowers have mainly been used. Detonative or pulsed combustion sootblowers have recently been proposed. An example of such a sootblower is in US Patent 7011047.

SUMMARY

[0004] The burning of fuel (e.g., coal) in industrial equipment generates an exhaust flow containing airborne particulate. The flow is passed through a rotary heat exchanger to preheat inlet air. The heat exchanger element is subject to fouling and is cleaned by a pulsed combustion device. The device is operated by introducing a fuel and oxidizer charge to at least one conduit and initiating combustion of the charge. The combustion generates a shock wave to which the element is exposed, dislodging and/or otherwise removing the deposits.

[0005] According to an aspect of the present invention, there is provided an apparatus comprising:

a combustor;
an inlet air flowpath extending to the combustor;
an exhaust flowpath extending from the combustor;
a rotary heat exchanger along the inlet air flowpath and exhaust flowpath; and
a pulsed-combustion device positioned to direct a shock wave toward a core of the heat exchanger and comprising:
a source of fuel and oxidizer;
at least one combustion conduit coupled to the source to receive charges of said fuel and oxidizer; and
at least one ignitor coupled to the combustion conduit to ignite the charges.

[0006] In a preferred embodiment, the combustor is a coal-burning furnace.

[0007] In a preferred embodiment, the pulsed combustion device comprises first and second said conduits, the first conduit having an outlet upstream of the core along the exhaust flowpath and the second conduit having an outlet downstream of the core along the exhaust flowpath. The first and second conduits preferably each have a plurality of outlets at different radial positions relative to an axis of rotation of the core. The first and second conduits preferably have a decreasing cross-sectional area within the exhaust flowpath, and the plurality of outlets are preferably along respective portions of different cross-sectional area.

[0008] Preferably, the combustion conduits have outlets aimed transverse to a downstream direction of the flowpath.

[0009] Preferably, at least four of said combustion conduits are positioned at essentially a common streamwise location along the exhaust flowpath.

[0010] In a preferred embodiment, the apparatus preferably further comprises a smokestack forming an outlet of the exhaust flowpath to atmosphere.

[0011] In a preferred embodiment, the source comprises: a first source of said fuel, said fuel consisting in majority part, by mass, of fuel selected from the group consisting of hydrogen, hydrocarbon fuels, and their mixtures; and a second source of said oxidizer, said oxidizer consisting essentially of oxygen.

[0012] Preferably, the combustion conduits have lengths of 0.5-4m and cross-sectional areas of 20-730cm^2.

[0013] In a preferred embodiment, the apparatus further comprises a controller configured to fire the device a plurality of times to provide circumferential coverage of the core. The controller is preferably configured to synchronize firing of the device relative to rotation of the core.

[0014] According to another aspect of the present invention, there is provided an apparatus comprising:

a combustor;
an exhaust flowpath extending from the combustor;
an inlet air flowpath extending to the combustor;
a rotary heat exchanger along the inlet air flowpath and exhaust flowpath; and
pulsed-combustion means for cleaning a core of the rotary heat exchanger.

[0015] Preferably, the combustor is a fossil fuel-burning furnace.

[0016] Preferably, the apparatus is a boiler system.

[0017] According to a further aspect of the present invention, there is provided a method for operating a plant comprising:

burning a plant fuel and generating a flow containing particles;
passing the flow through a heat exchanger to heat an inlet air flow; and

cleaning a core of the heat exchanger by a pulsed detonation process including:

introducing a fuel and oxidizer charge to at least one conduit;
initiating combustion of the charge; and
exposing the core to shock waves generated by combustion.

[0018] In a preferred embodiment, the passing of the flow comprises an axial flow through the core while the core rotates about a core axis.

[0019] Preferably, the plant fuel is selected from the group consisting of coal, fuel oil, hydrocarbon gas biomass, trash, and combinations thereof.

[0020] Preferably, the cleaning comprises exposing said core to said shock waves from a plurality of said conduits.

[0021] Preferably, the cleaning comprises exposing the core to shock waves from opposed outlets of one or more pairs of said conduits.

[0022] Preferably, the charge comprises hydrogen as a by weight majority of the fuel.

[0023] Preferably, the at least one conduit is operated with an air purge before each charge introduction.

[0024] Preferably, the cleaning is initiated responsive to a sensed condition of the core.

[0025] Preferably, the conduit is fired a plurality of times in synchronization with rotation of the core so as to provide a, full circumferential cleaning of the core.

[0026] The details of one or more embodiments are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027]

FIG. 1 is a partially schematic view of a coal-fired boiler system.
FIG. 2 is a view of a boiler unit of the system of FIG. 1.
FIG. 3 is a longitudinally cut-away view of a heat exchanger of the system of FIG. 1 with a first detonative core cleaning system.
FIG. 4 is a partially schematic streamwise view of the heat exchanger of FIG. 3.
FIG. 5 is a longitudinally cut-away view of a heat exchanger of the system of FIG. 1 with a second detonative core cleaning system.
FIG. 6 is a partially schematic streamwise view of the heat exchanger of FIG. 5.
FIG. 7 is a longitudinally cut-away view of a heat exchanger of the system of FIG. 1 with a third detonative core cleaning system.
FIG. 8 is a partially schematic streamwise view of the heat exchanger of FIG. 7.
FIG. 9 is a longitudinally cut-away view of a heat exchanger of the system of FIG. 1 with a fourth detonative core cleaning system.
FIG. 10 is a partially schematic streamwise view of the heat exchanger of FIG. 9.

[0028] Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0029] FIG. 1 shows a schematic view of a pulverized coal-fired electric power plant 20. The exemplary plant may be an electrical power plant having a steam generator 22 providing steam to a steam turbine electrical generator unit 24. Along a combustion flowpath, the steam generator 22 has an upstream radiant (furnace) zone 26 followed by a downstream convective (backpass) zone 28. The steam generator 22 receives input flows of coal 30, air 32, and water 34.

[0030] The coal 30 passes through a pulverizer system 40. The air flow 32 passes through an air heater 50 (discussed below) at a downstream end of the backpass 28. The backpass heat exchangers may comprise vertical/streamwise or horizontal/transverse tube arrays. The air enters the furnace 42 as a preheated flow 52 partially including entrained pulverized coal 44. The furnace serves as a combustor combusting the coal and air mixture. A combustion flow 54 passes downstream along the combustion/exhaust flowpath.

[0031] The water flow 34 enters the convective zone 28 where it is preheated in an economizer 56 before entering the vertical walls (water walls-typically vertically extending tube arrays) 58 of the furnace 42. Heat exchange from the combustion products 54 boils the water to produce steam. Downstream along both the gas/combustion products flowpath and water/steam flowpath, the steam is superheated to high temperature and, in turn, delivered to a high pressure turbine 60. Exemplary superheating occurs in a two-stage process, first in a primary superheater 62 across the convective zone upstream of the economizer 56 and then in a pendant secondary superheater 64 on the radiant zone. In the radiant zone 26, flow is primarily upward and, in the convective zone, primarily downward. The two zones are separated by a bull nose 66 adjacent the pendant heat exchanger (s).

[0032] Steam from the high pressure turbine 60 continues along the water/steam flowpath and returns to the boiler to be reheated. Exemplary reheating is in a two-stage process, with a primary reheating (e.g., in a heat exchanger 70 across the convective zone between the primary superheater 62 and economizer 56) and a secondary reheating (e.g., in a pendant reheater 72 spanning the radiant and convective zones). Thereafter, the re-heated steam is delivered to an intermediate pressure turbine 80.

[0033] Steam exiting the intermediate pressure turbine

80 is directed to a low pressure turbine 82. Steam (and optionally water) exiting low pressure turbine 82 may proceed to a condenser 84 for correction and processing (e.g., to return as the stream 34). Energy extracted by the turbines drives an electrical generator 90 to produce electrical power.

[0034] After heating the water in the backpass region, the flow 54 heats the incoming air in the air heater 50 and then may proceed to a pollution control system 100. The exemplary system 100 includes an upstream chemical scrubber 102 and a downstream particulate removal device 104 (e.g., a bag house or electrostatic precipitator). Thereafter, the combustion products may pass through a stack 110 for discharge to atmosphere.

[0035] FIG. 2 shows the air heater 50 as a rotary air heater having a housing or body 120. The housing 120 has a first portion 122 along the exhaust flowpath 124 and a second portion 126 along the inlet air flowpath 128. A heat transfer core 130 is mounted within the housing to rotate about an axis 132. FIG. 3 shows the exemplary core 130 as including a hub 140 supported by an axle to be driven by an electric motor for rotation about the axis 132. A plurality of heat transfer surfaces 142 (e.g., plates) extend radially outward from the hub to a periphery 144. The core has a first axial surface 150 and a second axial surface 152. In the exemplary implementation, the first axial surface 150 is upstream along the exhaust flowpath and the second axial surface 152 is downstream. Depending upon implementation, the surface will not be a single face but, rather, will be formed by discrete portions (e.g., edge portions of plates). The rotation of the core brings heat transfer portions of the core 130 sequentially through the exhaust gas flowpath and the inlet air flowpath. The exemplary heat exchanger is positioned so that the heat exchange is counterflow (i.e., the exhaust flow and air inlet flow are in opposite directions).

[0036] As so-far described, the system is illustrative of just one of a variety of plant configurations to which the present invention may be applied. According to the present invention, one or more detonative cleaning systems may be located along the air/combustion products flowpath and positioned to clean the element.

[0037] FIGS. 3 and 4 show an exemplary cleaning system 220. The exemplary system 220 includes a plurality of pulsed combustion devices 222 and 223. In the exemplary implementation, two devices are shown, the first device 222 being upstream of the core along the exhaust flowpath and the second device 223 being downstream of the core along the exhaust flowpath. Each device 222, 223 has a conduit 224 having an outlet 226 at one end in interior 228 of the housing 120 and facing an associated core axial end 150, 152. Exemplary combustion conduits have lengths of 0.5-4m and cross-sectional areas of 20-730cm^2. The conduit 224 may include one or more inlets for receiving fuel and oxidizer. FIG. 2 shows exemplary fuel and oxidizer lines 240 and 242 coupled to common fuel and oxidizer sources 244 and 246 (e.g., tank systems). Exemplary fuel consists in majority part, by mass, of fuel selected from the group consisting of hydrogen, hydrocarbon fuels, and their mixtures. Exemplary oxidizer consists essentially of oxygen (e.g., from liquid oxygen tanks). Alternative oxidizer is compressed air. Ignitors (e.g., spark plugs 248) may be positioned to ignite admitted fuel/oxidizer charges.

[0038] The exemplary system further includes a control module 250 which may be connected to a central control system 252. Additional structural and operational details may be similar to those of pulsed combustion cleaning apparatus such as shown in US Pregrant Patent Publications 2005-0112516 and US 2005-0199743.

[0039] The control system 252 may operate the devices 222 and 223 to repeatedly combust charges of the fuel and oxidizer. Exemplary combustion includes detonation producing associated shock waves 270. The shockwaves may pass along the core plates, cleaning the plate surfaces.

[0040] Particular physical and operational parameters will depend on the characteristics of the heat exchanger. For coal-powered plants, this may partially be influenced by the nature of the particular coal being burned. and the nature of the particular heart exchanger core. The exemplary devices 222 and 223 may be fired simultaneously (e.g., repetitively and without interruption while the furnace is in operation or sequentially).

[0041] An exemplary control and firing protocol involves a series of discharges timed to provide full circumferential coverage. For example, the coverage of a single firing may be deemed effective for a relatively small sector (e.g., ~10°, more broadly 5-20°). The firing may be synchronized to the rotation of the core so as to provide complete coverage. If the firing cycle is short enough, consecutive sectors may be progressively sequentially cleaned with the next uncleaned sector being cleaned immediately after the prior sector. If the cycle/refresh rate is not sufficient for this, an uncleaned sector may be allowed to pass unaddressed through the cleaning zone. For example, one full revolution plus the sector increment (e.g., the ~10°) could pass between each of the firings (an exemplary thirty-six total firings, each separated from the prior firing by 370°, if the increment is 10°).

[0042] Other timing variations involve redundant coverage of firings, repeat firings along a given sector, and the like. Other variations involve different delays between firings. For example, if the cycle/refresh rate is sufficient the second firing could be made before a full revolution has passed from the first firing, but sill leaving an intervening uncleaned portion. With the 10° example, the second firing could be more than 10° but less than 370° after the first, etc. For example the second firing could be 180° after the first. The third could be 190° after the second. The fourth could be 180° after the third, with subsequent alternating 190° and 180° intervals. There could be a rotation sensor 280 for detecting rotation of the core and coupled to the control system to permit the synchronization.

[0043] An exemplary operation is a continuous operation with individual discharges/firings at a fixed frequency (or nearly fixed due to the synchronization with rotation noted above). An exemplary nominal frequency is 0.5-2.0 firings per minute. Alternatively, each full cleaning of the core may be initiated responsive to sensed parameters passing a predetermined first threshold and/or the passage of a predetermined interval. An exemplary interval may be up to daily. An exemplary sensed condition may involve a pressure difference across the core on one or both of the hot side and cool side (e.g., as detected by upstream pressure sensor 284 and downstream pressure sensor 286). The cleaning may continue until the sensed condition has passes (below for a pressure drop) a predetermined second threshold.

[0044] FIGS. 5 and 6 show an alternate system configuration having respective upstream and downstream devices 320 and 322. the devices have conduits 324 which may be similar to conduits 224 except for the outlet 326. Relative to the outlet 226, the outlet 326 is closer to the wall surface of the body 120. The outlet 326, however is directed obliquely relative to the adjacent core surface/end 150, 152 to compensate so that the wave 340 has adequate coverage.

[0045] FIGS. 7 and 8 show an alternate system configuration having respective upstream and downstream devices 420 and 422. the devices have conduits 424 which may be similar to conduits 224 except for having multiple outlets 426, 428, 430, and 432 in a linear array along the side of the conduit. The array extends to a closed end 434. The conduit 424 may thus have a greater penetration into the flowpath. The outlets, however may produce overlapping shock waves 450 which yield a more radially uniform and circumferentially concentrated net effect.

[0046] FIGS. 9 and 10 show an alternate system configuration having respective upstream and downstream devices 520 and 522. the devices have conduits 524 which may be similar to conduits 424 except for one-to-all of: a progressive (e.g., step-wise) decrease in conduit cross-sectional area along the array of outlets 526, 528, 530, and 532; a progressive decrease in outlet size ; and a progressive decrease in outlet spacing. The array extends to a closed end 534. The outlets, may produce overlapping shock waves 450, 452, 454, and 456 which yield a more radially progressive distribution that compensates for the relatively slower speed of inboard portions of the core passing through the influence of the shock waves. The circumferential span of the effective shockwave footprint on the core may thus radially increase.

[0047] One or more embodiments have been described. Nevertheless, it will be understood that various modifications may be made. For example, when implemented in a reengineering or upgrade of an existing system configuration or system, details of the existing configuration may influence details of any particular implementation. Although illustrated with respect to a coal-burning plant, the invention applies to other heat transfer facilities that produce particulate. Some prime examples would be trash incinerators and biomass/wood burners. Although shown fixed, the conduits may be retractable (e.g., as are retractable sootblowers). Accordingly, other embodiments are within the scope of the following claims.

Claims

1. An apparatus comprising:

   a combustor (22);
   an exhaust flowpath (124) extending from the combustor (22);
   an inlet air flowpath (128) extending to the combustor (22);
   a rotary heat exchanger (50) along the inlet air flowpath (128) and exhaust flowpath (124); and
   pulsed-combustion means (222,223; 320,322; 420,422; 520,522) for cleaning a core of the rotary heat exchanger (50).

2. The apparatus of claim 1, wherein:

   the pulsed-combustion means comprises a pulsed-combustion device (222,223) positioned to direct a shock wave toward the core (130) of the heat exchanger (50) and which comprises:

      a source of fuel and oxidizer (244,246);
      at least one combustion conduit (224) coupled to the source (244,246) to receive charges of said fuel and oxidizer; and
      at least one ignitor (248) coupled to the combustion conduit (224) to ignite the charges.

3. The apparatus of claim 2 wherein:

   the pulsed combustion device comprises first and second said conduits, the first conduit having an outlet (226) upstream of the core (130) along the exhaust flowpath (124) and the second conduit having an outlet downstream of the core (130) along the exhaust flowpath (124).

4. The apparatus of claim 3 wherein:

   the first and second conduits each have a plurality of outlets (426,428,430,432) at different radial positions relative to an axis of rotation of the core (130).

5. The apparatus of claim 4 wherein:

   the first and second conduits have a decreasing cross-sectional area within the exhaust flowpath (124); and
   the plurality of outlets (426,428,430,432) are

along respective portions of different cross-sectional area.

6. The apparatus of any of claims 2 to 5 wherein:

said combustion conduits (224) have outlets (226) aimed transverse to a downstream direction of the flowpath.

7. The apparatus of any of claims 2 to 6 wherein:

at least four of said combustion conduits (224) are positioned at essentially a common streamwise location along the exhaust flowpath (124).

8. The apparatus of any of claims 2 to 7 wherein the source comprises:

a first source of said fuel (244), said fuel consisting in majority part, by mass, of fuel selected from the group consisting of hydrogen, hydrocarbon fuels, and their mixtures; and
a second source of said oxidizer (246), said oxidizer consisting essentially of oxygen.

9. The apparatus of any of claims 2 to 8 further comprising:

a controller (250,252) configured to fire the pulsed-combustion device (222,223) a plurality of times to provide circumferential coverage of the core (130).

10. The apparatus of claim 9 wherein:

the controller (250,252) is configured to synchronize firing of the device pulsed-combustion (222,223) relative to rotation of the core (130).

11. The apparatus of any preceding claim wherein the combustor is a coal-burning furnace, and wherein the apparatus further comprises:

a smokestack forming an outlet of the exhaust flowpath (124) to atmosphere.

12. A method for operating a plant comprising:

burning a plant fuel and generating a flow containing particles;
passing the flow through a heat exchanger (50) to heat an inlet air flow; and
cleaning a core (130) of the heat exchanger (50) by a pulsed detonation process including:

introducing a fuel and oxidizer charge to at least one conduit (224);
initiating combustion of the charge; and
exposing the core (130) to shock waves generated by combustion.

13. The method of claim 12 wherein:

the passing of the flow comprises an axial flow through the core (130) while the core rotates about a core axis (132).

14. The method of claim 12 or 13 wherein:

the cleaning comprises exposing the core (130) to shock waves from opposed outlets (226) of one or more pairs of said conduits (224).

15. The method of any of claims 12 to 14 wherein:

the conduit (224) is fired a plurality of times in synchronization with rotation of the core (130) so as to provide a full circumferential cleaning of the core (130).

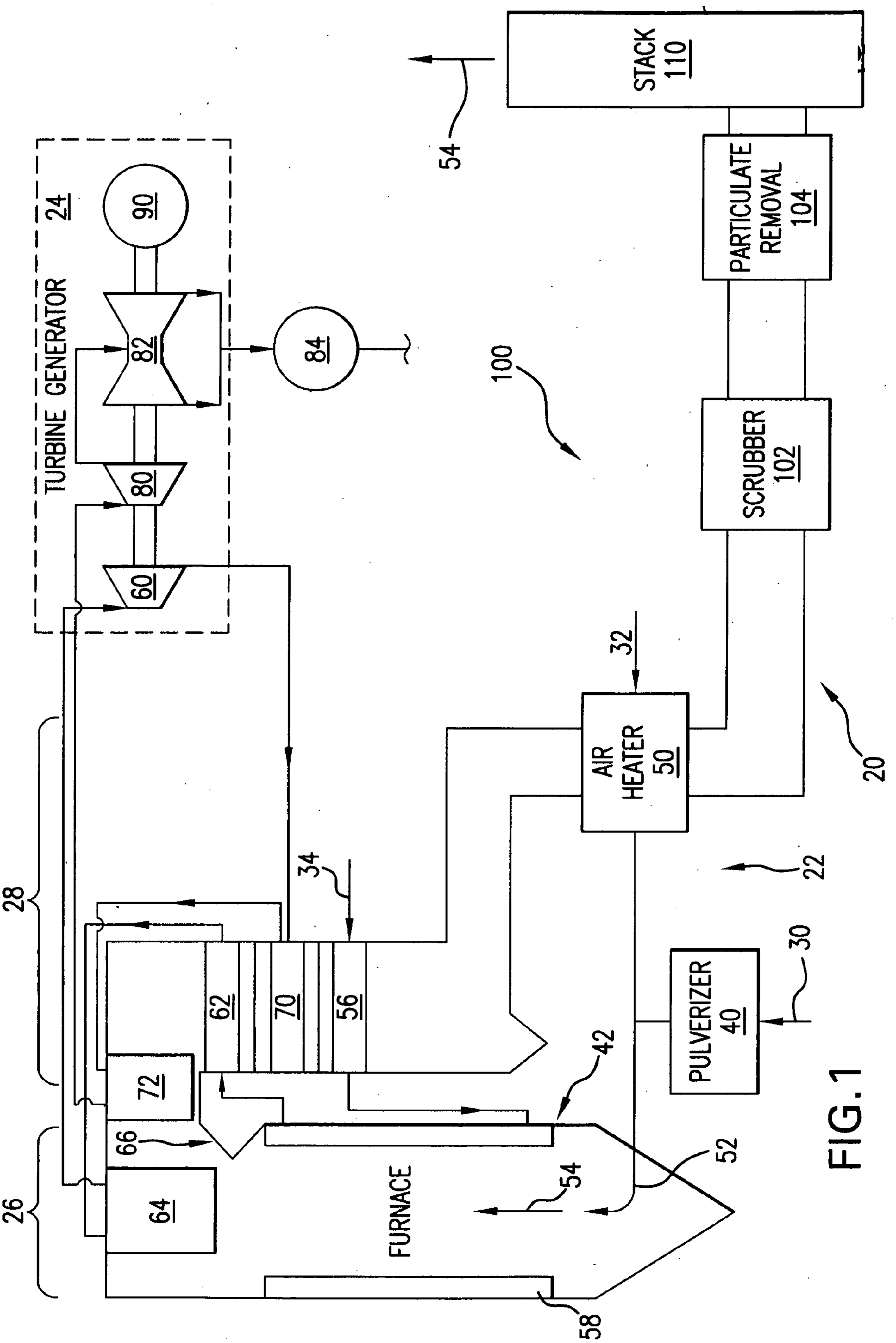
TURBINE GENERATOR
24
90
82
80
60
84
54
STACK
110
PARTICULATE
REMOVAL
104
SCRUBBER
102
100
AIR
HEATER
50
32
20
22
28
34
62
70
56
72
66
64
26
FURNACE
54
52
42
58
PULVERIZER
40
30

FIG. 1

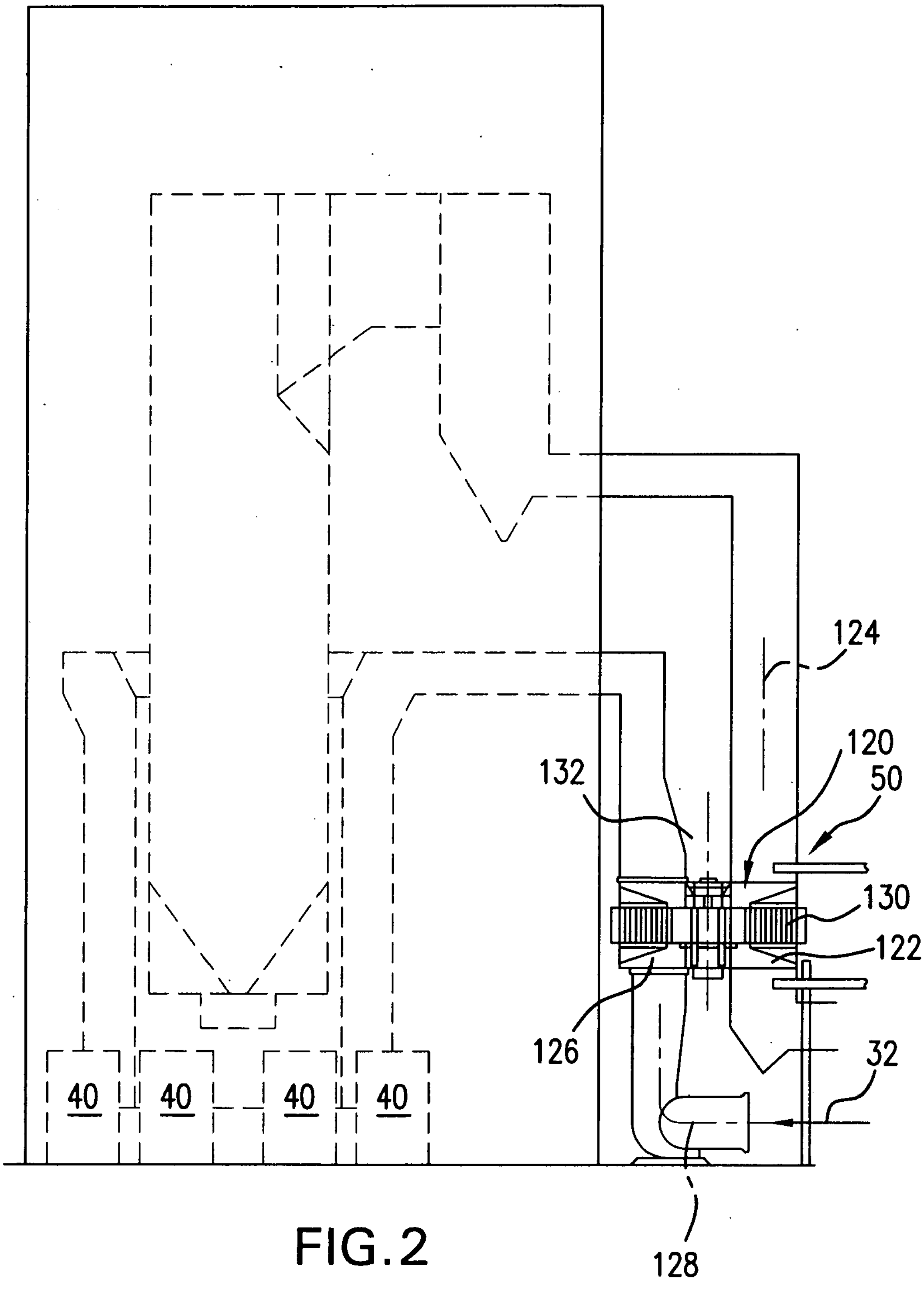

FIG.2

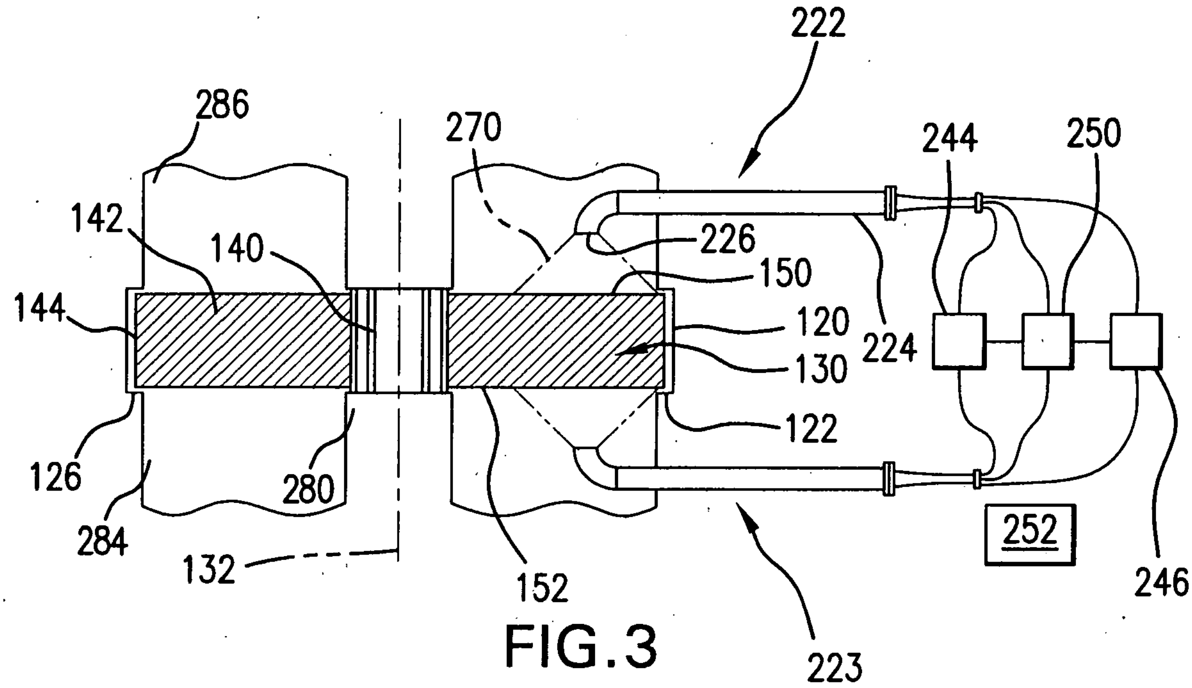
222
286
270
244
250
142
226
140
150
144
120
224
130
122
126
280
284
252
132
152
246
223

FIG.3

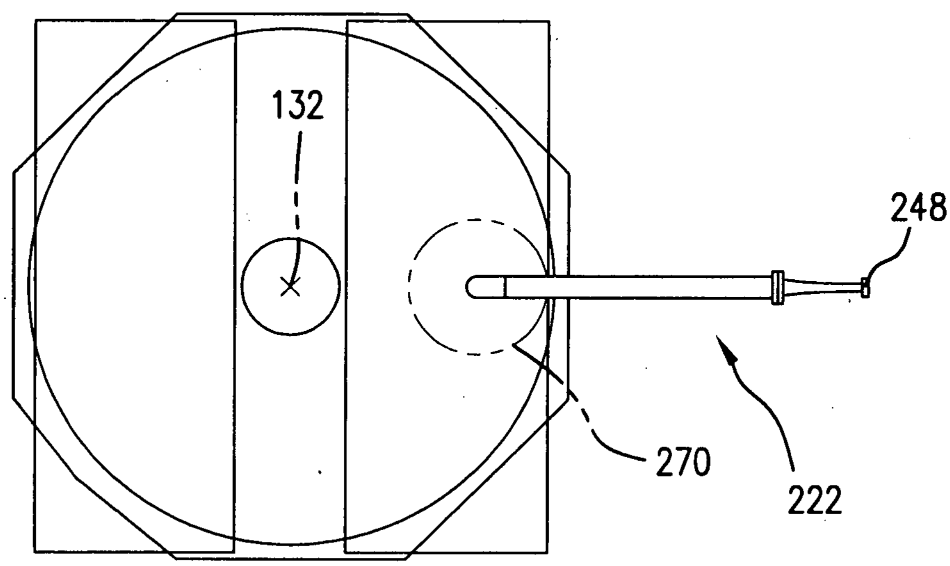
132
248
270
222

FIG.4

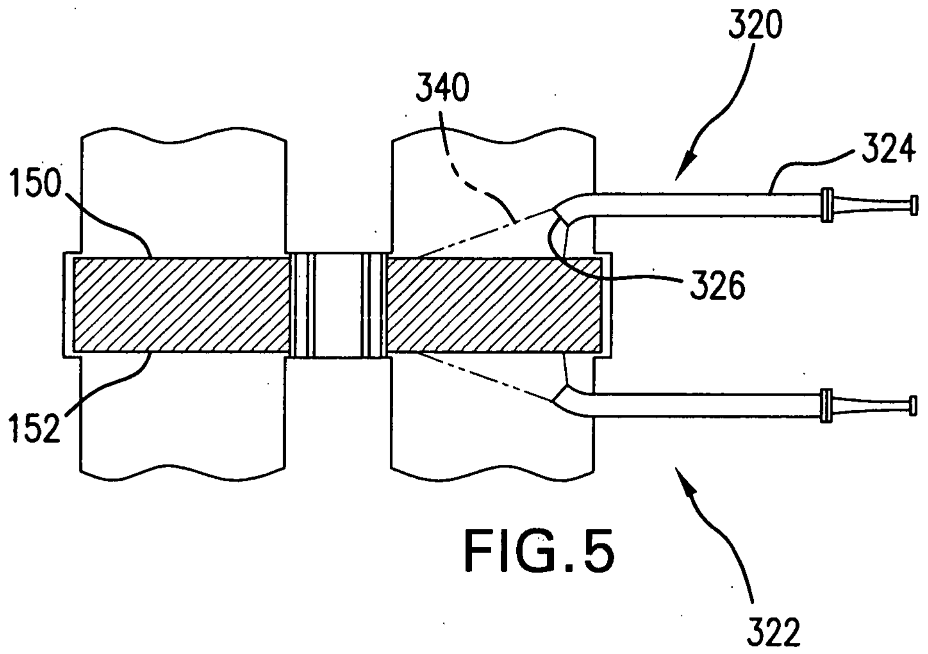

FIG.5

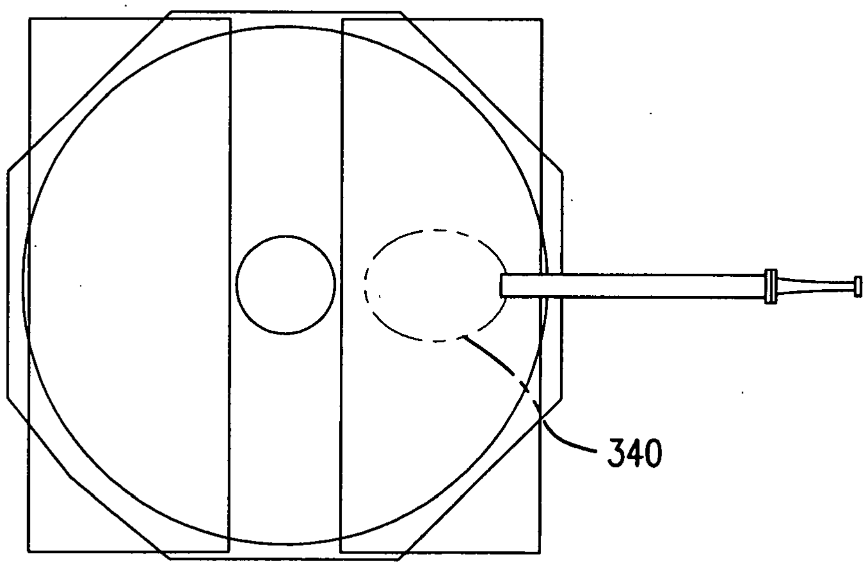

FIG.6

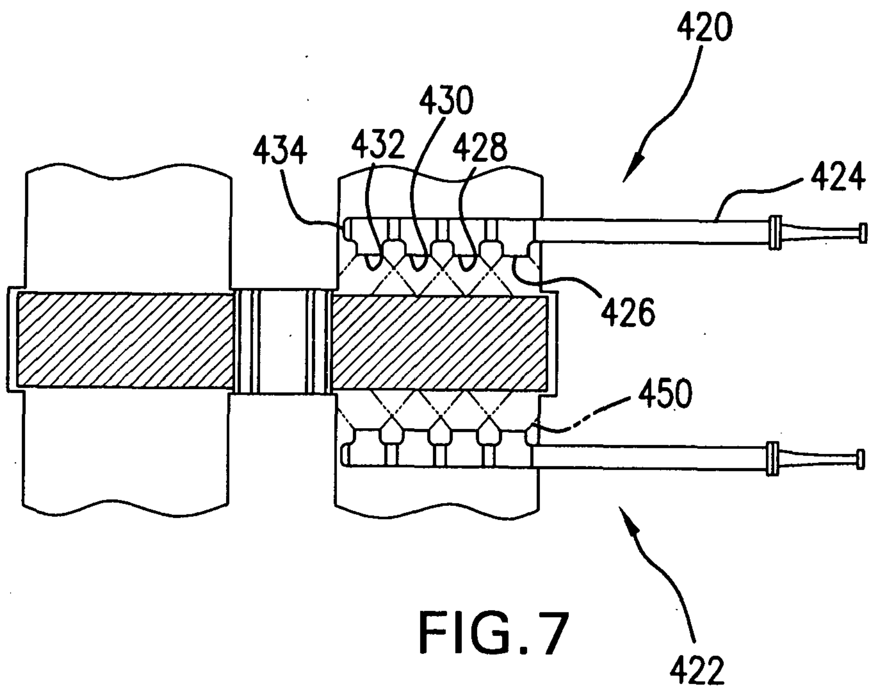

FIG.7

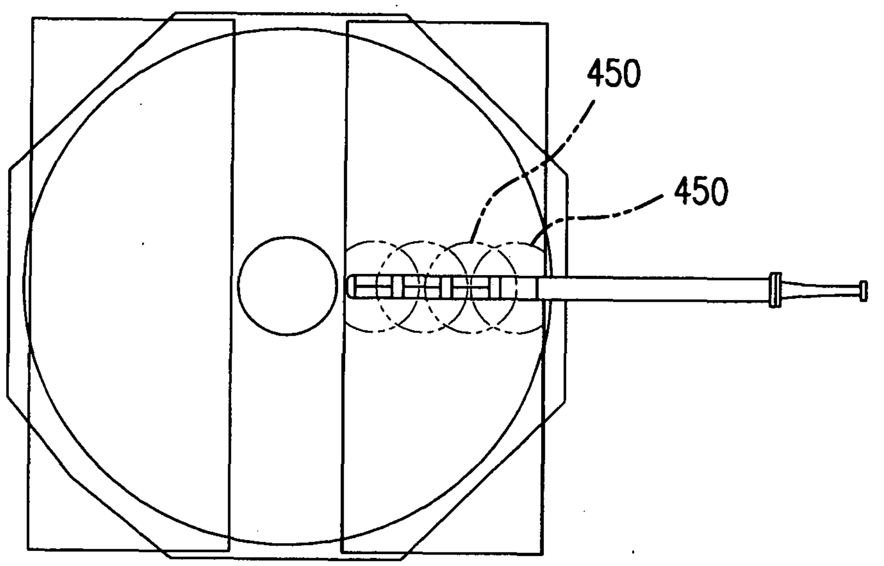

FIG.8

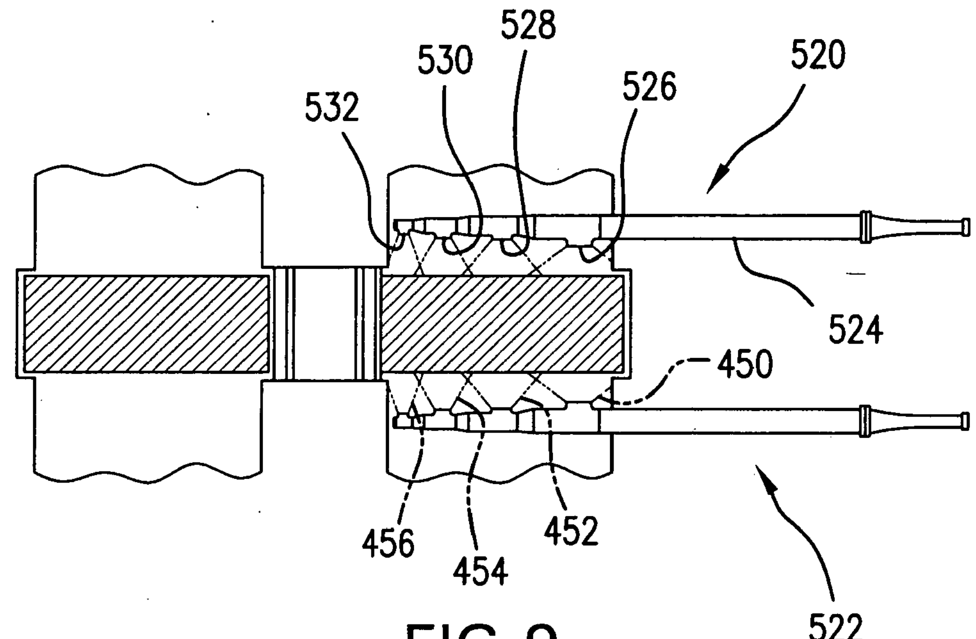

FIG.9

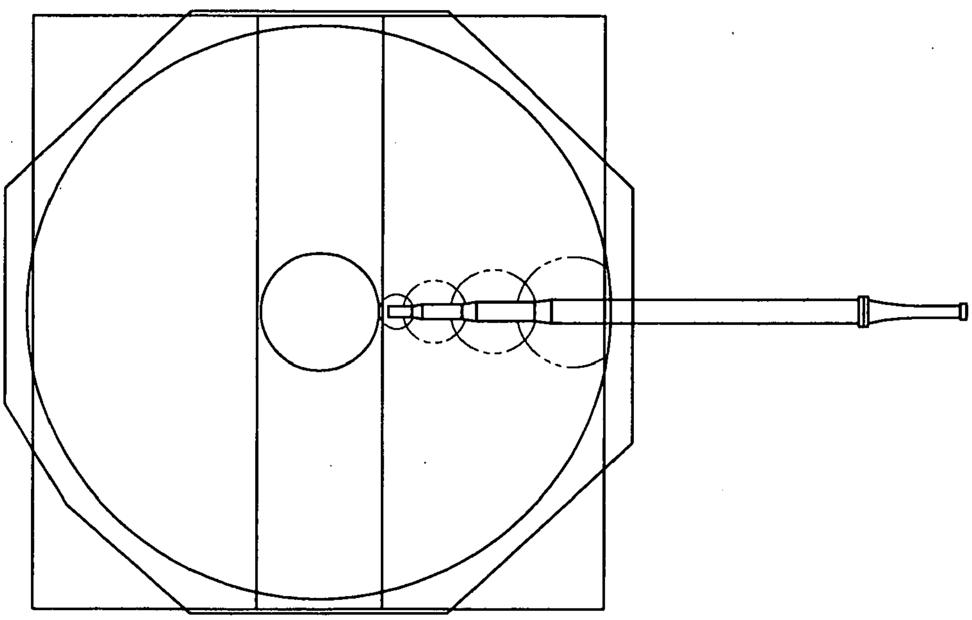

FIG.10

REFERENCES CITED IN THE DESCRIPTION

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