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PATENT SPECIFICATION

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(19)

(54) VAPOR LIQUID FRACTION DETERMINATION

(71) We, AUBURN INTERNATIONAL, INC., of 1 Southside Road, Danvers, Massachusetts, United States of America, a corporation organised and existing under the laws of Commonwealth of Massachusetts, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to the determination of liquid and vapor fractions in a non-homogeneous fluid flowing through an elongate conduit, such as may be required with boiling water, non-boiling turbulent flows, fluidized bed experiments, water-gas mixing analysis, and nuclear plant cooling.

The prior art includes a number of mechanical and electrical approaches to the problems that arise in making such determinations, these approaches being limited principally by their failure to deal effectively with the non-homogenous character of the vapor and liquid mixture across the cross section of a conduit in most practical applications.

The invention accordingly provides a method of determining liquid and vapor fractions in a non-homogeneous conductive fluid flowing through an elongate conduit with a flow axis, the method comprising establishing a moving electric field vector by application of polyphase alternating electrical field excitation to the fluid by direct contact to create alternating currents with distributed but crossing alternating current loci across the cross section of the conduit on a cyclic repeating basis, and measuring and summing the magnitudes of such currents to produce a conductivity signal representative of the liquid and vapor fractions of fluid flowing through the conduit.

The invention also provides an apparatus for determining liquid and vapor fractions in a non-homogeneous conductive fluid flowing through an elongate conduit with a flow axis, the apparatus comprising means arranged to establish a moving electric field vector by application of polyphase alternating electric field excitation to the fluid by direct contact to create alternating currents with distributed but crossing alternating current loci across the cross section of the conduit on a cyclic repeating basis, and measuring and summing means arranged to measure and sum the magnitudes of such currents to produce a conductivity signal representative of the liquid and vapor fractions of fluid flowing through the conduit.

The means arranged to establish the moving electric field vector can comprise a plurality of means for establishing a conductive loop including the fluid and a load resistor with the loops overlapping and distributed across the conduit cross section, and means for exciting each loop by an alternating voltage source, the alternating voltage sources being out of phase with one another.

The electrical field is preferably rotational and provided through multiple pairs of opposing electrodes arrayed to provide the electrical field and distribution discussed above. Additionally, the electrodes and intervening insulators can define a flow cross section between them. Interfaces between the electrodes and intervening insulators can allow relative movement to accommodate thermal expansion and contraction differences between the electrode and insulator materials which may have greatly differing coefficients of thermal expansion and contraction, but along planes which do not intersect the flow axis, so as to avoid excessive loading of individual pieces. All pieces in the electrode/insulator assembly can be vented to provide pressure equalization out to the inner wall surface of a pressure vessel (usually a pipe) containing them thus reducing structural requirements of the individual pieces and yielding conditions permitting the use of spring loading on the electrodes and sliding surface indexing of the array. The assembly is jam proof notwithstanding the pressure and expansion/contraction requirements of its operation.

Other features of the invention will be apparent from the following detailed description of preferred embodiments thereof taken in connection with the accompanying drawings, in which,

Fig. 1 is a block diagram of the measuring system in accordance with a preferred embodiment of the invention;

Fig. 1A is a voltage-time trace showing the phase relationship of oscillator driving signal to three sets of poled electrode pairs for the Fig. 1 embodiment;

Figs. 2—5 are cross section diagrams of the electrode array showing electric field rotation with vector positions corresponding to the positions indicated as fractions or multiples of pi radians of revolution in Fig. 1A;

Figs. 6, 8 and 9 are cross section views of the mechanical arrangement of an electrode assembly for the Fig. 1 embodiment taken at the locations indicated at 6—6, 8—8, and 9—9 in Fig. 7 which, is a partial longitudinal section thereof.

Referring now to Fig. 1, it is shown that the apparatus of the invention comprises a flow conduit indicated schematically at 10 and containing therein electrodes 11—16, wired so that electrodes 11 and 12 comprise an oppositely poled pair in a first phase indicated as phase-A plus (+) and phase-A minus (−) and similar pairs are provided by electrodes 13—14 and 15—16 for phases B and C respectively. Arrows indicate the direction of flow through the conduit of liquid whose liquid/void fractions are to be determined through conduit 10. A three phase, five kilohertz oscillator indicated at 20 provides voltages to control circuits 22, 24, and 26 for phases A, B and C respectively. The control circuit 26 is shown in detail, as representative of all three control circuits, and will be seen to comprise plus and minus terminals for connection to the electrodes, the terminals being connected to sections S1 and S2 of the secondary windings of a transformer with a primary winding P connected to the oscillator voltage source. The secondary windings are in series with a low impedance (preferably 5—15 ohms) resistor R_{LC} which is connected in delta circuit with low impedance resistors—R_{LA} and R_{LB} (not shown)—of the other two phases.

A tap is taken from each side of the load resistor R_{LC} through respective non-inverting amplifiers A_1 and A_2 to a differential amplifier DA. The output of amplifier DA is taken through a high pass filter f_0 to an absolute value (rectified) summing circuit Σ with calibrations means Z and S which produces an output x which is divided by a reference signal y using a multiplier/divider device (e.g., Intronics 530J four quadrant multiplier/divider) or equivalent. The quotient is fed to a meter M to indicate percent liquid in the sensor. The reference signal y is obtained from a reference control circuit RS of which the output is fed to an absolute value circuit | REF | with calibration means Z and S.

The reference control circuit RS is associated with a reference sensor located in the liquid only and which is also excited by the oscillator 20. As stated above, this compensates for changes in bulk conductivity of the fluid medium flowing through conduit 10. The reference sensor has a single pair of electrodes E1, E2 of the same materials as the electrode pairs on the main sensor. The reference control circuit RS is similar to circuits 22, 24 and 26 with the exception that its load resistor is not connected to the load resistors of the other circuits nor to any other external circuits.

The isolation transformer in each phase control circuit is of low output impedance, of the order of 10 to 15 ohms, and the load resistor of each loop has a load value of the order of 10 ohms so that changes in conductivity between electrodes will primarily control the current through the loop and hence the voltage across the load resistor will represent the true conductivity between the electrodes. The isolation transformer also prevents spurious current paths through other electrodes, other sensors and power ground loops.

To insure balance of common mode paths, three high value resistors, for example of the order of 1 megohm, (not shown) are connected from each node of the load resistor delta to ground.

The non-inverting inputs of the two operational amplifiers A_1 and A_2 are employed to provide high impedance connections (of the order of 5 to 20 megohms) to the load resistor minimizing the possibility of extraneous current paths. The outputs of the operational amplifiers A_1 and A_2 are combined by differential amplifier DA to form a signal referenced to ground. High pass f_0 combined with the high frequency rolloff characteristics of the operational amplifiers forms a band pass filter characteristic centered about the operating frequency for the system.

The operating frequency in each phase established by the three phase oscillator is about 5 kilohertz, but may be as low as 1 kilohertz or as high as 30 kilohertz. This is greatly displaced from the competing frequency operations of power equipment and radio equipment.

The operational amplifiers employed throughout the circuitry are bipolar differential input devices with high input and low output impedances; also they are of IC (integrated circuit) construction and are selected such that their high frequency cut-off is higher than the operating frequency.

Referring now to Figs. 6—9, the mechanical configuration of the electrode assembly may comprise six ceramic insulator blocks of rectangular cross section and elongated lengths, indicated at 51, interspersed with hexagonal conductive electrode blocks 54 of similar elongated lengths, the latter being backed by peripheral insulating spacer elements 50 to define among them a central conduit cross-section 10A which has the same flow cross section as adjacent lengths of conduit in the system whose fluid is to be measured. The electrode-insulator array contains features for venting flow pressure forces directly to the outer pressure tube reducing structural requirements of individual internal sensor items.

End caps 56 are provided for the sensor assembly and they are separated from the electrodes 54 by end insulators 52. End assembly rings 57 mounted from the end caps hold the interlocking assembly array in place. The electrodes 54 are undercut at their ends at 55 to provide room for Belleville-spring washer stacks 58 (and stack locating dowel pins (not shown)) between 50 and 54 to force the latter inwardly until stopped by interfacial contact of inwardly converging walls 54W of 54 with the straight walls of 51 which are parallel but not coincident with radial lines from the center of the assembly. Belleville washers have the necessary force deflection characteristics (e.g. 100 lb force in .04 deflection) to provide the necessary loading in small electrode assembly space. The inward convergence of the inner sidewalls of electrodes 54 is such that the convergence is not at the center of the conduit but rather short of that point to lower the loading which occurs on individual pieces.

Referring to Fig. 6, a force diagram of applied spring forces F acting radially inwardly against normal reaction forces P, in cooperation with the just mentioned broad convergence angle (defined by half-angle α) and a static coefficient of friction of μ, is analyzed. For electrode 54 to retract rather than jam upon radial inward contraction of the assembly (e.g., as a result of large, rapid reductions in temperature) F must be greater than P.

The relevant force equation is:

$$F=2P\ (\mu \cos \alpha+\sin \alpha)$$

For the force F to be greater than the force P, the term $(\mu \cos \alpha+\sin \alpha)$ which is a function of the friction of the electrode/insulator surfaces (μ) and the half angle (α) of the wedge section (of which the electrode represents a part) must equal 0.5 or greater.

For the expected range of friction values of possible electrode/insulator surfaces this will most readily be accomplished if the intersection of the projection of the electrode surfaces 54W for any electrode intersect at a point between the electrode and the center of the flow tube.

The back-up insulating segments 50 are of greater length than electrodes 54 by a length dimension slightly greater than is required to accommodate the difference in the thermal expansion of the two materials. Lengths of insulating segments 51 are equivalent to the distance between end caps 56 and these insulators 51 are retained by dowel pins 59 at their ends which index into holes 56H in the end caps 56 at the ends. Such holes are oversized to allow slight radial displacement of the insulators 51 to accommodate the internal pressure and pressure tube expansions due to extreme temperature conditions encountered with some flows to be measured while retaining the insulators 51 from collapsing into the flow cross section.

The materials of construction of the various components may be any conductor for electrodes which is structurally able to withstand flow environment conditions, stainless steel being preferred for boiling water applications and fused alumina being preferred for insulators in such applications. The side walls of the electrodes may be coated with insulating oxide by flame spraying or other methods to provide electrical insulation and limit leakage currents (e.g., to metal pressure vessel surfaces). The springs S may be surrounded by Teflon (a trade mark) or other insulating sleeves to similarly limit leakage currents.

The electrode/insulator assembly is mounted in a pressure vessel tube PV having flanges FL. Electrical connection and feed through to outside for the six electrodes is accomplished using spark plug type ceramic feed throughs FT passing through an outer wall (one of which is shown), and also passing through holes 50H in insulator 50 and connected to the electrodes by means of helical compression spring conductors S. The pairs of connector springs S are longitudinally offset. For insertion or removal of the assembly into or from PV, springs S and feed throughs FT are retracted.

The Belleville stack configurations are determined by specific loading and deflection requirements of a fluid line. Similarly, helical compression spring connections S to electrodes 50 are determined by such characteristics. The number and length of electrodes can vary based on electrical and spatial considerations for a specific application. In general, the electrode length must be such in relation to fluid flow rate that the measurements can be taken as though the fluid was standing still, in effect. When the number of electrodes is other than six and when the shape of the electrodes has cross sections other than hexagonal used, the maintenance of sliding surfaces between electrodes and insulators whose planes are non-concentric with the flow of pressure to the center and a compliance electrode/insulator array will provide equivalent or almost equivalent parameter and performance, with respect to the preferred embodiment described above.

WHAT WE CLAIM IS:—

1. A method of determining liquid and vapor fractions in a non-homogeneous con-

ductive fluid flowing through an elongate conduit with a flow axis, the method comprising establishing a moving electric field vector by application of polyphase alternating electrical field excitation to the fluid by direct contact to create alternating currents with distributed but crossing alternating current loci across the cross section of the conduit on a cyclic repeating basis, and measuring and summing the magnitudes of such currents to produce a conductivity signal representative of the liquid and vapor fractions of fluid flowing through the conduit.

2. A method as claimed in claim 1 wherein a separate reference conductivity measurement is made, in the liquid fraction only, to compensate bulk conductivity changes.

3. A method as claimed in claim 1 or 2 wherein the moving electric field vector is a rotating electric field vector.

4. A method as claimed in claim 3 wherein the electric field vector is established by three poled pairs of electrodes at 120° electrical phase difference and in circular array, the electrode pairs being excited from a common voltage source at 1 to 30 kilohertz.

5. An apparatus for determining liquid and vapor fractions in a non-homogeneous conductive fluid flowing through an elongate conduit with a flow axis, the apparatus comprising means arranged to establish a moving electric field vector by application of polyphase alternating electric field excitation to the fluid by direct contact to create alternating currents with distributed but crossing alternating current loci across the cross section of the conduit on a cyclic repeating basis, and measuring and summing means arranged to measure and sum the magnitudes of such currents to produce a conductivity signal representative of the liquid and vapor fractions of fluid flowing through the conduit.

6. An apparatus as claimed in claim 5 wherein the means arranged to establish the moving electric field vector comprise a plurality of means for establishing a conductive loop including the fluid and a load resistor with the loops overlapping and distributed across the conduit cross section, and means for exciting each loop by an alternating voltage source, the alternating voltage sources being out of phase with one another.

7. An apparatus as claimed in claim 6 having three of the loops, each loop comprising a pair of opposing elongated electrodes located on a diameter of the conduit and extending longitudinally parallel to the flow axis and an isolation transformer means for exciting each loop, the load resistors of the three loops being arranged in a delta circuit and each load resistor of each loop being placed between halves of the divided secondary of the isolation transformer of the loop.

8. An apparatus as claimed in claim 7 having insulator spacers positions peripherally between the electrodes, the electrodes together with the intermediate insulator spacers forming a flow passage outer surface.

9. An apparatus as claimed in claim 8 wherein the electrodes have hexagonal cross sections and the intervening spacers have elongate rectangular cross sections such as to provide radial space behind each electrode, further insulator means are provided in the radial spaces, the further insulator means having lengths substantially equal to those of the electrodes, and the insulator spacers and means are pinned and the electrode insulator array is configured to prevent inward collapse and to accommodate thermal expansion and contraction differences between the electrodes and insulator spacers and means through sliding motion along interface planes which do not intersect the flow passage center but which mutually intersect short thereof.

10. An apparatus as claimed in claim 9 wherein the electrodes are contacted by radially external spring contact members and are arranged to load Belleville washer stacks by their outward expansion.

11. An apparatus as claimed in claim 10 having means defining a pressure vessel, the spring contacts being anchored on the pressure vessel.

12. An apparatus as claimed in any one of claims 5 to 11 having differential amplifier conductivity measuring means for minimising extraneous current paths.

13. A method of determining liquid and vapor fractions in a non-homogeneous conductive fluid substantially as herein described with reference to the accompanying drawings.

14. An apparatus for measuring liquid and vapor fraction in a fluid substantially as herein described with reference to the accompanying drawings.

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1559044 COMPLETE SPECIFICATION

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Sheet 1

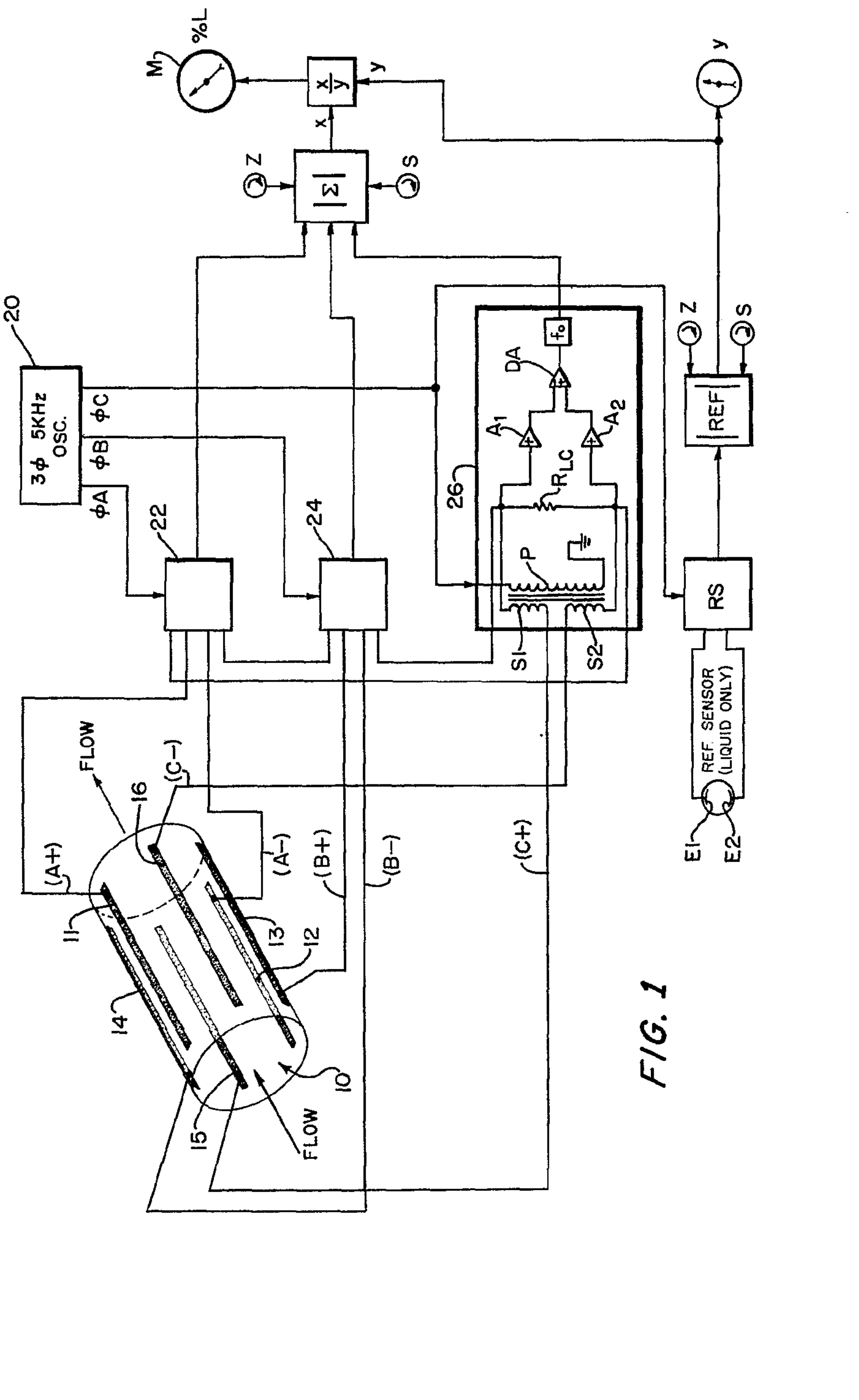

FIG. 1

1559044 COMPLETE SPECIFICATION

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Sheet 2

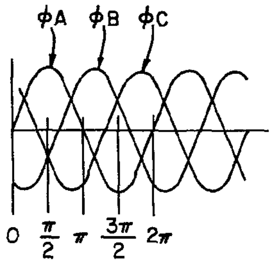

FIG. 1A

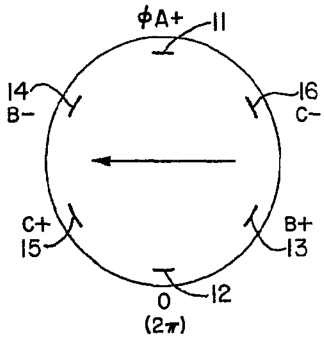

FIG. 2

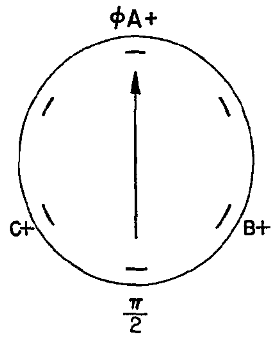

FIG. 3

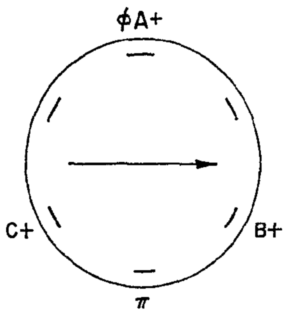

FIG. 4

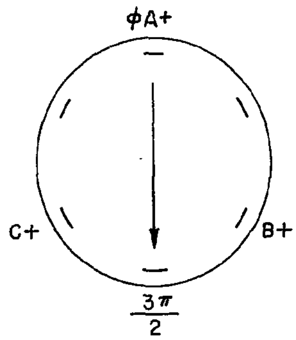

FIG. 5

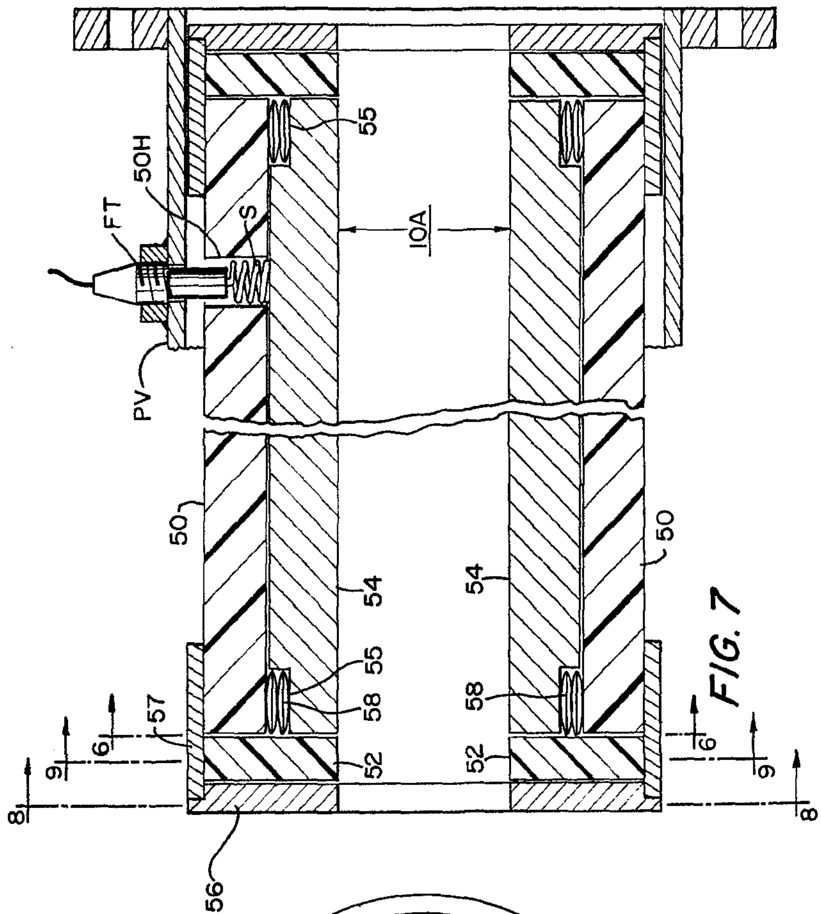

FIG. 7

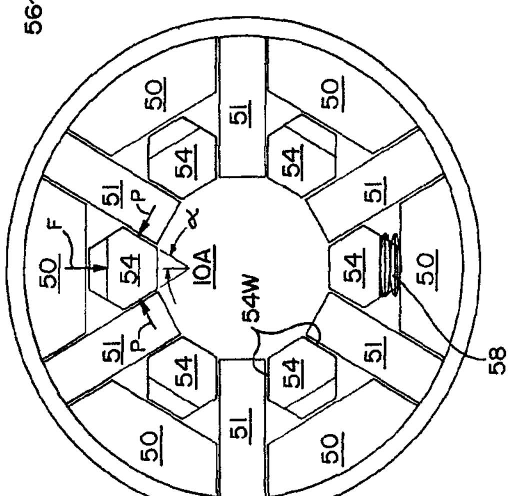

FIG. 6

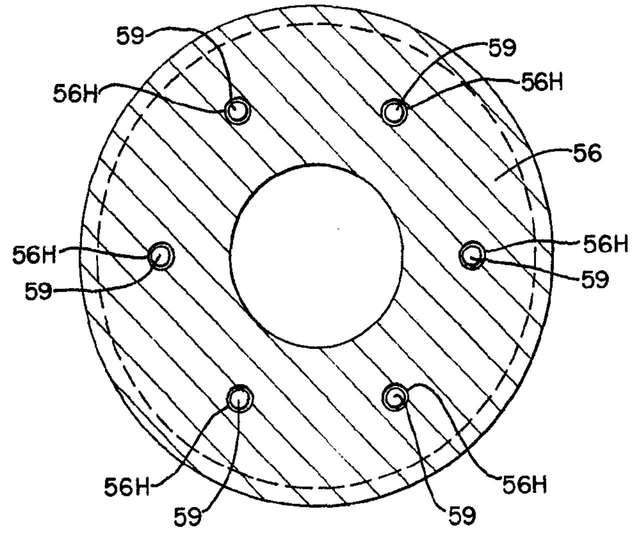
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FIG. 8

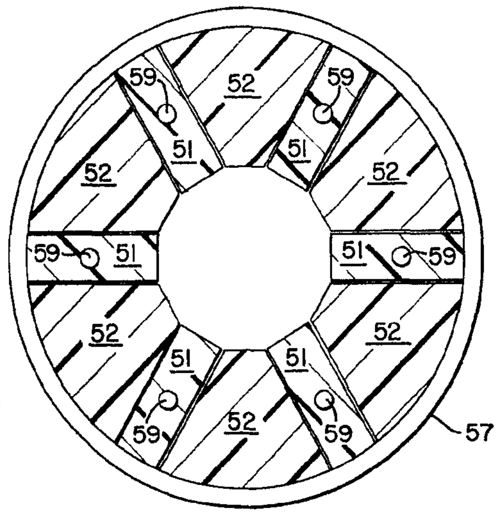
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FIG. 9