

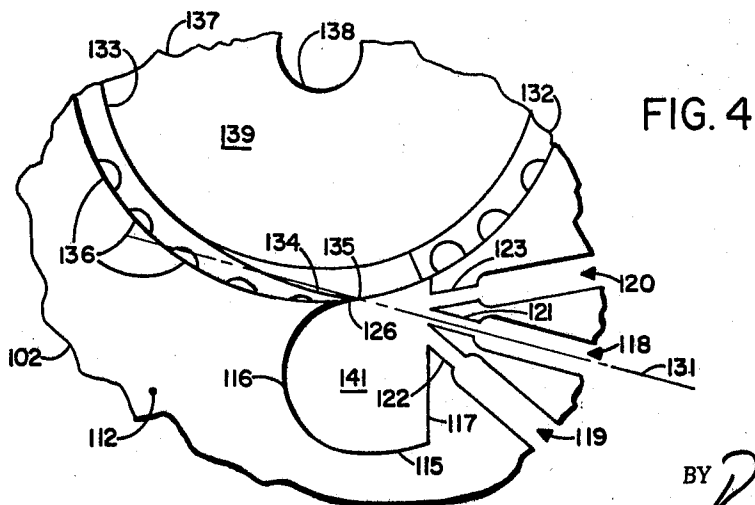
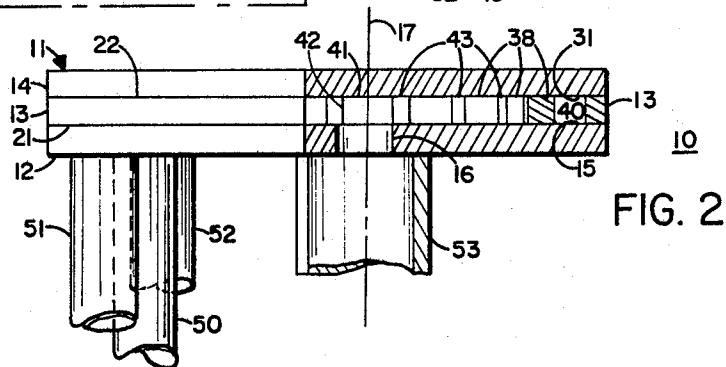
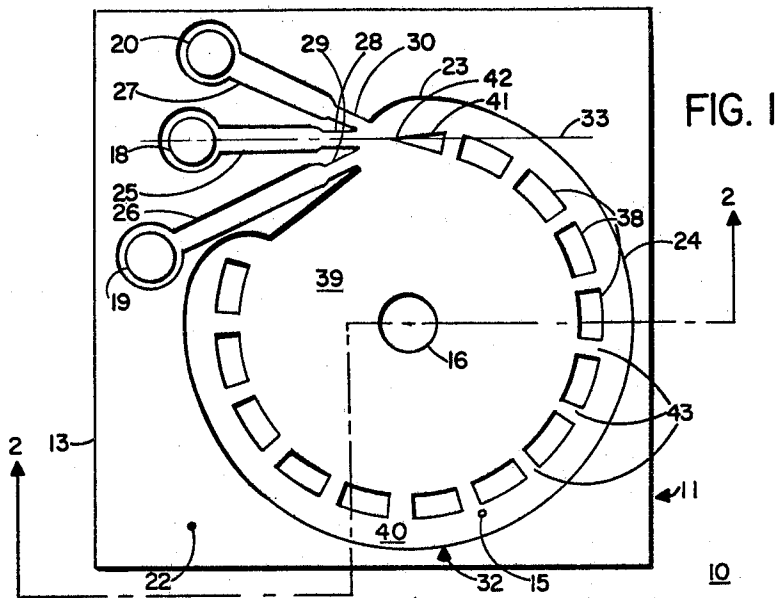
Dec. 2, 1969

J. B. STARR
FLUID APPARATUS

3,481,352

Filed Aug. 9, 1967

2 Sheets-Sheet 1



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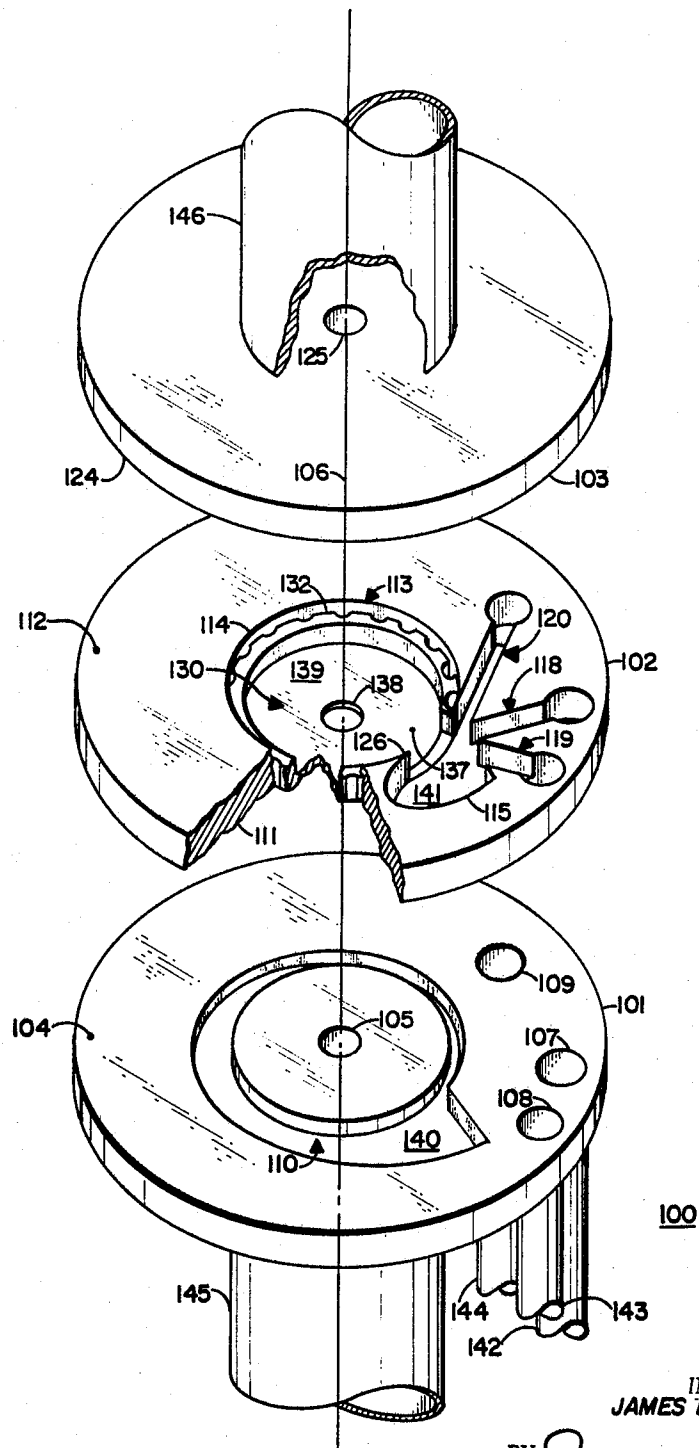
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FLUID APPARATUS

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8 Claims

ABSTRACT OF THE DISCLOSURE

A fluidic flow controller which provides a continuous range of impedances to the flow of fluid therethrough. The controller comprises a vortex chamber having a radial flow distribution manifold around its circumference and means to control the portions of fluid flowing only through the vortex chamber and through both the distribution manifold and vortex chamber. Vortical flow of the fluid flowing only through the vortex chamber results in a high flow impedance condition. Radial flow of the fluid flowing through the vortex chamber from the distribution manifold results in a low flow impedance condition.

BACKGROUND OF THE INVENTION

This invention relates generally to fluid handling apparatus, and more specifically to fluidic flow controllers and modulation devices.

Fluid amplifiers and other fluidic components have been known in the art for some time. The inherent simplicity, ruggedness and reliability of these devices make them particularly well suited for use in control systems. One of the operations required in a great many control systems is the control of fluid flow rate on command. A further requirement is that the flow rate be controllable over a wide range of values. It is highly desirable that an efficient fluidic device be provided for performing this operation.

Various fluidic devices capable of fluid flow control are known. However all of these prior art devices have features which make them unusable in many applications. For example, it has been proposed to use a proportional fluid amplifier in series with a vortex valve for controlling fluid flow. In this technique a first outlet passage of the proportional fluid amplifier is connected to the radial flow inlet of the vortex valve. The radial flow inlet provides for radial flow through the vortex chamber of the valve. A second outlet passage of the proportional amplifier is connected to the tangential flow inlet of the vortex valve. The tangential flow inlet provides for vortical flow through the vortex chamber. Fluid is introduced into the vortex chamber through the radial and tangential inlets in any desired proportion. Flow control is achieved by proportioning the incoming fluid between the two inlets. Introducing all of the fluid through the radial flow inlet results in a minimum impedance to flow. Introducing all of the fluid through the tangential flow inlet results in a maximum impedance to flow. Intermediate impedances to flow can be achieved by properly proportioning the fluid between the two inlets.

In a device of this type, fluid whose flow is being controlled must pass through the power nozzle of the proportional amplifier and the inlet nozzles of the vortex valve before passing through the vortex chamber. These nozzles are fixed impedances to fluid flow. The fluid then passes through the vortex chamber which is a variable impedance to flow. The impedance change of the device relative to its total impedance is reduced because of the fixed impedances of the proportional amplifier and the vortex valve. Thus, the range of values over which flow rate can be controlled is reduced and a large turndown ratio cannot be achieved. Turndown ratio is defined as

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the ratio of maximum flow rate to minimum flow rate under a given set of operating conditions. A large turndown ratio is required in many systems, thus, precluding the use of prior art devices of this type.

It has also been proposed to use a proportional jet deflection device in conjunction with a vortex valve for controlling fluid flow. In a device of this type, the jet deflection device directs the incoming fluid into the vortex chamber along a path which can range from tangent to the periphery of the chamber to coincident with a radius of the chamber. In this technique, the radial introduction of fluid essentially provides for a single radial flow path through the vortex chamber. The tangential introduction of fluid provides for vortical flow paths through the vortex chamber. Maximum flow impedance is achieved by introducing all of the fluid into the chamber along a tangential path. Minimum flow impedance is achieved by introducing all of the fluid into the chamber along the radial flow path.

Devices of this type wherein essentially only a single radial flow path exists for the minimum flow impedance condition are generally unstable and produce erratic behavior especially at low flow impedances. Thus, devices of this type are unusable in many systems.

SUMMARY OF THE INVENTION

The applicant's flow controller comprises a vortex chamber having a radial flow distribution manifold around its circumference and means, including only a single power nozzle, for introducing fluid into the vortex chamber and the distribution manifold in any desired proportion. For the purpose of this specification, power nozzle is defined to be any nozzle through which the fluid whose flow is being controlled must pass. The fluid introduced directly into the vortex chamber enters the chamber tangentially. The fluid introduced into the distribution manifold subsequently enters the vortex chamber radially along substantially all radii thereof. Radial flow through the vortex chamber results in a low impedance flow condition. Nearly circular vortical flow from the tangential entry of fluid into the vortex chamber results in a high impedance flow condition. Any flow impedance between the maximum and minimum values may be achieved by causing the fluid to take an appropriate path through the vortex chamber intermediate the substantially circular and radial flow paths. The appropriate flow path through the vortex chamber is achieved by controlling the amount of fluid entering the vortex chamber directly relative to the amount of fluid entering the vortex chamber from the radial flow distribution manifold.

In accordance with the teachings of this invention, the flow controlling operation is accomplished with a single fluidic component. In addition, the flow controller of this invention includes only a single power nozzle through which the fluid whose flow is being controlled must pass prior to entering the vortex chamber. Further, this flow controller provides for radial flow through its vortex chamber along an essentially infinite number of radii. Thus, the applicant's unique fluidic flow controller provides a large turndown ratio and stable operation at all flow impedance conditions.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a plan view of one embodiment of a fluidic flow controller in accordance with this invention, the cover element being removed;

FIGURE 2 is a partial sectional frontal view of the fluidic flow controller of FIGURE 1 taken along planes 2—2;

FIGURE 3 is a partial sectional exploded view of a second embodiment of a fluidic flow controller in accordance with this invention; and

FIGURE 4 is an enlarged scale plan view of the splitter element of the fluidic flow controller of FIGURE 3.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIGURES 1 and 2, reference numeral 10 generally refers to one embodiment of the applicant's fluidic flow controller. Flow controller 10 has a housing 11 made up of a lower element 12, an intermediate element 13 and a cover element 14. Elements 12, 13 and 14 may be made of any suitable material such as metal or plastic. The material from which elements 12, 13 and 14 are made should be substantially rigid, impervious to fluids and not subject to corrosion by fluids in contact therewith. Lower element 12 has a substantially plane upper surface 15. Lower element 12 is provided with a central discharge opening 16 therethrough aligned with an axis 17. Openings 18, 19 and 20 are also provided in element 12 and spaced apart from opening 16. The purpose of openings 16, 18, 19 and 20 will hereinafter be discussed. Intermediate element 13 has substantially plane lower and upper surfaces 21 and 22 respectively. Intermediate element 13 is provided with an interior opening 23 therethrough surrounding axis 17. Interior opening 23 is cylindrical and includes a substantially circular portion 24 aligned with axis 17. Interior opening 23 also includes three additional portions which are provided to allow for fluid passageways 25, 26 and 27, power nozzle 28, and control ports 29 and 30. The purpose of opening 23 will hereinafter be further discussed. Cover element 14 has a substantially plane lower surface 31. Elements 12, 13 and 14 are secured together in any suitable manner such as with bolts or adhesives (not shown) with surfaces 15 and 21 and surfaces 22 and 31 in fluid tight engagement.

Elements 12, 13 and 14 cooperate to form an interior chamber 32 whose cross section perpendicular to axis 17 is generally circular. Elements 12, 13 and 14 also cooperate to form fluid passageways 25, 26 and 27, power nozzle 28, and control ports 29 and 30. Fluid passageways 25, 26 and 27 communicate at one end thereof with interior chamber 32 through power nozzle 28 and control ports 29 and 30 respectively. The other end of fluid passageways 25, 26 and 27 communicate with openings 18, 19 and 20 respectively in lower element 12. Power nozzle 28 is aligned with an axis 33. Control ports 29 and 30 are in communication with power nozzle 28 on opposite sides of axis 33 and are oppositely oriented.

A substantially cylindrical separation element 38 is located inside chamber 32 surrounding axis 17. The cross section of separation element 38 perpendicular to axis 17 is substantially a segment of an annulus centered on axis 17. Separation element 38 separates chamber 32 into inner and outer portions 39 and 40 respectively. Inner portion 39 is a vortex chamber. Outer portion 40 is a radial flow distribution manifold. One end of separation element 38 is provided with a splitter element 41. Splitter element 41 is substantially aligned with axis 33 such that its apex 42 is oriented toward power nozzle 28. Separation element 38 is provided with a plurality of apertures 43 therethrough. Each aperture 43 is in communication with radial flow distribution manifold 40 and vortex chamber 39. Further, each aperture 43 is oriented toward axis 17 to provide for radial flow of fluid into vortex chamber 39 from radial flow distribution manifold 40. Although separation element 38 is shown having apertures therethrough, it should be understood that other types of separation elements will work equally as well. For example, separation element 38 may be replaced with a plurality of vanes or may be made of sintered ceramics or metals or other materials which are permeable to fluids and provide low impedance to flow therethrough.

Opening 18 in element 12 is adapted to be connected to any suitable fluid source (not shown) by means of inlet conduit 50. Openings 19 and 20 in element 12 are adapted to be connected to variable fluid pressure differential

source (not shown) by means of control conduits 51 and 52 respectively. Opening 16 in element 12 is adapted to be connected to any desired utilization device (not shown) by means of discharge tube 53.

In operation, fluid under pressure is supplied to power nozzle 28 from a fluid source by means of inlet conduit 50, opening 18 and fluid passage 25. A fluid pressure differential control signal from any desired source is supplied to control ports 29 and 30 by means of control conduits 51 and 52, openings 19 and 20 and passageways 26 and 27 respectively. The source, for example, may be a part of a control system. In the absence of a pressure differential between control ports 29 and 30, a fluid stream issues from power nozzle 28 substantially along axis 33. The fluid stream issuing from power nozzle 28 impinges on apex 42 of splitter element 41 and divides with substantially equal portions entering vortex chamber 39 and radial flow distribution manifold 40. The portion entering vortex chamber 39 directly from power nozzle 28 tends to take a nearly circular vortical path within the chamber. The portion entering radial flow distribution manifold 40 is substantially evenly distributed around the circumference of vortex chamber 39 and enters vortex chamber 39 substantially radially along a plurality of radii by means of apertures 43 in separation element 38. The combined tangential and radial introduction of fluid into vortex chamber 39 results in the fluid flowing there-through towards discharge opening 16 along spiral paths. As the flow spirals closer to discharge opening 16, the radii of the fluid paths decrease and the tangential velocity of the fluid increases due to inherent conservation of angular momentum. Shear stress and centrifugal forces in the rotating fluid lead to a pressure drop in the fluid as it spirals inward. In turn, impedance to the fluid flow results which tends to decrease the fluid flow through flow controller 10. These shear stresses and centrifugal forces result primarily from the rotational component of the fluid flow. Thus the impedance to fluid flow increases and the flow through flow controller 10 decreases as the rotational component of the flow increases.

A minimum flow impedance and a maximum flow condition through flow controller 10 can be achieved by deflecting the entire power stream from power nozzle 28 into radial flow distribution manifold 40. In this case all of the fluid flowing through flow controller 10 is distributed around the circumference of vortex chamber 39 and enters vortex chamber 39 radially through apertures 43 in separation element 38. Since the flow through vortex chamber 39 has no rotational component, there is a minimum pressure drop in the chamber. Therefore, a maximum flow condition through flow controller 10 exists. The entire stream issuing from power nozzle 28 can be deflected into radial flow distribution manifold 40 by supplying a control pressure to control port 29 which is sufficiently greater than the control pressure supplied to control port 30. If, however, the pressure supplied to control port 30 is sufficiently greater than that supplied to control port 29, the entire stream issuing from power nozzle 28 will be deflected tangentially into vortex chamber 39. This results in the fluid flowing through vortex chamber 39 having a maximum rotational component. Therefore, there is a maximum pressure drop across vortex chamber 39, a maximum flow impedance condition exists, and there is a minimum flow condition through flow controller 10. There exists a continuous range of flow conditions through flow controller 10 between the maximum flow condition resulting from entirely radial flow through vortex chamber 39 and the minimum flow condition resulting from flow through vortex chamber 39 having a maximum rotational component. The intermediate flow conditions are achieved by supplying a pressure differential to control ports 29 and 30 such that fluid in the power stream enters vortex chamber 39 tangentially from power nozzle 28 and radially from radial flow distribution manifold 40 in the proper proportions.

It should be noted that the applicant's flow controller provides for radial introduction of fluid into vortex chamber 39 along a plurality of radial paths. It should also be noted that a single power nozzle 28 performs both the function of producing a jet whose direction can be controlled to enter vortex chamber 39 directly or through radial flow distribution manifold 40 and the function of generating a jet of sufficient momentum to produce the required vortical flow. These features result in a significant improvement in the turndown ratio of the applicant's flow controller over the prior art. For example, under a given set of operating conditions, a series combination of a proportional amplifier and vortex valve achieved a maximum turndown ratio of 1.65 to 1. This is contrasted to the applicant's flow controller which, under the same set of operating conditions, achieved a turndown ratio of 3.65 to 1. It is thereby apparent that the applicant's fluidic flow controller offers a significant improvement in operation over the prior art fluidic flow controllers.

Referring now to FIGURES 3 and 4, reference numeral 100 generally refers to a second embodiment of a fluidic flow controller in accordance with the present invention. Flow controller 100 comprises a housing made up of a lower plate element 101, an intermediate plate element 102 and a cover plate element 103. Elements 101, 102 and 103 may be made of any suitable materials such as metals or plastics. The material from which elements 101, 102 and 103 are made should be substantially rigid, impervious to fluids and not subject to corrosion by fluids in contact therewith. Lower plate element 101 has a substantially plane upper surface 104. Lower plate element 101 is provided with a central discharge opening 105 therethrough aligned with an axis 106. Openings 107, 108 and 109 are also provided in element 101 and spaced apart from opening 105. Surface 104 of element 101 has formed therein a channel 110 located about axis 106. The functions of openings 105, 107, 108 and 109 and channel 110 will hereinafter be discussed. Intermediate plate element 102 has substantially plane lower and upper surfaces 111 and 112 respectively. Intermediate element 102 also has an interior opening 113 therethrough surrounding axis 106. Interior opening 113 is cylindrical and includes a substantially circular portion 114 aligned with axis 106. Circular portion 114 is in peripheral communication with a portion 115 of opening 113 having a curved wall 116 and a flat wall 117. The curved wall 116 and the wall of circular portion 114 cooperate to form a wedge-shaped intersection 126. Interior opening 113 in element 102 also includes three additional portions which are provided to allow for fluid passageways 118, 119 and 120, power nozzle 121, and control ports 122 and 123. The purpose of opening 113 will hereinafter be further discussed. Cover plate element 103 has a substantially plane lower surface 124 and is provided with a centrally located discharge opening 125 therethrough aligned with axis 106. Elements 101, 102 and 103 are secured together in any suitable manner such as with bolts or adhesives (not shown) with surfaces 104 and 111 and surfaces 112 and 124 in fluid tight engagement.

Elements 101, 102 and 103 cooperate to form an interior chamber 130, fluid passageways 118, 119 and 120, power nozzle 121, and control ports 122 and 123. Fluid passageways 118, 119 and 120 communicate at one end thereof with interior chamber 130 through power nozzle 121 and control ports 122 and 123 respectively as can best be seen in FIGURE 4. The other end of fluid passageways 118, 119 and 120 communicate with openings 107, 108, and 109 respectively in lower plate element 101. Power nozzle 121 is oriented toward wedge-shaped intersection 126 along an axis 131. Control ports 122 and 123 are in communication with power nozzle 121 on opposite sides of axis 131 and are opposingly oriented.

Interior chamber 130 is fitted with a separation element 132. Separation element 132 comprises a substantially circular cylindrical wall 133 oriented parallel to axis 106.

The outside diameter of separation element 132 is substantially equal to the diameter of circular portion 114 of interior opening 113. The height of wall 133 is slightly less than the thickness of intermediate plate element 102 for reasons which will hereafter be apparent. A cylindrical section of wall 133 adjacent to the area of communication between circular portion 114 and portion 115 of interior opening 113 is open. The edge of wall 133 along the opening therein adjacent to wedge-shaped intersection 126 is also wedge shaped and cooperates with intersection 126 to form a wedge-shaped splitter element 134 aligned with axis 131 and having its apex 135 oriented toward power nozzle 121. The exterior surface of wall 133 is provided with a plurality of cylindrical channels 136 parallel to axis 106. The channels increase in cross sectional area with distance around wall 133 from splitter element 134.

Separation element 132 is positioned within intermediate plate element 102 such that a first end thereof is substantially flush with lower surface 111 of element 102. Since the height of wall 133 is slightly less than the thickness of element 102, a gap exists between the second end of wall 133 and lower surface 124 of cover plate element 103. The first end of wall 133 may be provided with a closure 137 having a central opening 138 therethrough. Opening 138 in closure 137 is in communication with central discharge opening 105 in lower plate element 101. Separation element 132 is held in position by any suitable means such as bolts or adhesives (not shown). Other means may also be provided for holding separation element 132 in position. For example, closure 137 may be provided with a nipple concentric with opening 138 which mates with an internally threaded portion of lower plate element 101 concentric with central discharge opening 105.

The internal surface of wall 133, closure 137 and a portion of lower surface 124 of upper plate element 103 cooperate to form a vortex chamber 139. Channel 110 in lower plate element 101 and a portion of lower surface 111 of intermediate plate element 102 cooperate to form a radial flow distribution manifold 140. Portion 115 of interior opening 113 forms a fluid transfer passage 141 which is in communication with power nozzle 121, control ports 122 and 123, vortex chamber 139, and radial flow distribution manifold 140. Channels 136 in coupling element 132 are in communication at opposite ends thereof with vortex chamber 139 and radial flow distribution manifold 140. Channel 110 in lower plate element 101 has a maximum width adjacent to transfer passage 141. The width of channel 110 decreases with distance from transfer passage 141 taken in the direction of increase of the cross sectional areas of channels 136. Therefore, radial flow distribution manifold 140 has a maximum cross sectional area adjacent to transfer passage 141 and its cross sectional area decreases with distance from transfer passage 141. The decreasing cross sectional area of radial flow distribution manifold 140 and increasing cross sectional areas of channels 136 with distance from transfer passage 141 function to provide substantially uniform radial introduction of fluid into vortex chamber 139 as will be discussed.

Opening 107 in lower plate element 101 is adapted to be connected to any suitable fluid source (not shown) by means of inlet conduit 142. Openings 108 and 109 in lower plate element 101 are adapted to be connected to a control source (not shown) having a pressure differential output by means of control conduits 143 and 144 respectively. Central discharge openings 105 and 125 in lower and cover plate elements 101 and 103 are adapted to be connected to any desired utilization device (not shown) by means of discharge tubes 145 and 146 respectively.

In operation, the fluid under pressure is supplied to power nozzle 121 from a fluid source by means of inlet conduit 142, opening 107 and fluid passage 118. A fluid pressure differential control signal from any suitable con-

trol source is supplied to control ports 122 and 123 by means of control conduits 143 and 144, openings 108 and 109 and passageways 119 and 120 respectively. The source of control signals, for example, may be a part of a control system. In the absence of a pressure differential between control ports 122 and 123, a fluid stream issues from power nozzle 121 substantially along axis 131. The fluid stream issuing from power nozzle 121 impinges on apex 135 of splitter element 134 and divides with substantially equal portions entering vortex chamber 139 and transfer passage 141. The portion entering vortex chamber 139 directly from power nozzle 121 tends to take a nearly circular vortical path within the chamber. The portion entering transfer passage 141 subsequently enters radial flow distribution manifold 140. The only exit available to the fluid entering radial flow distribution manifold 140 is through channels 136 in separation element 132. The fluid flowing through channels 136 enters vortex chamber 139 radially through the gap between the second end of wall 133 and lower surface 124 of cover plate element 103. Thus, the fluid entering transfer passage 141 is distributed within radial flow distribution manifold 140 from where it enters vortex chamber 139 substantially radially along a plurality of radii through channels 136 and the gap between the second end of wall 133 and lower surface 124 of element 103. Since there is a pressure drop in radial flow distribution manifold 140 with flow path distance from transfer passage 141, the increasing cross sectional areas of channels 136 in separation element 132 provide for transferring fluid from radial flow distribution manifold 140 into vortex chamber 139 at a substantially equal rate around substantially the entire circumference thereof. Further, since the amount of fluid transferred into vortex chamber 139 from radial flow distribution manifold 140 increases with flow path distance therein, radial flow distribution manifold 140 is required to carry less fluid with distance from transfer passage 141. Therefore, the decreasing cross sectional area of radial flow distribution manifold 140 with distance from transfer passage 141 further aids in the equal transfer of fluid into vortex chamber 139 around substantially its entire circumference.

The combined tangential and radial introduction of fluid into vortex chamber 139 results in the fluid flowing therethrough toward discharge openings 105 and 125 along spiral paths. As the flow spirals closer to discharge openings 105 and 125, the radii of the fluid paths decrease and the tangential velocity of the fluid increases to conserve angular momentum. As hereinbefore discussed, shear stresses and centrifugal forces in the rotating fluid lead to a pressure drop in the fluid as it spirals inward. Thus, impedance to the flow occurs and tends to decrease the fluid flow through flow controller 100.

A minimum flow impedance and maximum flow condition through flow controller 100 can be achieved by deflecting the entire power stream from power nozzle 121 into transfer passage 141. All the fluid flowing through flow controller 100 is thereby distributed within radial flow distribution manifold 140 from where it is radially introduced into vortex chamber 139 by means of channels 136 and the gap between the second end of wall 133 of separation element 132 and lower surface 124 of cover plate element 103. Since the flow through vortex chamber 139 has no rotational component, there is a minimum pressure drop in the chamber. Therefore, a maximum flow condition through flow controller 100 exists. The entire stream issuing from power nozzle 121 can be deflected into transfer passage 141 by supplying a control pressure to control port 123 which is sufficiently greater than the control pressure supplied to control port 122. Conversely, a maximum flow impedance and minimum flow condition through flow controller 100 can be achieved by deflecting the entire power stream from power nozzle 121 tangentially into vortex chamber 139. The fluid flowing through vortex chamber 139 will there-

fore have a maximum rotational component which will cause a maximum flow impedance condition and minimum flow through flow controller 100. The entire stream from power nozzle 121 can be deflected tangentially into vortex chamber 139 by providing a pressure at control port 122 which is sufficiently greater than the pressure at control port 123.

There exists a continuous range of flow conditions through flow controller 100 between the maximum flow condition resulting from entirely radial flow through vortex chamber 139 and a minimum flow condition resulting from flow through vortex chamber 139 having a maximum rotational component. Intermediate flow conditions are achieved by supplying a pressure differential to control ports 122 and 123 such that fluid enters vortex chamber 139 tangentially from power nozzle 121 and radially from radial flow distribution manifold 140 in the proper proportions.

What is claimed is:

1. Fluid flow control apparatus comprising:
 - means defining a vortex chamber having a central fluid discharge opening;
 - means for providing a radial flow pattern within substantially the entire vortex chamber from its periphery to the central fluid discharge opening;
 - means for providing a vortical flow pattern within said vortex chamber;
 - means including only a single power nozzle for transferring fluid to said means for providing a radial flow pattern and said means for providing a vortical flow pattern; and
 - means for controlling the transfer of fluid to said means for providing a radial flow pattern and said means for providing a vortical flow pattern.
2. Fluid flow apparatus comprising:
 - means defining a chamber, said chamber having a longitudinal axis;
 - a supply passage in fluid communication with said chamber and adapted to provide fluid to said chamber with a rotational component of velocity with respect to said axis;
 - separating means dividing said chamber into a vortex chamber and a distribution manifold, said separating means being permeable to fluids and allowing only substantially radial flow of fluid therethrough about the periphery of said vortex chamber;
 - a central discharge passage in fluid communication with said vortex chamber; and
 - means for controlling the portion of fluid from said supply passage that flows through said separating means.
3. Fluid flow control apparatus comprising:
 - a housing having therein a chamber, a power nozzle in communication with the chamber, first and second control ports in communication with the power nozzle, and at least one discharge opening in communication with the chamber, the power nozzle being oriented to normally direct a stream of fluid into the chamber along a first axis, the discharge opening being centrally located with respect to the chamber and aligned with a second axis;
 - a separation element located within the chamber about the second axis, the periphery of said separation element being substantially tangent to the first axis, said separation element dividing the chamber into a vortex chamber and a distribution manifold, said separation element providing only substantially radial fluid flow into said vortex chamber from the distribution manifold; and
 - a splitter element located within the chamber at the periphery of said separation element, said splitter element being substantially aligned with the first axis, the apex of said splitter element being oriented toward said power nozzle, a fluid signal in the first

control port being effective to deflect at least a portion of a fluid stream issuing from the power nozzle to one side of said splitter element and into the distribution manifold whereby a lower impedance flow condition through said fluid flow control apparatus is produced, and a fluid signal in the second control port being effective to deflect at least a portion of a fluid stream issuing from the power nozzle to the other side of said splitter element and into the vortex chamber whereby a higher impedance flow condition through said fluid flow control apparatus is produced.

4. The fluid flow control apparatus of claim 3 wherein the cross sectional area of the distribution manifold decreases with fluid flow path distance from said power nozzle.

5. The fluid flow control apparatus of claim 4 wherein said separation element has fluid passages therein connecting the distribution manifold with the vortex chamber.

6. The fluid flow control apparatus of claim 5 wherein the cross sectional area of said fluid passages increase with fluid flow path distance from said power nozzle.

7. Fluid flow control apparatus comprising:

a housing having therein a substantially cylindrical chamber, a power nozzle in communication with the chamber, first and second control ports in communication with the power nozzle, and a discharge opening in communication with the chamber, the power nozzle being oriented to normally direct a stream of fluid into the chamber along a first axis, the discharge opening being centrally located with respect to the chamber and aligned with a second axis; and

a separation element located within the chamber about the second axis, the cross section of said separation

element perpendicular to the second axis being a segment of an annulus substantially centered on the second axis, said separation element dividing the chamber into a vortex chamber and a radial flow distribution manifold, one end of said separation element forming a splitter element, the splitter element being substantially aligned with the first axis, the apex of the splitter element being oriented toward the power nozzle, the first control port being oriented to deflect a fluid stream issuing from the power nozzle toward the radial flow distribution manifold, and the second control port being oriented to deflect a fluid stream issuing from the power nozzle toward the vortex chamber.

8. The fluid flow control apparatus of claim 7 wherein said separation element has fluid passages therein connecting the radial flow distribution manifold and the vortex chamber, and wherein the cross sectional area of the radial flow distribution manifold decreases with fluid flow path distance from the power nozzle.

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