July 22, 1969 E. A. MAYER 3,456,667

BISTABLE FLUID DEVICE

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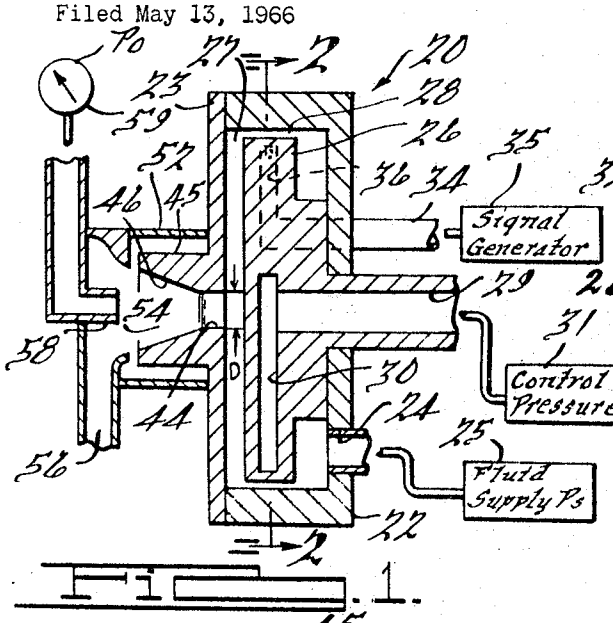


Fig. 1.

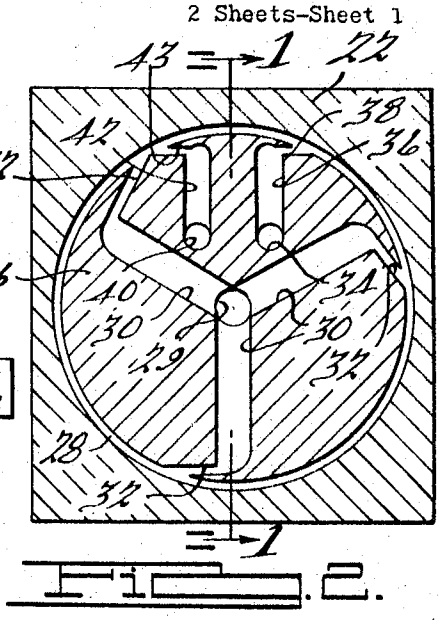


Fig. 2.

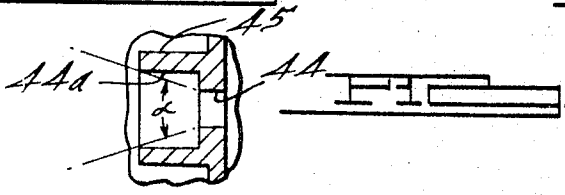


Fig. 1a.

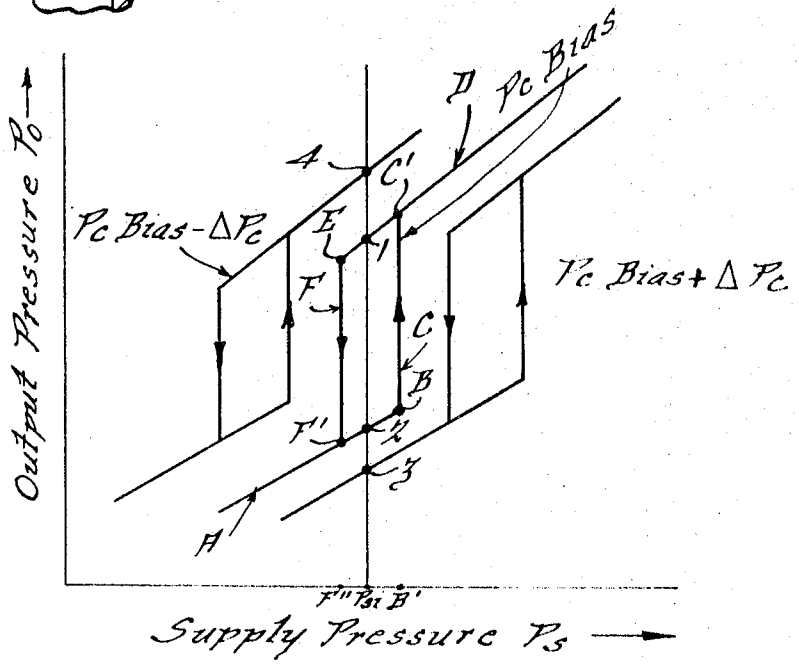


Fig. 3.

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BISTABLE FLUID DEVICE

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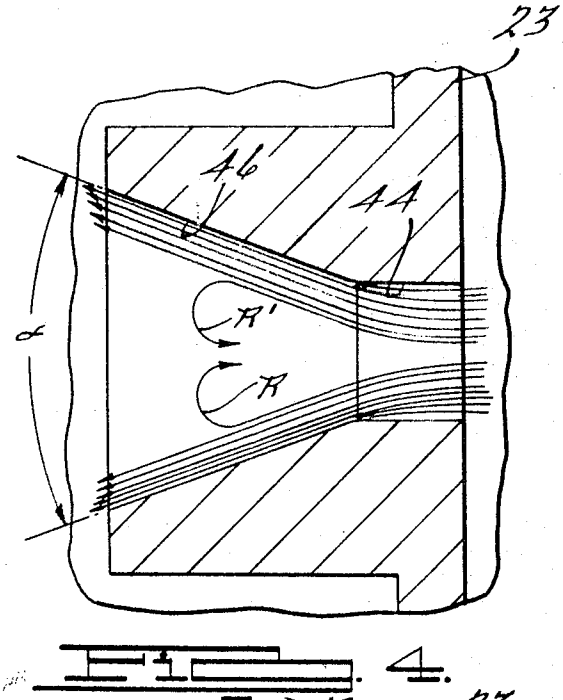


FIG. 4.

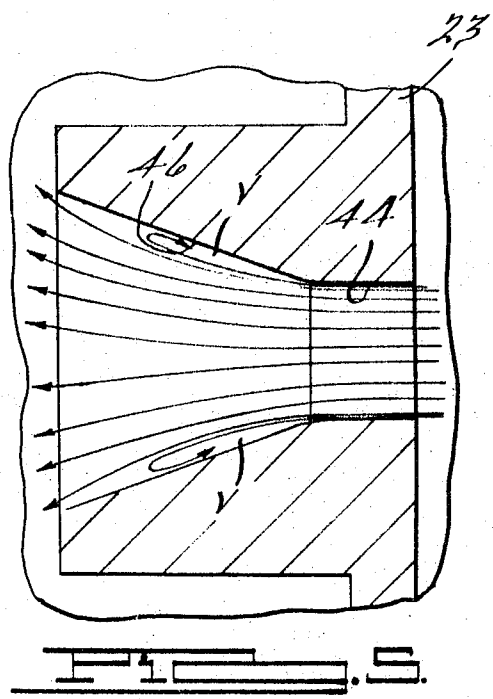


FIG. 5.

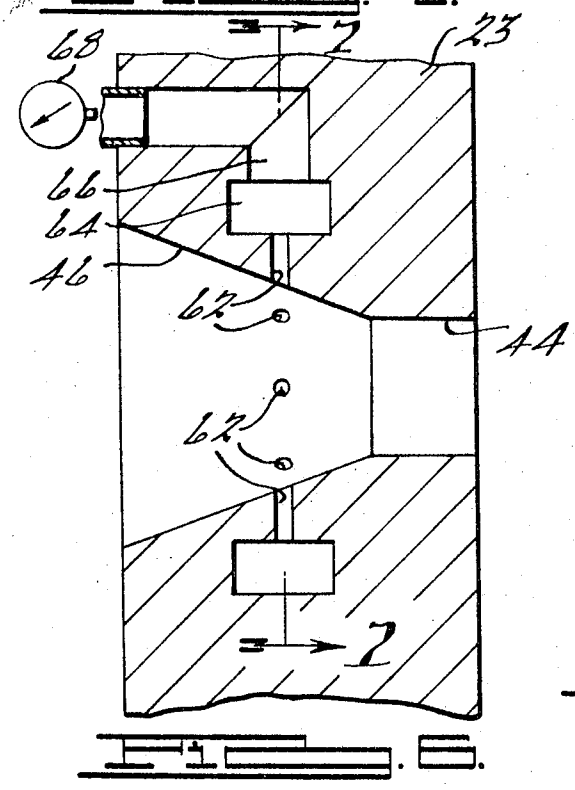


FIG. 6.

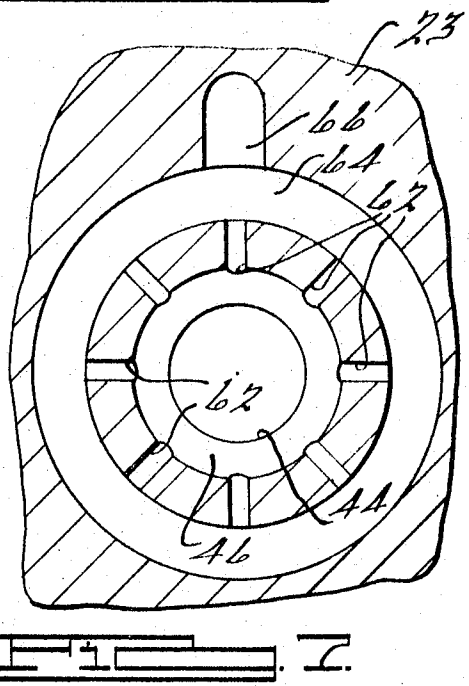


FIG. 7.

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BISTABLE FLUID DEVICE

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U.S. Cl. 137—81.5 10 Claims

ABSTRACT OF THE DISCLOSURE

A bistable vortex device having a divergent exhaust port providing two stable output pressure distributions in response to vortical flow rate of fluid in the device.

This invention pertains to a bistable fluid device and more particularly to a vortex device wherein supply fluid is admitted to a cylindrical chamber and control fluid, admitted to the chamber through control ports, imparts a vortical flow to the supply fluid which emerges from an exhaust port at the center of the cylinder.

It is an object of this invention to provide in such a vortex device two stable output conditions for a given supply pressure and control pressure.

It is an object of this invention to provide in such a vortex device of the previous object means for supplying incremental control pressure in one instance to reinforce the vortical flow and in another instance to oppose the vortical flow, to determine which bistable state at which the vortex device is operating by observing any change in the output flow or pressure.

It is an object of this invention to provide such a bistable vortex device by having an exhaust port which has an increased diameter in the direction of the exhaust flow to induce the formation of an area of reduced pressure along the walls of the exhaust port at which time is provided a sudden increase in output flow and pressure, and will provide a corresponding sudden decrease in output flow and pressure when the area of reduced pressure is removed; with the sudden increase occurring at a different supply pressure than the sudden decrease thereby providing a hysteresis loop.

It is an object of this invention to provide the increase in diameter of the exhaust port gradually thereby forming a cone shaped surface.

It is an object of this invention to increase the diameter of the exhaust port in a step from a smaller diameter to a larger diameter.

These and other objects will become more apparent when preferred embodiments of this invention are considered in connection with the drawings in which:

FIGURE 1 is a section taken at 1—1 of FIGURE 2 and shows a schematic view of a preferred embodiment;

FIGURE 1*a* is an enlarged section of a modified stepped exhaust port;

FIGURE 2 is a section taken at 2—2 of FIGURE 1;

FIGURE 3 is a graph showing three hysteresis loops with the abscissa being supply pressure P_S and with the ordinate being output pressure P_O with the three hysteresis loops being for three different control pressures;

FIGURE 4 is an enlarged sectional view showing the fluid flow for one stage of operation;

FIGURE 5 is an enlarged sectional view showing the fluid flow for a second stage of operation wherein there is formed an area of reduced pressure for this invention;

FIGURE 6 is an enlarged sectional view showing a chamber provided about the exhaust port at the area where the reduced pressure is formed; and

FIGURE 7 is an enlarged section taken at 7—7 of FIGURE 6.

In FIGURE 1 is shown vortex device 20 having cylindrical housing 22 with a plate 23 covering one end thereof. A supply port 24 is formed in housing 20 and is connected to a fluid supply 25. A button 26 is inserted in housing 22 and is spaced from wall 23 thereby forming a chamber 27 therebetween. Also, button 26 is spaced from walls of housing 22 to form an annular clearance 28 therebetween.

A control inlet 29 is formed centrally of button 26 and is connected to radial passages 30 each of which terminate in a nozzle 32 which, under sufficient control pressure from source 31, will direct fluid into annular space 28 causing fluid supply passing through port 24 to swirl or assume a vortical flow which increases in rate as it moves towards exhaust port 44 which is formed centrally of wall 23 within annular extension 45.

A signal tube 34 is provided through housing 22 and through button 26 and is connected to passage 36 and jet 38 and introduces fluid flow from signal generator 35 which aids the flow from jets or nozzles 32.

A second signal tube 40 also connected to signal generator 35 passes through the wall of housing 22 and through button 26 connecting to passage 42 and nozzle 43 to introduce a flow in annular space 28 which opposes the flow from nozzles 32.

Exhaust port 44 increases in diameter in the direction of exhaust flow to form a conical like surface 46. As can be seen in FIGURE 1, the exhaust port length is greater than its inlet diameter D. This surface could also be increased as shown in the cross section of FIGURE 1*a* where exhaust port 44 has two diameters; a smaller diameter and a stepped larger diameter 44*a*. As will become apparent, it is this increase in diameter which provides structure for developing the bistable nature of this invention.

An annular wall 52 is connected to plate 23 and forms a vent chamber 54 about exhaust port extension 45. Vent port 56 connects chamber 54 to a pressure less than the supply pressure P_S, which may be atmospheric pressure in this embodiment.

A pickoff tube 58 is axially aligned with exhaust port 44 and axially spaced therefrom. The pressure in tube 58 corresponds to the flow emerging from port 44. The flow emerging from port 44 has an axial portion which is surrounded by a conical portion with the axial portion diminishing and the conical portion increasing as the amount of swirl in chamber 27 is increased due to increased control pressure P_C. As control pressure P_C is increased, the output flow is decreased and the axial portion of the stream is decreased thereby decreasing the pressure in tube 58 and the reading on pressure gauge 59. However, as the swirl is decreased due to a decreased pressure control P_C, the axial flow and the total flow from port 44 is increased and the pressure in tube 58 is correspondingly increased.

Operation

In normal operation of the device shown in FIGURES 1 and 2, a pressure control bias, P_C Bias, is applied to passage 29 to establish an operating range which may be increased or decreased by applying a signal flow to jets 38, 43 respectively. As the supply pressure is increased from zero, the output pressure will follow line A in the hysteresis loop marked P_C Bias which is the center loop in the graph of FIGURE 3. When the output pressure reaches point B, there will be a sudden increase as shown by line C to point C′ on line D where an increase in supply pressure will result in a gradual increase in output pressure P_O.

As the supply pressure P_S is decreased, the output pressure P_O will follow line D until point E where there is a sudden decrease in output pressure as shown by line F

until it intersects at point F' with line A and then any further decrease in supply pressure will cause output pressure to follow line A. A resultant hysteresis loop is formed as shown in FIGURE 3.

While it is not definitely understood the exact reason for the hysteresis loop, one possible explanation will be made in connection with FIGURES 4 and 5. FIGURE 4 shows the flow from exhaust port **44** during the operation on line A in the graph of FIGURE 3 and it is seen that the flow is close against the flared walls **46** with a slight recirculation flow R, R' taking place. Recirculation flow R, R' tends to reduce the amount of flow coming from port **44**. FIGURE 5 shows the flow from port **44** at point B on line A in the graph of FIGURE 3 and here it is seen that the flow has separated from the flared walls **46** and there is created an annular region of reduced pressure V which increases the pressure drop through port **44** thereby increasing the flow therethrough which accounts for the jump in output pressure to line D in the graph of FIGURE 3. Also aiding in this sudden increase of output pressure is the fact that the recirculation flow R, R', has been largely eliminated thereby reducing resistance to output flow from port **44**.

It has been found that when the included angle α of flare **46**, also shown in FIGURE 1*a*, is in a range between 5 and 45 degrees, the advantages of this invention can be achieved. If the flare angle alpha is too small, the flow will not separate from the flare walls to form the annular ring V of reduced pressure and if the flare angle alpha is too large, the flow is not able to attach to the walls **46** at all. For smaller angles of alpha, the higher the swirl of fluid coming from port **44**, which is caused by a higher control pressure P_C, the lower the chance that an area of reduced pressure V will be formed. However, the more swirl to the air leaving the exhaust port **44**, the larger the flare angle alpha can be and still obtain an area of reduced pressure V. In other words, the swirl tends to force the flow against the flared walls and a larger angle alpha is needed to develop a vacuum region V.

It is therefore seen in the graph of FIGURE 3 that for a given supply pressure P_{S1}, there are two stable output states, those being shown at points **1**, **2**. The stable states can be changed by either decreasing the supply pressure P_S below the point F'', in the event that the stable state is at point **1**, or by increasing the supply pressure to point B, in the event the stable state is at point **2**, and then in both cases returning the supply pressure to P_{S1}.

The stable states can also be changed by changing the pressure control bias, P_C Bias. In the graph of FIGURE 3 are shown two additional hysteresis loops one labeled P_C Bias$-\Delta P_C$ and P_C Bias$+\Delta P_C$. P_C Bias$-\Delta P_C$ can be obtained by supplying a fluid signal to tube **40** which will cause a flow ΔP_C from nozzle **43** which opposes and hence reduces the P_C Bias flow from nozzles **32**. P_C Bias$+\Delta P_C$ loop can be obtained by causing a fluid signal ΔP_C to pass through tube **34** and out nozzle **38** aiding the swirl caused by the P_C Bias flow from nozzles **32**.

If the embodiment of FIGURE 1 is operating at state **1** and a $-\Delta P_C$ is applied by a fluid signal through nozzle **43**, the operating point will go from **1** to **4** and upon removal of the $-\Delta P_C$ signal, the operating point will return to **1** resulting in no output pressure P_O change. However, if the operating point is at **2** and a $-\Delta P_C$ is initiated, the operating point will again go to **4** and when the $-\Delta P_C$ signal is removed, the operating point will go to **1** resulting in a substantial output pressure P_O change signifying that the stable state was at point **2**.

The operating point may also be determined by application of a $+\Delta P_C$ signal obtained by applying a fluid signal through nozzle **38**. If the operating point is at point **1** and a $+\Delta P_C$ signal is applied, the operating point will go to point **3** and upon removal of the $+\Delta P_C$ signal, the operating point will go to point **2** resulting in a substantial change in output pressure P_O. If, however, the operating point is at point **2**, application of a $+\Delta P_C$ pressure through nozzle **38** will result in the pressure going to point **3** and removal of the $+\Delta P_C$ signal will cause the operating point to return to point **2** with no change in output pressure P_O being noticeable at gauge **59**.

If desired, output flow can be plotted against supply pressure in the graph of FIGURE 3 and this could be done by modifying the device of FIGURE 1 to eliminate the pickoff tube **58** and by applying a flowmeter to passage **56**. The output flow would vary in the same manner as shown in the hysteresis loops in the graph of FIGURE 3 although the output pressures obtainable would be somewhat lower than those obtainable with the use of pickoff tube **38**.

Embodiment of FIGURE 6

Another embodiment for obtaining a pressure indication of the stable state to which the vortex device is operating is shown in FIGURES 6 and 7. In FIGURE 6 is shown a section of exhaust passage **44** wherein a plurality of radial passages **62** are formed at that point on wall **46** where the area of reduced pressure V occurs. Annulus **64** connects each of the passages **62** to output port **66** which is connected to pressure gauge **68**. When there is an area of reduced pressure formed along wall **46** which corresponds to a higher output pressure indicating operation at point **1**, the pressure at gauge **68** will be substantially reduced. However, when there is no area of reduced pressure, corresponding to a lower output pressure and operation at point **2**, the pressure in gauge **68** will be relatively high.

Although this invention has been disclosed and illustrated with reference to particular applications, the principles involved are susceptible to numerous other applications which will be apparent to persons skilled in the art.

Having thus described my invention, I claim:

1. An apparatus comprising:

housing means providing a chamber for containing vortical flow;

means including a supply port adapted to be connected to a source of fluid for providing a preselected first vortical flow rate of said fluid in said chamber and a preselected second vortical flow rate of said fluid in said chamber, said first vortical flow rate being greater than said second vortical flow rate;

said housing having an exhaust port for egress of said fluid, said exhaust port having means including a predetermined divergence in the direction of fluid flow for providing a first stable pressure distribution downstream of said exhaust port at said first vortical flow rate characterized by having a first pressure central of said exhaust port and further which provides a second stable pressure distribution downstream of said exhaust port at said second vortical flow rate characterized by having a second pressure central of said exhaust port being greater than said first pressure; and

pressure responsive means operably associated with said exhaust port for providing an output signal indicative of said first and second stable pressure distributions.

2. The apparatus of claim **1** wherein said exhaust port is continuously divergent.

3. The apparatus of claim **1** wherein said exhaust port is a conical opening having an included angle in the range of 5° and 45°.

4. The apparatus of claim **1** wherein said exhaust port is of circular cross section and has an inlet diameter D and a length which is at least D.

5. The apparatus of claim **1** wherein said exhaust port is of circular cross section and has a first diameter for receiving said fluid and a second diameter downstream of said first diameter forming a step outwardly from the first diameter.

6. The apparatus of claim **1** wherein said means for

providing said first and second vortical flow rate includes a fluid port substantially tangentially oriented with respect to said vortex chamber for incrementally influencing the rate of vortex flow in said chamber.

7. The apparatus of claim **6** wherein said means for providing said first and second vortical flow rates further includes a second fluid port substantially tangentially oriented with respect to said vortex chamber in a direction for incrementally influencing said vortical flow rate in an opposite rotational direction than said first fluid port.

8. The apparatus of claim **1** wherein said means for providing said first and second vortical rates includes means for incrementally varying the flow rate of said fluid into said chamber.

9. The apparatus of claim **1** wherein said pressure responsive means includes a pick off tube axially lined with and axially spaced from said exhaust port to receive the flow therefrom thereby providing a pressure in said tube being indicative of said first and second stable pressure distribution.

10. The apparatus of claim **1** wherein said pressure responsive means includes a fluid passage substantially radially communicating with said exhaust port thereby

providing a pressure in said passage being indicative of said first and second stable pressure distribution.

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