Jan. 20, 1970 F. D. EZEKIEL ET AL 3,490,477

ROTATED PATTERN FLUIDIC ELEMENT

Filed Aug. 18, 1967 2 Sheets-Sheet 1

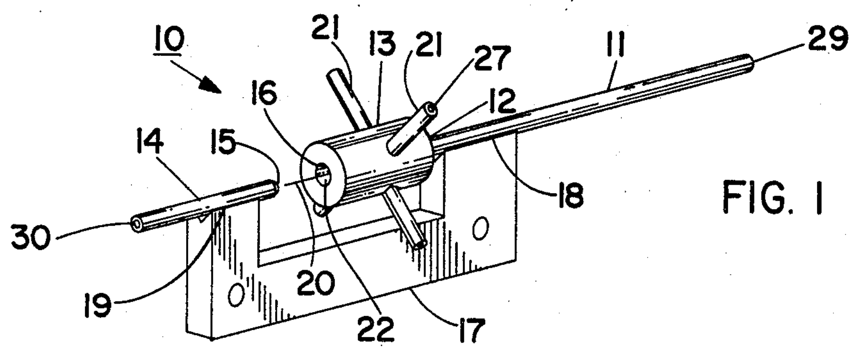

FIG. 1

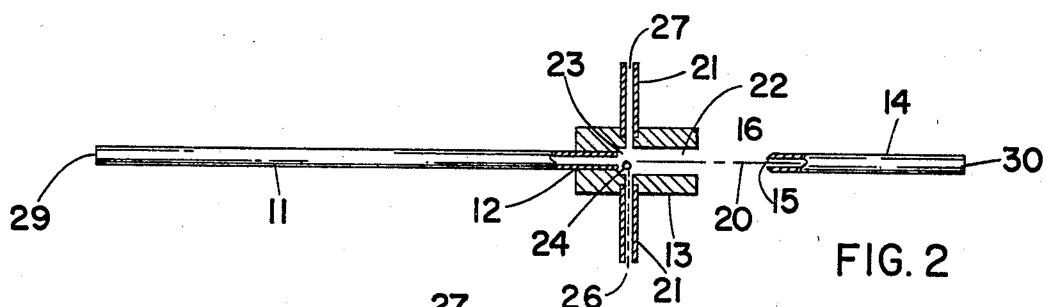

FIG. 2

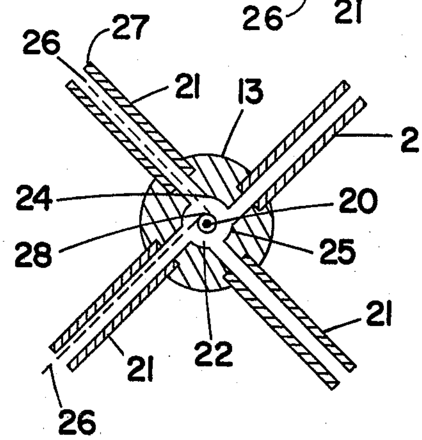

FIG. 3

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ROTATED PATTERN FLUIDIC ELEMENT

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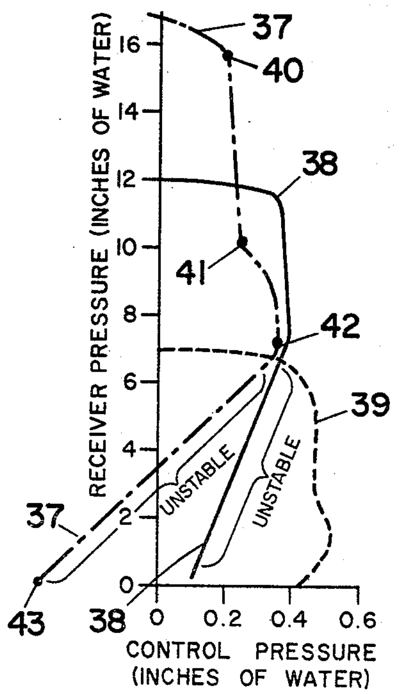

FIG. 5

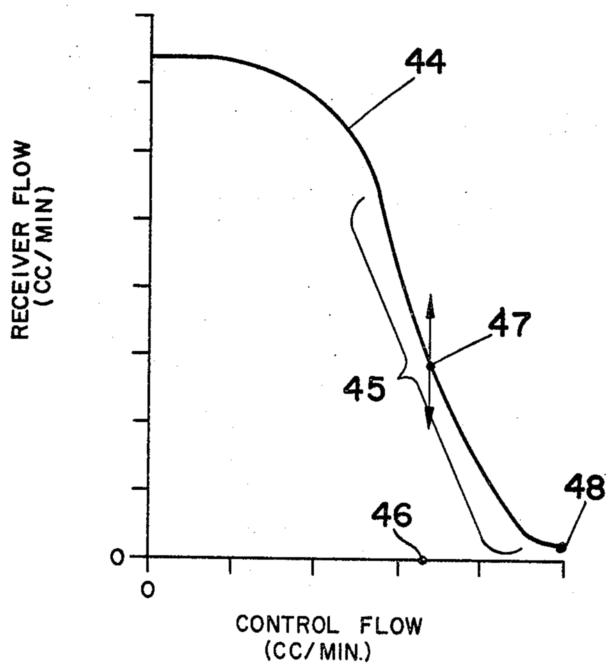

FIG. 6

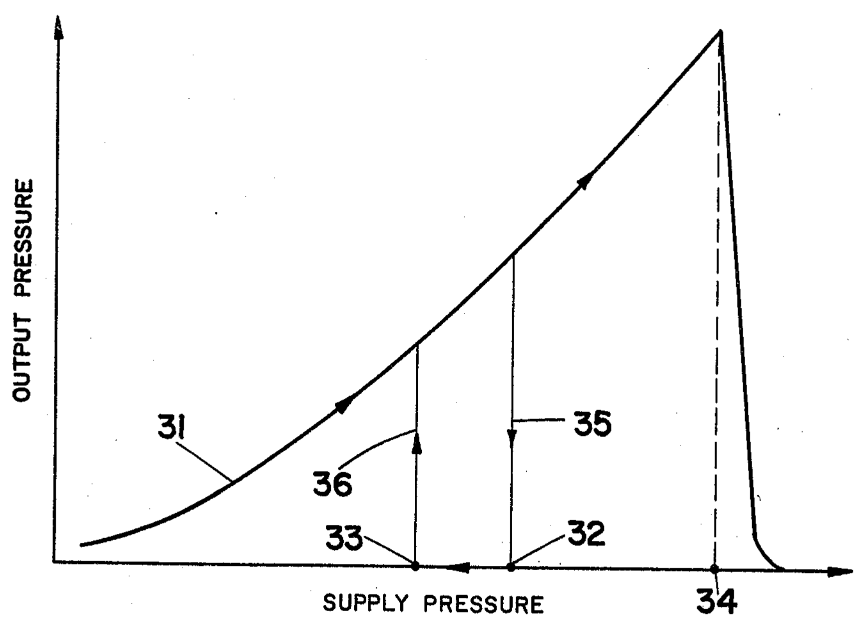

FIG. 4

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United States Patent Office 3,490,477
Patented Jan. 20, 1970

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3,490,477
ROTATED PATTERN FLUIDIC ELEMENT

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Filed Aug. 18, 1967, Ser. No. 661,605
Int. Cl. F15c 1/18
U.S. Cl. 137—81.5 5 Claims

ABSTRACT OF THE DISCLOSURE

A fluidic element having a supply conduit communicating with a chamber, a control conduit communicating with said chamber with a direction adapted to impart axial rotation to fluid issuing from said supply circuit, and a receiver conduit aligned with said supply conduit on a common central axis, exhibits a state wherein fluid issuing from said supply conduit and chamber combination maintains a laminar flow pattern impressing a high pressure level at said receiver conduit; this state may be altered by control flow through said control conduit which operates to torque the supply flow passing through said chamber thereby redirecting the supply flow into a pattern having a rotated vector, which rotated vector flow pattern upon issuing from the termination of said chamber takes the shape of a cone about said central axis exhibiting a substantially reduced pressure effect at said receiver conduit.

This invention relates to fluidic elements, and more particularly to fluidic elements having an output signal related to an input control signal thereto.

The prior art includes a variety of fluidic elements having an output pressure signal which is a functions of an input control pressure signal, there usually being some form of gain in the signal conversion. These fluidic devices operate on various principles. A common type is the wall-attachment fluidic element in which a turbulent flow is moved between stable attached positions by the action of a control jet directed at a cross-section of the supply flow. Another type is disclosed as early as Hall Patent Nos. 1,205,530 and 1,628,723, in which a laminar flow is controllably disrupted to a turbulent condition by the action of a control jet intersecting the axis of the laminar flow; the output is taken from a device sensing the distinction between the laminar and turbulent flow velocities.

The fluidic elements of the prior art have various limitations, the laminar-turbulence elements being susceptible to the influence of sonic noise, with a consequent unstable output signal. Additionally, the power-switching capabilities of these elements are generally restricted. The wall-attachment fluidic elements have a relatively low efficiency, and must generally operate at high pressure levels, requiring large amounts of supply air and consequently presents a high fluidic power supply requirement in multi-element applications.

The present invention is directed to a fluidic element utilizing a principle based upon redirection of a laminar flow into a pattern exhibiting a rotated vector; the receiver senses a consequent reduction in velocity from that attendant upon laminar flow in the un-redirected state. This redirection is accomplished by incorporating a chamber having a fluid supply conduit thereto, with a control conduit communicating into the chamber with its axis off-set from the central axis of the supply tube as projected through the chamber, so that rotation may be imparted to the supply flow by the application of a control flow through the control conduit. Such application of control flow operates in conjunction with the chamber configuration to redirect the supply flow through the chamber into a pattern having a substantial rotated component; owing to the continuous movement of the supply flow in the downstream direction, a helical component is thereby formed within the confines of the chamber. As the redirected flow is projected from the chamber in the general direction of the receiver conduit, the flow assumes the general configuration of a cone. The flow particles in the cone are assumed to be projected each along individual straight lines thereby making up the cone shape. Each particle, however, is assumed to have a rotated vector resulting from the rotation of the fluid in the chamber. Thus, within the chamber the fluid may be said to exhibit a rotating vector, while after projection, a rotated vector. In this sense, the term rotated vector applies to the entire flow, inasmuch as each particle is affected by control torquing and is rotated to some extent. The velocity of the fluid taking this cone shape is most substantially reduced as compared with the velocity of laminar flow. The receiver conduit senses this reduction in velocity, and provides the output for the rotated pattern fluidic element.

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The rotated pattern fluidic element of the present invention provides the advantage of a relatively large power-handling capability, the output range extending into values measured in dynamic pounds per square inch. The rotated pattern fluidic elements exhibits a relatively high pressure recovery, and is generally operable with a small power level of control flow. Additionally, the output of a device constructed in accordance with the invention exhibits an improved stability and insensitivity to noise sources, such as adjacent sonic sources. By virtue of the novel characteristics of the invention, it may be employed in many functional modes, for example, as a bistable device, an amplifier, a NOR logic element, a latching relay, or an alarm sensor. The generality of application inherent in such a diversity of functions offers economies obtainable by the use of large numbers of a single standardized basic system element.

Briefly stated, the novel fluidic element of the invention utilizes a supply conduit opening into a chamber having an increased diameter as compared to the diameter of the supply conduit, the chamber having a control conduit communicating thereto with its axis displaced from the axial centerline of the flow of supply fluid passing through the chamber. A receiver conduit is spaced from the flow-projecting termination of the chamber with its axis aligned with the axis of the supply conduit so that it is disposed to receive the impact of flow projection from the supply tube and the chamber combination. This receiver conduit provides the output of the fluidic element. The application of a control signal to the control conduit causes a flow to be induced into the chamber superimposing a rotational component of flow pattern upon the flow issuing from the supply conduit. Thereby, the supply flow is redirected into a pattern exhibiting a rotated vector, which flow is projected in a cone shape having generally reduced velocities as compared with the flow velocity of the projected laminar flow in the un-redirected state of operation. This conical shape of the projected rotated vector flow with its generally reduced velocities transfers a low pressure to the receiver tube; this action provides for a large range of pressure switching between the straight laminar flow condition and the redirected condition.

The cooperation of the control flow off-set with the confining chamber acts upon the supply flow to produce a very low flow velocity along the central axis at a very short distance from the flow-projecting end of the chamber. This permits placing the receiver tube inlet correspondingly close to the flow-projecting end of the chamber with substantially no input pressure build-up when the flow is in the conical mode; the relative distance between the supply tube outlet and the receiver tube inlet is thereby closer than would be practicable in the absence of the chamber. This location of the receiving tube in close proximity to the supply provides high impact pressure in the receiver tube when the supply flow is in the laminar mode.

These and other advantages of the invention will be in part apparent from the specification below and in part from the several figures herewith, in which:

FIGURE 1 is a three-dimensional view of an embodiment of the rotated pattern fluidic element of the invention;

FIGURE 2 is a cross-sectional view of the embodiment along the axis thereof;

FIGURE 3 is a cross-section of the embodiment guiding chamber normal to the central axis thereof;

FIGURE 4 contains a plot of supply pressure versus output pressure for an embodiment of the invention;

FIGURE 5 contains plots of a family of control pressure versus output pressure curves for an embodiment of the invention; and

FIGURE 6 contains a plot of control flow versus output flow for an embodiment of the invention.

Referring to FIGURE 1, rotated pattern fluid element **10** is depicted in three-dimension form, consisting of supply tube **11** having its downstream end **12** connecting to chamber housing **13**, and with receiver tube **14** having its sensing end **15** separated at a distance from exit orifice **16** of chamber housing **13**. Base member **17** has support portions **18** and **19** thereof respectively supporting tube **11** and receiver tube **14** in a manner to register the central axes thereof in alignment with central axis **20** of the rotated pattern fluidic element **10**. Control tubes **21** connect to and through chamber housing **13** to communicate therein with the interior recess chamber **22**. As is more fully depicted in FIGURE 2, an illustration of an axial cross-section of the rotated pattern element **10**, chamber **22** is oriented on central axis **20**. Supply tube **11** opens into chamber **22** at chamber supply end **23**. Supply tube **11** is of sufficient length to project a laminar flow therefrom at the flow rates of interest. The diameter of chamber supply end **23** is greater than the diameter of supply tube **11**. In practice, it is convenient and desirable to provide for an increased cross-sectional area normal to central axis **20** of chamber **22** as compared with the diameter of supply tube **11**. The transition between the diameters of supply tube **11** and chamber **22** may be a sharp one, as illustrated in FIGURE 2 at the location of supply end **23**. On the other hand, other forms of transitions may be employed, such as a conic shape of transition region instead of the right-angled transition illustrated. Indeed, curvatures of any type may be employed, and the distinction between supply tube **11** and chamber **22** may not be readily apparent in some embodiments.

Chamber **22** is shown with an axial cross-section having a shape with opposed parallels, such as a cylinder or a box may have, but it is possible to have a wide variety of configurations, such as a bell-shape, or for that matter, shape having any convenient and desirable curvature.

In FIGURE 3, a cross-section normal to axis **20** in the plane of control tubes **21**, it may be seen that each control tube **21** has inner termination **24** which opens into chamber **22**, opening therein approximately normal to central axis **20**. In addition, central axis **26** of each control tube **21** is directed through chamber **22** at an offset from central axis **20**, so as not to intercept central axis **20**. With this orientation of control tube **21**, it will be fairly evident that a fluidic control flow supplied to end **27** of control tube **21** and issuing into chamber **22** tends to impart a degree of rotation about central axis **20** to a supply fluid issuing from supply tube **12** into and through chamber **22**.

A circular cross-section is illustrated for chamber **22**, but experiment shows that circularity is not essential, and chamber **22** is not necessarily limited thereto. In particular, cross-sections of a wide variety of shapes may be advantageously employed, such as conveniently-fabricated square cross-sections. More generally, the cross-section of chamber **22** may include polygons of any order, with those polygons of very high orders approaching circles, ovals, and the like. It is only required that the chamber **22** shape permit the rotated vector principle to obtain.

It is supposed that the discontinuity between supply tube **11** and chamber end **23**, as well as the discontinuity at flow-projecting termination **16** of chamber **22** appreciably affect the operating characteristics of the structural combination making up element **10**.

The structure depicted in FIGURES 1, 2 and 3 provides a fluidic element for redirecting a flow from supply tube **11** into a pattern having a rotated vector. The configuration of flow through chamber **22** is influenced by the peripheral confining shape of chamber **22** as well as by the rotational influence of the control flow through control tube **21**.

The fluidic element of the invention may perform a variety of functions, according to the operating parameters selected. In one mode of operation, if a supply pressure is communicated to upstream end **29** of supply tube **11**, and a pressure sensing device is connected to downstream end **30** of receiver tube **14**, and if illustratively three of the four control tubes **21** are closed off while the remaining control tube **21** is allowed to aspirate from atmosphere through an open upstream end **27**, increasing the supply pressure from zero will produce an increasing output pressure transmitted to output end **30** of receiver **14** as shown in curve **31** of FIGURE 4. As supply pressure continues to increase a critical supply pressure point **32** is reached at which the flow issuing into chamber **22** from supply tube **11** becomes redirected into a rotated pattern within chamber **22** by virtue of the shape of chamber **22** and the influence of an inward aspiration through the open control tube **21**. As a consequence, the output pressure is substantially reduced to zero as signified by line **35** in FIGURE 4. The projected flow between end **16** of chamber **22** and receiver inlet **15** during the formation of the rotated vector pattern exhibits very low velocity compared to laminar flow velocity on axis **20**, causing reduction in the flow velocity sensed by receiver **14**. It is to be noted that when supply pressure increases to critical supply pressure point **32** and the rotated pattern of flow has thereby been formed, a subsequent decrease in supply pressure does not result in re-initiation of the laminar mode of flow until an appreciable supply pressure reduction has been made to a lower point **33**.

When point **33** is thus reached, the receiver **14** output pressure increases as signified by line **36** in FIGURE 4. It is supposed that this latching condition obtains due to an aspiration flow through the open control tube **21** which tends to sustain the flow pattern once it has been initiated. This supposition is reinforced by the result of the closure of all the control tubes **21** so no flow therethrough may occur while element **10** is in a latched condition (supply pressure between points **32** and **33** with receiver **14** output zero as a consequence of the rotated vector flow pattern). Upon this closure, the latching effect disappears and the flow pattern reconverts to the laminar mode. With the supply pressure in the range between points **32** and **33**, illustrated in FIGURE 4, and if aspiration through control tube **21** is permitted, if a short control pulse is applied to any control tube **21** the output **30** of receiver **14** will drop to a substantially zero condition and remain latched in this condition until such time as all aspirations are terminated by closure of all control tubes **21**, or, alternatively, until the supply pressure is dropped below supply pressure point **33**. A suitable negative control flow pulse applied at end **27** of a control tube **21** tends to withdraw flow from chamber **22** and may also operate to end the latched condition of operation by restoring the laminar flow mode.

Increase of the supply pressure above point **32** causes the aspiration type of latching, that is, the receiver **14** output signal goes to zero when a control tube **21** is allower to aspirate. If all control tubes **21** are closed, increasing supply pressure is attended by increasing output pressure until the supply pressure reaches a limiting point 34; higher supply pressures than this tend to switch fluidic element out of its laminar mode, although all control tubes 21 are closed off. The element 10 output is thereby reduced, making the general region of operation above supply pressure point 34 not generally suitable for control purposes. Limiting point 34 may be utilized in some applications, such as alarm or threshold types of applications.

Fluidic element 10 can operate as a NOR logic element, that is, the signal at output 30 drops to "0" where ever a control input is present at any one of the control tubes 21. Absence of any control input to control tubes 21 will always result in an "on" or "1" logic condition if no aspiration is permitted.

As an illustrative example of a practical working embodiment, a structure corresponding to that illustrated in FIGURES 1 through 3 has been operated having the following dimensions: supply tube 11 inside diameter, .0312 inch; free space between chamber termination 16 and receiver end 15, .25 inch; control tube 21 inside diameter, .031 inch; control tube axis 26 off-set from central axis 20, .016 inch. The control tube 21 inlet 24 into chamber 22 is located less than 10% of the chamber 22 length from end 23 thereof. A structure for amplifier 10 having these dimensions may be illustratively operated with a supply pressure applied to upstream end 29 of supply tube 11 having a pressure of 20 inches of water. Typically, receiver 14 may produce a signal at output end 30 thereof realizing an 85% pressure recovery, or 17.5 inches of water. The application of a small control pressure, in the order of 0.2–0.3 inch of water to end 27 of control tube 21 typically will reduce the output signal at receiver 14 to less than 0.1 inch of water, representing a ratio of over 170 between the laminar and redirected modes of operation of amplifier 10.

Referring to FIGURE 5, a family of input-output curves 37, 38 and 39 is illustrated, these being respective plots for three supply pressure levels of 20 inches, 15 inches, and 10 inches of water, with the relationship between control input pressure and receiver output pressure being illustrated for each of these supply pressures. This family of curves 37, 38 and 39, applies to a fluidic element 10 structure having the dimensions given as an example above. All control tubes 21 except one are closed off.

Curves, 37, 38 and 39 each exhibit negative curvatures, which are the consequence of increasing aspiration as the control pressure is increased. For example, curve 37, corresponding to 20 inches of water, shows a slowly decreasing receiver output signal starting at about 17 inches of water as the control pressure is increased from zero. The receiver output pressure decreases to less than 16 inches of water as the control pressure is increased up to 0.21 inch of water. This operating point is illustrated by reference numeral 40. A further small increase in control pressure of 0.26 inch of water causes a sharp drop in output pressure to 10 inches of water, shown by point 41. Further control pressure increases to 0.35 inch of water causes a less sharp output pressure reduction to 7 inches of water, shown by point 42. From point 45, additional control flow supplied through the control tube does not result in an increase control pressure, inasmuch as the rotation of the flow in the chamber has a pressure effect causing a tendency to aspirate a control flow inwards, which effect increasingly tends to pull in more control flow than is incrementally supplied from the control source. This effect appears between points 42 and 43, with so much aspiration occurring at point 43, that the chamber is pulling more than the control source supplies, with a consequent negative control pressure as measured at inlet 27 of control tube 21. At point 43, the receiver pressure output is substantially zero. For curve 37, the region between points 42 and 43 is generally indicated as unstable, inasmuch as the control pressure tends to oscillate about an average pressure in this region. That is, control flow may be held to a substantial constant in this region, but owing to the phenomena associated with the aspiration effects, control pressure will fluctuate over a variable range. In general, maximum oscillation occurs in the middle of point 42 and 43, when oscillation reducing to zero as points 42 or 43 are reached. Thus, it is seen the operation of element 10 may include switching through a region of instability in going from a maximum receiver pressure output to a minimum.

Curves 38 and 39 each exhibit smaller regions of negative curvature, the aspiration effects being correspondingly less at these reduced supply pressures. Curve 39 exhibits no significant instability region, and may represent a preferable operating condition for some applications.

FIGURE 6 illustrates a representative plot 44 of control flow versus receiver flow. Here, it may be seen that a more linear relationship exists than that seen in FIGURE 5. In addition, it may be noted an unstable output flow corresponds to the control flow region 45 associated with an oscillatory control pressure. With control flow held constant at point 46, for example, receiver flow will oscillate as illustrated with respect to unstable point 47 on the curve 44. A lesser degree of oscillation occurs as the control flow approaches the stable regions on curve 44. Note receiver flow cut-off point 48 is a stable operating point. Other typical control flow versus receiver flow curve may exhibit greater or lesser regions of instability, in a manner analogous to the curves of FIGURE 2.

The high pressure recovery, high gain, near-zero output obtainable in the controlled state, the latching effect in the absence of a control signal, and the good stability observed in fluidic element 10 represent a device having marked improvements and advantages over fluidic elements heretofore available to the art. In particular, comparison with fluidic elements employing the principles illustrated in the Hall patents demonstrates a marked superiority of the present invention for a wide variety of applications. In general, Hall type fluidic elements, even operating with lower supply pressures than 20 inches of water, 10 inches being a common value, cannot readily achieve a controlled output pressure reduction less than 0.5 inch of water. Commercially available Hall-type elements typically exhibit on-off pressure ratios of the order of 10 or less. In addition, the pressure recovery typically available from the Hall-type elements is considerably less than 85% obtainable from the present invention, a typical recovery for commercially available Hall-type elements being 50%.

Other embodiments of the present invention may readily be provided, a wide range of physical structures being possible for incorporating the principle of the rotated vector flow. A large range of element dimensions may be employed appropriate to the desired operating conditions for the intended applications. There is no absolute maximum or minimum limitation on the size of fluid element 10 or on the dimensions of the subcomponents thereof. In general, the considerations are as follows, respecting the inter-relationships of the subcomponents: the supply tube 11 and receiver tube 14 must be axially aligned; it is found convenient to make chamber 22 also axially aligned with supply tube 11 and receiver tube 14, with the diameter of chamber 22 being somewhat larger than the inside diameter of supply tube 11; control tube 21 opens into chamber 22 with its centerline 26 sufficiently off-set from axial centerline 20 of the chamber 22 to produce a rotated vector of supply flow upon application of a control flow aspiration. The chamber 22 is illustratively cylindrically-shaped in the figures, but may exhibit a variety of other configurations, such as bell-shapes, cones, or configurations embodying curvatures of any description.

Within these considerations for the inter-relationships of the subcomponents of fluidic element 10, it may readily be appreciated that many shapes and sizes may be produced each embodying the principle of the rotated vector operation. It is found that improved ranges of operation obtain when control tube **21** opens into chamber **22** nearest the end of supply tube **11** attachment. Also advantages of higher ranges of pressure recovery obtain when inlet **15** is located at relatively close spacings from end **16** of chamber **22**. If the off-set of centerline **26** of control tube **21** approaches center axis **20** of fluidic element **10** too closely it is found that operational characteristics become somewhat less desirable.

It has been observed that various off-sets of the control tube centerline **26** from center axis **20** may be used, including off-sets sufficiently large to permit a special separation within chamber **22** between the projected diameter of supply tube **11** and the projected diameter of control tube **21**, the confining function of chamber **22** apparently rendering them larger off-sets operable.

As an additional consideration centerline **26** of control tube **21** may be tilted to project control flow partly in the direction of the supply flow, or in the alternative, tilted back toward chamber **22** end **23**.

While there has been shown what is considered to be a preferred embodiment of the invention, it will be manifest that many changes and modifications may be made therein without departing from the essential spirit of the invention.

What is claimed is:

1. A fluidic element having a supply conduit and a housing defining a chamber therein downstream from said supply conduit with the central axis of said chamber aligned with the central axis of said supply conduit and with said chamber having a diameter at its downstream termination at least as great as the general diameter of said chamber and with the inner diameter of said supply conduit as projected downstream through said chamber being spaced from the walls of said chamber so that said inner diameter of said supply conduit as projected downstream through said chamber is everywhere equidistant from said walls of said chamber throughout each plane normal to said central axis of said chamber so that in a first control condition a supply flow is projected from said supply conduit in a laminar state through said chamber and along the central axis thereof without anywhere contacting said walls of said chamber with said supply flow in said first control condition continuing in a laminar state downstream past said downstream termination of said housing, said fluidic element incorporating a control conduit opening into said chamber with the centerline of said control conduit making an angle with said central axis of said chamber and said centerline also being offset from said central axis of said chamber so that in a second control condition a control flow applied through said control conduit enters into said chamber and cooperates with said walls of said chamber to effect a torquing of said supply flow about said central axis of said chamber producing a conically shaped dispersion of said supply flow from said downstream termination of said housing with said conically shaped dispersion being substantially centrally oriented about the projection of said central axis of said chamber in the downstream direction and with said conically shaped dispersion exhibiting reduced flow velocities therethrough as compared with the flow velocities of said supply flow projected through said housing in said laminar state of said first control condition, and sensing means positioned downstream from said termination of said housing in a manner to produce a signal discriminating between said first and second control conditions.

2. A fluidic element of claim **1** with said chamber having a volume sufficiently large to permit laminar projection of flow therethrough, but sufficiently small to cause an application of control flow to apply torque to the supply flow.

3. A fluidic element of claim **1** wherein said offset between said projected centerline of said control conduit and said projected central axis of said supply tube is sufficient to provide a spacing between the projected diameter of said supply flow and the projected diameter of said control flow.

4. The fluidic element of claim **1** with said sensing means aligned on said projection of said central axis of said chamber.

5. The fluidic element of claim **1** wherein the spacing between said supply flow projected through said chamber in a laminar state of said first control condition and said walls of said chamber is sufficiently narrow to result in interaction between said supply flow and said walls upon the application of said control flow.

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