This invention relates to a fluid modulating device and particularly to such a device having a unity pressure feedback characteristic.

Fluid controls have been recently developed in which fluid jets or streams are caused to interact to simulate electronic amplifying and switching devices. For example, the copending application of B. G. Bjornsen et al, entitled Fluid Control Apparatus which was filed on Nov. 1, 1963, with Ser. No. 320,680 now Patent No. 3,272,215 and assigned to the assignee of this application discloses a novel impacting type modulator wherein two opposed streams or jets impact and form a radial jet with respect to a collector orifice. The collector control defines a radially shaped orifice or reference chamber to one side thereof and a collector chamber or the like to the opposite side thereof. A deflection control stream may be applied to the one supply stream in the reference chamber in any suitable manner. The control stream deflects the supply stream and changes the location of the impacting point. Although this and similar fluid devices have provided satisfactory fluid controls, they have certain limitations in simulating electronic type control because of the problem of matching several interconnected stages. The input orifice or aperture for the control stream has a downstream pressure related to the reference pressure; i.e. atmospheric or relative ground. This is an essentially constant pressure and consequently the input impedance is independent of the load or variations in the supply. The pressure gain however, is very dependent upon the load; decreasing and increasing respectively with decreasing and increasing load impedances. This results in an operational limitation because the recovery or maximum output pressure correspondingly decreases with decreasing load impedance. The output impedance of the device will also generally be of the same order of magnitude as the input impedance.

The present invention is particularly directed to a very simple and novel modification of the prior art devices resulting in significant performance differences and particularly providing a fluid device having operating characteristics similar to an electronic follower. The characteristics include a high input impedance, a low output impedance and unity pressure gain; all of which are desirable for impedance matching between succeeding stages of a fluid control.

In accordance with the present invention, the output pressure signal is taken from the chamber which in the prior art served the function of a reference chamber. As a result of this configuration, it is possible to deliver essentially all the main supply flow as well as the input signal flows to the load with a resulting increase in saturation flow. Furthermore, the output pressure changes less with flow variations than the prior art devices. The device thus operates in a manner analogous to the transistor emitter follower circuit of the electronic art wherein all of the emitter current which consists of the base and the collector current is supplied to the load. In the present invention, the load or output pressure is the downstream pressure of the input pressure orifice; that pressure difference establishes the signal flow and any change in the downstream pressure is seen by the signal pressure and results in essentially unity pressure feedback, and thus essentially unit gain.

The drawings furnished herewith illustrate the several embodiments of the invention applied to different types of fluid amplifiers wherein the above advantages and features are clearly disclosed as well as others which will be clear from the following description.

In the drawings:

FIG. 1 is a simplified diagrammatic view of a transverse impact modulator constructed in accordance with the present invention;

FIG. 2 is a set of characteristic curves showing the input impedance characteristics of a device constructed in accordance with the present invention;

FIG. 3 is a set of curves showing the gain characteristics of the same device employed to obtain the curves of FIG. 2;

FIG. 4 is a set of curves showing the output impedance of the same device employed to obtain the curves of FIG. 1;

FIG. 5 is a view similar to FIG. 1 showing a three terminal fluid amplifying device constructed in accordance with the present invention;

FIG. 6 is a simplified diagrammatic top view of a beam deflection amplifier modified in accordance with the present invention; and

FIG. 7 is a side view of FIG. 6.

Referring to the drawings and particularly to FIG. 1, the illustrated fluid device is an impact modulator generally constructed in accordance with the teaching of the previously identified application of Bjornsen et al, employing free streams in a three dimensional construction and modified in accordance with the teaching of the present invention. Generally, the impact modulator includes a pair of opposed stream forming supply nozzles 1 and 2 terminating in similar orifices 3 and 4. The nozzles 1 and 2 are mounted in spaced aligned relationship to establish a pair of impacting streams 5 and 6 defining an impact balance position shown diagrammatically at 7. The nozzles 1 and 2 are mounted within opposite end walls of an enclosure 8 and terminating to the opposite sides of a central orifice wall 9 defining a pair of chambers 10 and 11. The orifice wall 9 includes a collector orifice 12 aligned with the orifices 3 and 4 of the nozzles 1 and 2. The wall 9 is positioned intermediate the nozzles 1 and 2 to locate the collector orifice 12 with respect to and in operative relation to the impacting position 7 of the two streams 5 and 6.

A control nozzle 13 is mounted at right angles to the first supply nozzle 1 and has an end orifice 14 defining a control or signal stream 15 which engages the main supply stream 5. The signal stream 15 causes proportionate deflection of the supply stream 5 with respect to the second supply stream 6. In this manner the effective strength of the stream 5 is modulated or controlled.

As more fully developed in the previously referred to copending application, the impact or balance position 7 is
highly sensitive to the relative strength of the opposed components of the two streams 5 and 6 and consequently the deflection of the one stream with respect to the other results in a variation in the impact position 7 with respect to the collector orifice 12.

In accordance with the present invention, an output tap 16 is connected to the same chamber 10 within which the signal nozzle 13 terminates. The tap 16 is shown having a retrictor 17 formed therein to indicate a load. The chamber 11 to the opposite side of the control wall 9 is connected to atmosphere or some other suitable reference pressure.

It should be noted that this provides an opposite connection to that suggested in the prior art; namely, the load signal being normally taken from the second chamber 11 with the signal nozzle chamber 10 connected to the reference or atmosphere.

This has been found to result in a highly significant modification in the characteristics of the device. In this construction and configuration, the impact point of the two supply jets or streams 5 and 6 as well as the signal stream 15 all terminate within the output chamber 10 and consequently essentially all of the supply and the input flow when delivered to the load 17. As a result, the saturation flow is substantially increased. Further, the input orifice 14 sees the output pressure and consequently the down-stream pressure of the signal stream 15 is essentially equal to the output pressure. Therefore, any change in the output pressure is seen by the input pressure and the device operates with essentially unity pressure feedback. The fluid device of this invention therefore provides a substantial increase in the input impedance seen by the signal source and a decrease in the output impedance and a device having all of the characteristics desirable in an impedance matching device. This is in contrast to the conventional impact modulator constructions wherein the input and output impedance are normally of a similar magnitude and the pressure gain is highly sensitive to the load characteristics.

FIGS. 2-4 show the characteristics of a transverse impact modulator constructed in accordance with the present invention. In the device from which curves 2-5 were derived, the supply nozzles 1 and 2 were terminated in similar orifices with diameters equal to 0.016 inch. The orifices were respectively spaced from the collector orifice 12 by a distance of 0.055 inch for nozzle 1, and 0.016 inch for nozzle 2. The control signal orifice centerline 14 was spaced from the supply orifice 3 by a distance of 0.016 inch and from the main stream centerline by a distance of 0.016. The fluid employed was air from regulated supplies. The pressure of stream 5 was 10.0 p.s.i.g. The pressure of the opposite control stream 6 was 8.45 p.s.i.g.

Referring particularly to FIG. 2, the characteristic input impedance of the device connected as a fluid follower is shown for several loads or sized restrictors 17. The input signal pressure applied to the signal orifice 14 is shown on the horizontal axis in p.s.i.g. The input flow in inches cubed per minute is shown on the vertical axis. The three curves 18, 19 and 20 are respectively for load orifice diameters of 0.025 inch, 0.016 inch and zero; i.e. essentially closed or dead-ended to prevent any significant output flow. Each of these curves generally has an initial inclined portion with a central relatively flat portion and a final inclined portion. The input impedance or flow resistance is the slope of the curves and is therefore defined by the ratio of the change in input pressure to a related change in flow, and is relatively high particularly over the range of approximately 2 to 7 p.s.i.g. input pressure when the curve is essentially flat.

FIG. 3 is a set of curves for the same loads as employed in the circuit of FIG. 2 and discloses the gain characteristics of the follower for the several loads. The input pressure of the signal nozzle orifice 14 is plotted on the X axis and output pressure is plotted on the Y axis. The gain curves 21, 22 and 23 correspond to the loads used to obtain curves 18, 19 and 20, respectively. The gain curves are essentially straight and parallel over a substantial range of zero to seven or eight p.s.i.g.

Gain loss occurs as input pressures increase above that range with the loss beginning sooner for larger diameter loads. Thus, the divergence occurs at about 7 p.s.i.g. at the lowest load and at about 8 p.s.i.g. for the two higher loads.

The gain is defined by the slope of the curves and particularly the ratio of the output pressure change to input pressure change and is seen to approach unity as the load diameter approaches zero.

The present invention thus provides a device having unity pressure feedback with the resultant highly desirable impedance matching characteristics. FIG. 3 also shows that the pressure gain which is approximately equal to unity is also essentially insensitive to changes in the load characteristic.

The pressure flow relationship for an orifice operated with incompressible fluids can be expressed as:

\[ w = K \frac{A}{P_1} - \frac{P_2}{P_1} \]  
(A)

where:

- \( w \) = mass flow
- \( K \) = constant
- \( A \) = orifice area
- \( P_1 \) = upstream pressure
- \( P_2 \) = downstream pressure

For normal transverse impact modulator performance the downstream pressure of the input orifice is the constant reference pressure; thus the mass flow can be expressed as:

\[ W_n = W_{normal} = K \frac{A}{P_1} \]  
(B)

where \( P_1 \) is atmospheric pressure and \( P_1 \) is the gage upstream pressure.

For the follower the nozzle downstream pressure \( P_2 \) increases with input pressure as shown in FIG. 3. From the curves of FIG. 3, we can write the equation:

\[ P_2 = P_1 + \alpha P_1 \]  
(C)

or

\[ P_2 = \alpha P_1 \]  
(D)

where \( \alpha \) is the follower gain. Inserting the latter Equation D into the original Equation A defining the pressure flow relationship, we obtain:

\[ W_1 = W_{follower} = K \frac{A}{P_1} \frac{P_1}{P_2} \]

\[ = K \frac{A}{P_1} \frac{P_1}{P_1 - \alpha P_1} \]

\[ W_1 = K \left( \frac{A}{\sqrt{1 - \alpha}} \right) \sqrt{P_1} \]  
(E)

From Equation E we can conclude that the flow through the input orifice of the follower is reduced by a factor of \( \sqrt{1 - \alpha} \). Thus the apparent area of the follower input orifice is \( A \sqrt{1 - \alpha} \), and as \( \alpha \) approaches 1.0 the apparent area approaches zero, and the apparent input impedance approaches infinity.

FIG. 4 is a set of curves illustrating the output pressure versus output flow characteristics; i.e., the output impedance for the same device. Each of the curves 24, 25 and 26 represents a different constant input signal pressure and in particular pressures of 2.4 p.s.i.g., of 6.5 p.s.i.g. and of 9.15 p.s.i.g. respectively. The output impedance is the negative reciprocal slope of the curves and is therefore defined by the change in pressure divided by the corresponding change in flow. From a review of FIG. 4, the follower structure of the present invention provides an output impedance which is low. Generally, the characteristic curves for flows below saturation are parallel straight lines and clearly show that the output impedance remains essentially constant for various input pressures. This results from the unity pressure feedback characteristic of the device. The linear operating range decreases with increasing input signal pressure level, as
shown by a comparison of the curves 24, 25 and 26 particularly the curved upper ends 27 of the curves 25 and 26. The same basic concept applied to the transverse impact modulator can be employed to other fluid devices some of which are generally briefly diagrammatically shown in FIGS. 5-7.

Referring particularly to FIG. 5, a three terminal stream deflection amplifying device is shown. The three terminal device is essentially a pure deflection device having a main stream nozzle 28 generally feeding into receiving nozzle 29. A deflection signal stream nozzle 30 is mounted at right angles to the input nozzle 28 and causes deflection of the main stream with respect to the opposed nozzle. Generally, in accordance with the prior art, the output signal is taken from the opposed or second nozzle 29. In accordance with the concepts of this invention and similar to that shown in FIG. 1, the normal output nozzle 29 is connected to a reference or atmosphere and an output conduit 31 is connected to the interaction chamber 32 within which the nozzles 28 and 30 terminate.

The feedback operation of the embodiment shown in FIG. 5 is essentially identical to that shown in FIG. 1 as a result of the interaction within the output chamber and no further discussion appears necessary.

The present invention may also be applied to other fluid devices, for example, a beam deflection amplifier. FIGS. 6 and 7 diagrammatically illustrate a beam deflection amplifier following the teaching of this application. Such amplifiers are two dimensional devices and include a main stream orifice 33 to one side of a chamber and a pair of collector passageways or orifices 34 and 35 on the opposite side thereof.

In the illustrated embodiment of the invention, the one collector orifice 34 is aligned with the main stream orifice 33 and the second orifice 35 is angularly related with respect thereto. Control orifices 36 and 37 are also provided and located on opposite sides of the main stream. The main stream 38 flows through the chamber to either orifice 34 or 35, depending upon the output signal streams of orifices 36 and 37, and engages the top and bottom plates or walls of the chamber to divide the chamber into two operating input chambers 39 and 40.

In accordance with the present invention, the orifice 34 is connected to the reference or ground and only passageway or orifice 35 is connected as the output. The output is connected by a large conduit means 41 to the control chamber 39.

The conduit means 41 which forms the return or feedback pressure passageway is sufficiently large to transmit the output pressure to the chamber 39 essentially without any loss. The chamber 39 is shown with a slight restriction 42 outwardly of the signal orifice 36 and the connection of the conduit means 41 to insure that the feedback pressure is not lost. The opposite signal line 43 connected to orifice 37 is connected to atmosphere or other suitable reference.

In operation, the stream 38 separates the interaction chamber into the pair of chambers as a result of the two-dimensional configuration. The control portion of the chamber is connected to the output pressure and functions in the same general manner as the previously described modulator. Thus, the signal orifices sees the output pressure and operates with unity pressure feedback and thus essentially unity gain.

The present invention thus provides a highly useful fluid device having unity pressure feedback.

We claim:

1. A fluid pressure amplifying device, comprising an enclosure defining a chamber input orifice means establishing a main supply stream as a free stream in said chamber and a control stream orifice means establishing an interacting deflection control stream as a free stream within the chamber, a reference pressure orifice means connected directly to the chamber, and defining a restricted connection thereto, and a fluid output orifice means connected directly to the chamber and conjointly with the reference pressure orifice means establishing essentially full output pressure within the chamber which imposes the output pressure directly and essentially without loss to the control stream orifice means and establishes internal pressure feedback with the output pressure establishing the downstream pressure of said control stream orifice.

2. The fluid device of claim 1 wherein said control stream is generally perpendicularly related to the supply stream and the reference pressure means is located in substantially opposed relation to the main supply stream.

3. The fluid device of claim 1 having a main stream orifice and a control signal orifice terminating within the chamber, said control stream engaging the side of the main stream and deflecting the main stream within the chamber, and said reference pressure means constituting an orifice means mounted in opposed and generally aligned relation to the main stream orifice.

4. The fluid device of claim 1 wherein a second chamber is formed adjacent the first and connected by an orifice aligned with the main supply stream, said second chamber being connected to reference pressure means, and said input means includes means to establish a second free supply stream flowing in opposition to the first supply stream and impacting therewith within said first chamber.

5. The fluid device of claim 4 wherein said control stream is essentially perpendicularly related to the main streams.

6. The fluid device of claim 1 wherein the enclosure defines a pair of adjacent chambers connected by a collector orifice, said input means includes a pair of opposed supply stream nozzles aligned with the collector orifice and terminating one each within said chambers, a control signal nozzle means terminating within a first of said chambers to establish a control stream for engaging the side of the stream emitted from the nozzle within the first chamber, the output means includes an output signal conduit means connected to the first chamber, and a reference pressure means is connected to the second chamber.

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