

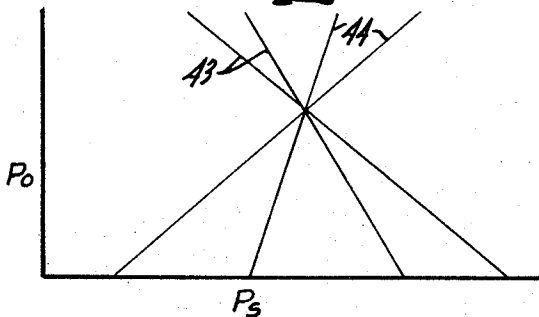
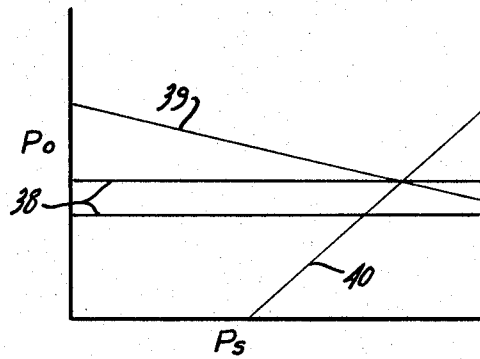
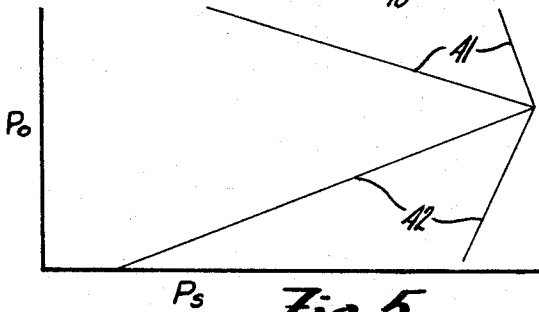
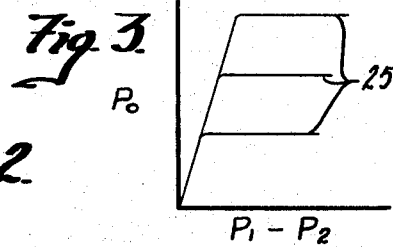
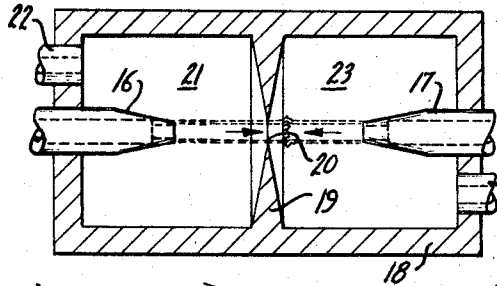
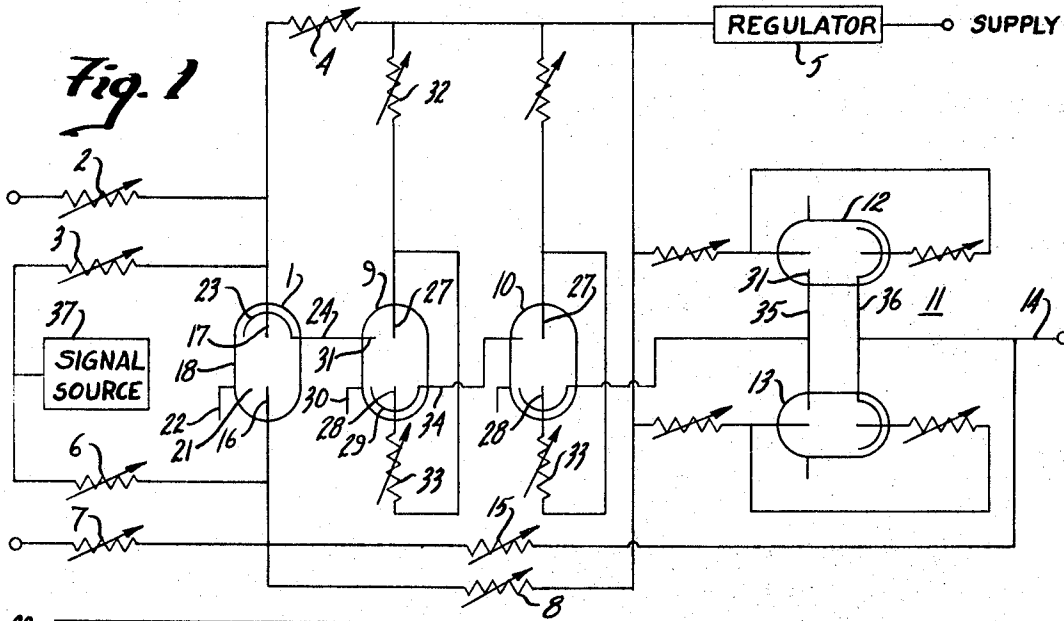
June 18, 1968

B. G. BJORNSEN
PURE FLUID SUMMING IMPACT MODULATOR AND UNIVERSAL
AMPLIFIERS CONSTRUCTED THEREWITH

3,388,713

Filed Jan. 25, 1965

2 Sheets-Sheet 1



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Fig. 6. Andrus & Starke
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2 Sheets-Sheet 2

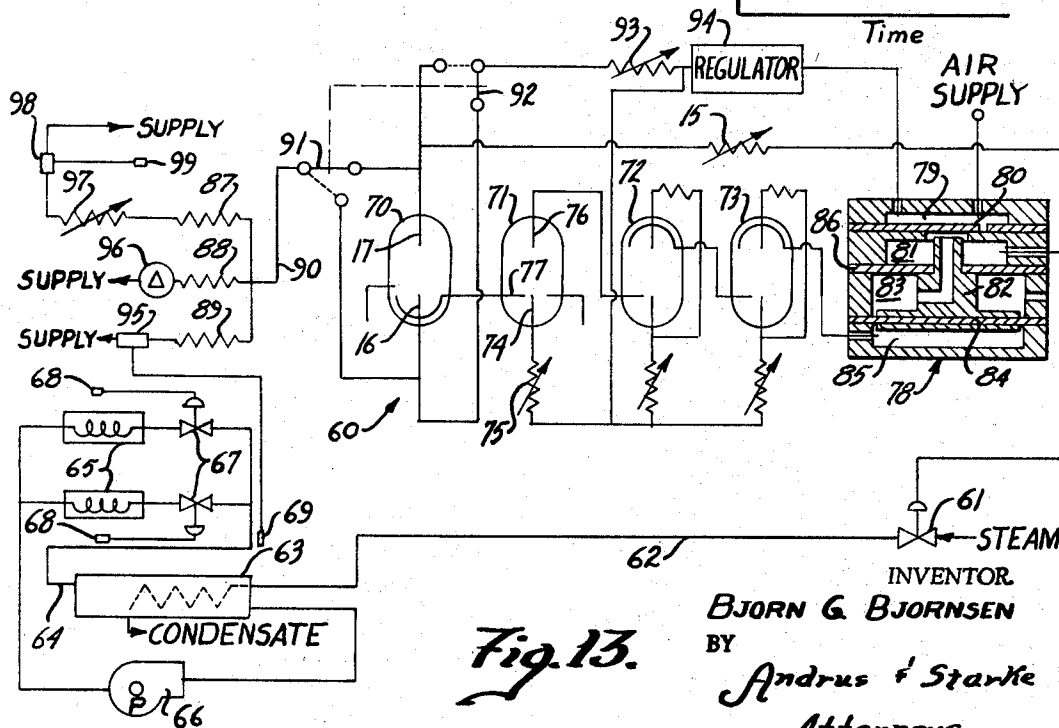
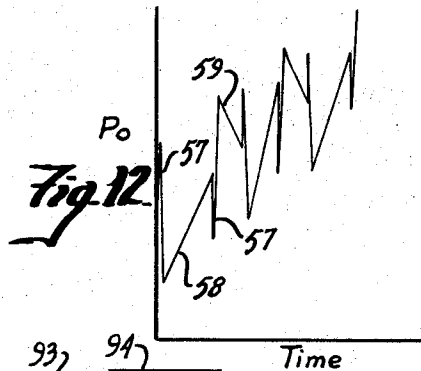
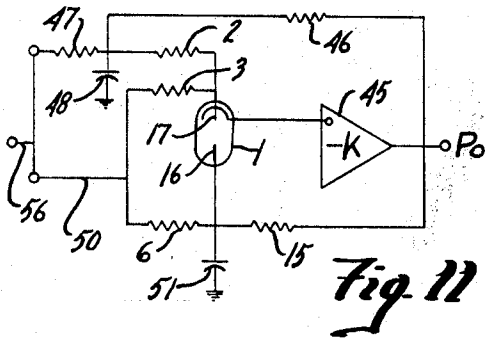
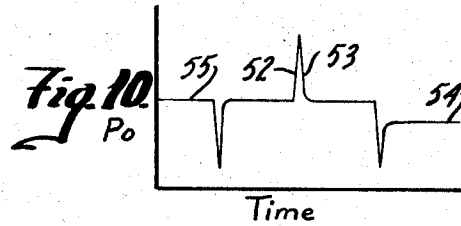
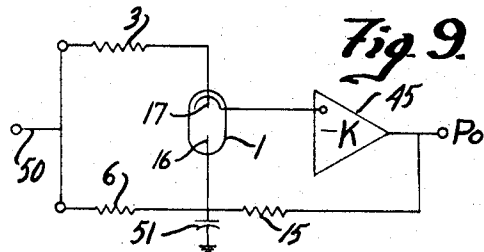
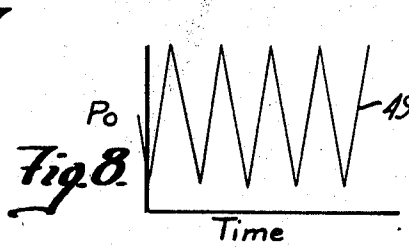
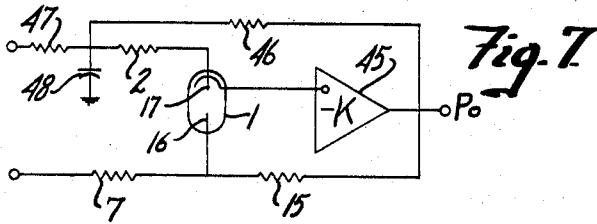


Fig. 13.

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1

3,388,713

PURE FLUID SUMMING IMPACT MODULATOR AND UNIVERSAL AMPLIFIERS CONSTRUCTED THEREWITH

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18 Claims. (Cl. 137—81.5)

ABSTRACT OF THE DISCLOSURE

A universal fluid amplifier includes a summing input impact modulator including a pair of opposing nozzles secured to the opposite sides of an enclosure having a central orifice wall defining a pair of chambers each of which includes one of the nozzles. One chamber is connected to a reference pressure and the opposite chamber is connected to an output line. Fluid control signals are connected through individual corresponding restrictors to the nozzles. To subtract, the signal restrictors are connected to the opposite nozzle and to add, they are connected in parallel to the one nozzle. The output chamber connection is to multiple stage transverse impact modulators each including opposed nozzles with an intermediate orifice wall defining a reference chamber to one side and a pressure or output chamber to the opposite side. The input to the summing impact modulator is amplified through the cascaded modulators. A feedback restrictor connects the output of the amplifying section to one of the two input nozzles of the summing impact modulator. A conventional pneumatic relay may be connected to the output of the amplifying stage.

This invention relates to a pure fluid summing impact modulator and a universal fluid amplifier employing the summing modulator as an input device.

In control and information handling circuits, mechanical, electronic or pneumatic devices can be employed. Recently, a variety of pure fluid active elements have been created for simulating active electronic elements, such as tubes and similar solid state devices but using flowing fluid instead of electrical electron flow. An unusually unique development is disclosed in the copending application of Bjorn G. Bjornsen and Thomas J. Lechner, Jr., entitled, Fluid Control Apparatus which was filed on Nov. 1, 1963, with Ser. No. 320,680, now Patent No. 3,272,215, and is assigned to the same assignee as the present application. The pure fluid device disclosed therein, known as an impact modulator, generally employs a pair of opposed fluid streams of air or other suitable fluid to form a pure fluid pressure balance system at the resulting position or plane of the two impacting streams. The position of the radial jet is determined by the relative strength of the impacting streams. A concentric orifice is aligned with the streams at the impact plane such that an output pressure or flow is developed to the one side of the orifice. The output signal is modulated or controlled by the varying of the strength of either one or both of the streams. One of the exceptionally unique characteristics of this device is that it has been found to permit design based on the interconnection of passive elements; that is, fluid restrictors generally corresponding to electrical resistors, fluid storage tanks similar to electrical capacitors and the compressibility of fluid corresponding to electrical inductance. For example, based on the concept of the impact modulators, a highly accurate and reliable pure fluid operational amplifier is disclosed in the copending application of Bjorn G. Bjornsen, et al. entitled Pure Fluid Operational Am-

2

plifier which was filed on Nov. 30, 1964, with Ser. No. 414,808 and a fluid integrator is disclosed in another copending application of Bjorn G. Bjornsen, et al. entitled Pure Fluid Integrator which was filed on Nov. 20, 1964, with Ser. No. 414,812, now Patent No. 3,294,319; both of the latter applications being assigned to the same assignee as the present application.

The application of fluid control systems employing pure fluid modulating devices will demand a great variety of different and additional circuit functions and thus a generally universal fluid amplifying means which could be built in a modular construction of a few basic modules which are interconnected by passive elements to determine the function must be recognized as a substantial advance in the art of fluid control systems. Thus, a controller of the closed loop type will include a control signal amplifying unit connected in the control loop to receive the control input signals and establish an error signal for actuating a load. A universal amplifying unit for different application should be readily constructed for either positive gain or negative gain and with addition or subtraction of two or more signals with the action of the unit determined by the use of properly connected passive elements and designed such that the action of the system can be accurately predicted. The amplifying unit may then be used to perform the functions such as differentiation and integration of control signals to provide various controls. Thus, a basic modular amplifying unit may then be connected in a closed control loop to produce any one of the desirable forms of controls including proportional control action with or without a rate action and/or a reset action. Additionally, where other analogue functions are desired, suitable nonlinear passive elements may be employed.

The present invention is particularly directed to an improved pure fluid impact modulator forming the input to an amplifying unit adapted to be driven by pressure signals and having an output power unit which may be either a pure fluid device to maintain a pure fluid system or other well known pneumatic relay devices such as a diaphragm controlled pneumatic relay. The present invention provides a universal fluid signal amplifying circuit which can be applied by proper connection of passive elements to many different control functions and include the simplicity and flexibility presently available in electronic controls while retaining direct control of pneumatic operators with their well known advantages.

Generally, in accordance with the present invention, the input device is constructed as a special impact modulator having a pair of opposing nozzles. The enclosure assembly thus defines a pair of chambers each of which includes one of the nozzles. The one chamber is selected as an output chamber and the opposite chamber forms a reference chamber which is connected to a suitable reference pressure less than either of the main supply pressures. The control signals are applied to either or both of the main power streams through suitable restrictors, depending upon the particular function to be performed. Thus, if a pair of signals is to be subtracted, the signals are applied one each to the opposite nozzles of the impact modulator such that the output signal is proportional to the difference of the two input signals. If the signals are to be added, the signals are connected in parallel through suitable individual restrictors to the one side or the other depending upon whether negative or positive gain is to be obtained. In accordance with the present invention, the input restrictors reduce the input signal levels to approach the reference pressure level and produce very small flow signals. Further, the orifices of the stream nozzles are such that the total flow produced by the multiple inputs are never capable of producing a signifi-

cant pressure drop relative to the reference pressure. This may be accomplished by having the orifice size selected such that its fluid resistance is negligible and inconsequential compared to each input signal summing restrictor associated with the input signals.

The output of the summing impact modulator is connected to suitable fluid signal amplifiers such as additional pure fluid amplifying devices which may advantageously be transverse impact modulators constructed as disclosed in the previously identified copending "Pure Fluid Operational Amplifier" application. The amplified output is applied to a power unit which may be an impact modulator designed to produce an operating pressure signal or a conventional pneumatic relay of the diaphragm variety. In a closed loop universal amplifier, the output signal is connected through a feedback restrictor to one of the input nozzles of the input device to provide the desired action. Thus, in the present invention, the feedback restrictor can be connected to either the negative or the positive side of the summing impact modulator in accordance with the sign of the forward gain of the amplifying unit to provide the desired control action.

In a preferred construction of the present invention for summing of signals, a plurality of signal input restrictors are connected in common to coupling means which is selectively connected to either side of the modulator. A calibrating or balancing restrictor is connected to a coupling means which is similarly selectively connected to the opposite side of the modulator to produce a stream opposing the stream generated or formed by the plurality of signal input restrictors. Where less than all of the input restrictors provided in the particular assembly are employed for modulation of the output, the other inputs are either closed or connected to a suitable supply to provide a set point adjustment. The output of the summing impact modulator is connected to a stream deflection amplifying unit such as the three terminal modulator disclosed in the copending application entitled Fluid Control filed on Sept. 30, 1963, with Ser. No. 312,550, now Patent No. 3,279,489, and to a pair of cascaded transverse impact modulators to provide an amplified fluid signal. This amplified fluid signal is applied to a diaphragm relay which in turn has its output connected to the summing modulator through an appropriate feedback restrictor and to a load means; for example, a conventional pneumatic operator. The system can be made direct acting or reverse acting by selecting the proper inlet connections to the two nozzles of the summing modulator. A manually or automatically controlled remote set point adjustment can be connected to a second input to affect the controlled variable according to a preselected schedule.

The use of a conventional pneumatic relay minimizes the fluid consumption of the circuit. Thus, a high pressure fluid supply is connected directly to the relay and throttled to the load demands by a relatively low level control signal impressed on its control chamber, this low level signal being supplied by the output of the transverse impact modulator immediately preceding the relay. The relay thus only draws as much air from the supply as required to operate the pneumatic operator except in the very small continuous supply through the feedback restrictor to the proper nozzle of the summing impact modulator and does not require a continuous maximum flow which is selectively diverted between the operator and a reference. The pure fluid amplifier for establishing the low level control signal feeding the relay can be constructed to use a minimal amount of air or other fluid. Although a pure fluid output device can be employed, such devices do require continuous standby flow to accommodate demands corresponding to a maximum output or demand pressure signal and relatively appreciable quantities of fluid. Consequently, when operating at less than maximum demand, the excess flow is lost.

The present invention thus provides a highly improved

fluid amplifying or modulating system which is simple, flexible and readily adapted by the proper interconnection of passive elements to provide a wide variety of functions.

The drawings furnished herewith illustrate a preferred construction of the present invention in which the above advantages and features are set forth as well as others which will be clear from the subsequent description of the drawings.

In the drawings:

FIG. 1 is a schematic diagram of a pure fluid universal amplifier constructed in accordance with the present invention;

FIG. 2 is a diagrammatic cross sectional view of a summing impact modulator schematically shown in FIG. 1;

FIG. 3 is a trace showing an input-output characteristic of the summing modulator;

FIG. 4 is a trace illustrating the comparator operation of the universal amplifier of FIG. 1;

FIG. 5 is a trace showing negative and positive gain characteristics of the universal amplifier operating about a selected maximum input set point for the receiver of FIG. 1;

FIG. 6 is a trace similar to FIG. 5 showing positive and negative gain characteristics operating at an intermediate input pressure set point;

FIG. 7 is a schematic diagram of a bootstrap integrator employing the universal amplifier of FIG. 1;

FIG. 8 is a graph showing an output integrated with respect to time for a square wave input;

FIG. 9 is a schematic diagram of a differentiating circuit employing the universal amplifier of FIG. 1;

FIG. 10 is a trace of the differentiated output generated with a square wave input;

FIG. 11 is a schematic diagram combining the integrating and differentiating systems of FIGS. 7 and 9;

FIG. 12 is a trace of an output derived from a system shown in FIG. 11; and

FIG. 13 is a schematic diagram showing a universal amplifier interconnected as a part of a temperature control unit and constructed in accordance with the present invention with a single set of paralleled input channels selectively connected to opposite sides of a summing impact modulator and with a conventional pneumatic output power relay.

Referring to the drawings and particularly to FIG. 1, one embodiment of a universal fluid amplifier constructed in accordance with the present invention is shown including a novel summing impact modulator 1 which is illustrated by a schematic representation in FIG. 1 and in more detail in FIG. 2. The impact modulator 1 is a special design of the general impact modulators disclosed in the previously identified application and generally includes a pair of opposed impacting streams defining a controllable output signal. The general overall connection of the modulator 1 in the circuit is briefly described and the individual components are then more fully described. In FIG. 1, the several fluid resistors or restrictors are schematically shown as being adjustable. In practice, a fixed restrictor in series with a fine adjustment restrictor may be employed as the fluid resistors for practical reasons, and where a single fixed design is made, fixed restrictors may be employed. Generally, filters, not shown, are also provided in the various input pressure lines in accordance with general practice in the pneumatic art.

The one stream input to modulator 1 is connected to a pair of positive gain input restrictors 2 and 3 and a calibrating restrictor 4, which constitutes a special input restrictor, all of which are connected thereto in parallel. Restrictor 4 is connected to a pressure supply by a pressure regulator 5 to provide a closely controlled pressure stream. The opposite input is connected to a pair of negative gain input restrictors 6 and 7 and a calibrating input restrictor 8, all of which are connected thereto in parallel.

The calibrating restrictor 8 is also connected to regulator 5. The output of the summing impact modulator 1 is equal to the gain of the modulator times the difference of the absolute total pressures at the two inputs, with the absolute total pressures being referred to a reference as subsequently described and is connected to a forward gain amplifier which in the broadest aspect of this invention may be any suitable amplifier responsive to the low level signal from the modulator. The illustrated amplifier includes a pair of cascaded transverse impact modulators 9 and 10 which amplify the summed output signal to a suitable level for operating a power stage 11 which may be any suitable unit adapted to increase a low level signal to a level for operating a pneumatic operator or the like; such as pure fluid power amplifiers, a pneumatic relay as shown in FIG. 13 or the like. The amplified signal is the input to the power stage 11 which in FIG. 1 is a pure fluid amplifier and includes a pair of transverse impact modulators 12 and 13 connected in parallel to provide a relatively high power output signal at an output line 14. A feedback restrictor 15 interconnects the output line 14 to the summing impact modulator 1 with the connection determined by the sign of the forward gain amplifier. In FIG. 1, the restrictor 15 is connected directly to the positive gain modulator input connected to the input restrictors 6 and 7 as the forward gain amplifier has a negative gain and provides an operational amplifier for addition or subtraction of a plurality of input signals at either or both of the inputs.

More particularly, the summing impact modulator 1 which makes the construction of a universal amplifier practical, is schematically represented in FIG. 1 and diagrammatically shown in a preferred construction in FIG. 2 and corresponding elements in FIGS. 1 and 2 are similarly numbered. The modulator 1 includes a pair of opposed stream nozzles 16 and 17 having stream forming orifices for forming the respective two stream forming inputs of the modulator 1. A concentric housing 18 encloses the terminal ends of the nozzles 16 and 17 and includes a transverse wall 19 centrally located with respect to the ends of nozzles 16 and 17. The wall 19 includes a control orifice 20 aligned with the nozzles 16 and 17 and preferably having a V-shaped cross section to define correspondingly shaped surfaces to the opposite sides of orifice 20 and a sharp edge at the orifice. The modulator 1 of this invention is thus symmetrically formed about the wall 19 which defines a first chamber 21 encircling and concentric with the nozzle 16 and which is provided with a fluid tap 22. A similar chamber 23 is defined by wall 19 concentric with nozzle 17 and is provided with a tap 24. The symmetrical formation of modulator 1 is of substantial significance as either chamber can be used as a reference or an output by proper connection in the flow circuit. In FIG. 1, the tap 22 is connected to provide a reference pressure within the corresponding chamber 21 and in the embodiment of the invention atmospheric pressure is selected as the reference. However, other pressures may be employed as hereinafter discussed. The tap 24 constitutes the output signal tap with the output pressure being generated or formed within the second chamber 23.

The input nozzle 17 is shown connected in series with the calibrating resistor 4 to a regulated supply of air pressure. The total signal at nozzle 17 is therefore the sum of the pressure or flows from the three paralleled paths.

Similarly, the nozzle 16 is connected in parallel to the signal restrictors 6 and 7 and the calibrating restrictor which is connected to the regulator. Thus, the total signal appearing at nozzle 17 is the algebraic sum of the pressures or flows established by the signals on restrictors 6 and 7 and the preset signal established by the calibrating restrictors 8 and 4.

Modulator 1 generally operates in accordance with the theory of the operation of impact modulators as disclosed in the previously first identified copending application.

Thus, impacting streams are formed by the nozzles 16 and 17 and establish a balance point adjacent the orifice 20. If the strength of the stream from nozzle 17 is sufficiently great relative to the strength of the stream from nozzle 16, the impact position is completely within the reference chamber 21 and a zero output is obtained. If the stream of nozzle 16 is sufficiently greater, the impact position is wholly with the output chamber 23, as shown in FIG. 2, and the maximum output signal is obtained. In practical operation, the system is designed to operate about a raised or mean output pressure at line 14 constituting a zero level such that both positive and negative signals can be obtained. The summing impact modulator 1 is therefore constructed to have an output signal related to the raised reference at output line 14 and this signal is modulated about that reference.

The specific operation of the summing impact modulator 1 (SIM) of this invention is selected to produce a particular function. The summing impact modulator 1 is specially constructed such that the output signal (P_{osim}) is equal to the gain of the modulator (K_{sim}) times the difference of the pressure P_1 at nozzle 16 and the pressure P_2 at nozzle 17; i.e., $P_{osim} = K_{sim}(P_1 - P_2)$ where P_1 and P_2 are greater than reference pressure P_{ref} established in reference chamber 21. Further, the pressure P_{osim} is in general never less than P_{ref} . This relationship is shown in a typical graphical representation in FIG. 3 for three different fixed pressure signals at nozzle 17 (P_2) and with a varying pressure signal at nozzle 16 (P_1) which is greater than P_2 : with the output pressure P_{osim} on the vertical axis and $P_1 - P_2$ on the horizontal axis. The three curves 25, one for each fixed P_2 , each includes a similar positive slope to the maximum available output pressure which is established by P_2 .

In certain applications, the reference pressure may beneficially be different than the ambient pressure as well as being different than that of other impact modulators within the total circuit.

In order to permit simplification of the performance curves as subsequently discussed, the modulator 1 is specially constructed to have relatively large input orifices with a resultant small orifice impedance and large conductance such that total flow produced by the several inputs is never sufficiently great to cause a significant pressure drop relative to the reference pressure. The summing impact modulator 1 is thus similar to a current device rather than a voltage device. The summing impact modulator 1 therefore employs a pair of streams of relatively low pressure, either or both of which are modulated in accordance with one or more signals.

The summing impact modulator 1 creates an amplified output, which is in a reversed sense for changes in the total input pressure at nozzle 17 and which is in the same sense for changes in the total input pressure at nozzle 16. Consequently, the input provides either positive or negative gain by proper connection to the nozzles 16 and 17 of the modulating or control signals. As previously noted, the output signal at output line 14 is raised to an artificial or reference zero and the impact modulator 1 must have a related means output. The latter is determined by the forward gain of the amplifying section formed by the transverse impact modulators 9, 10, 12 and 13; as presently described.

The cascaded transverse impact modulators 9 and 10 and the paralleled transverse impact modulators 12 and 13 etch reverse the sense of the input signal thereto. Consequently, a signal change at nozzle 17 results in proportional change in the output pressure in the same sense and restrictors 2 and 3 constitute positive gain inputs. Conversely, a signal change at nozzle 16 results in proportional change in the output pressure but in the opposite sense and restrictors 6 and 7 constitute negative gain inputs. In summary, the output signal of the illustrated universal amplifier increases from the mean reference pressure with a pressure increase at nozzle 17 or

a pressure decrease at nozzle 16 and will decrease from the means or reference pressure with a pressure decrease at nozzle 17 or a pressure increase at nozzle 16.

Each of the illustrated transverse impact modulators 9 and 10 is generally a negative gain amplifier as shown in the previously identified application entitled Pure Fluid Operational Amplifier to which reference may be made for details of construction and is only briefly described herein. Thus, each of the transverse impact modulators 9 and 10 includes a pair of opposed stream nozzles 27 and 28 establishing impacting streams with respect to an output chamber shown schematically at 29. However, the transverse modulators 9 and 10 are preferably constructed with the reference chamber closed and having a reference tap 30 to permit a selected reference, shown as ambient or atmosphere. A tap 30 is provided as in certain designs other than an ambient reference might be desirable. A transverse nozzle 31 is positioned adjacent to nozzle 27 within the reference chamber and connected to the output tap 24 of the summing impact modulator 1 such that the stream from nozzle 27 is deflected in accordance with the output of the modulator 1. The main stream nozzle 27 is connected to the supply pressure through an adjustable restrictor 32. Additionally, an adjustable restrictor 33 interconnects the nozzle 28 to the nozzle 27 and thus to the output side of the restrictor 32. The main streams provide a selected impact positioning in the absence of a signal from the summing impact modulator 1. The output of the summing impact modulator 1 deflects the stream emitted from nozzle 27 and thus reduces its effective strength relative to the stream from nozzle 28. This moves the impact position from the collector 29 to the reference side and reduces the output pressure at the collector 29 in accordance with the strength of the signal from the modulator 1, thereby producing a negative gain. The amplified signal appears at an output signal tap 34 to collector 29 and is connected as the input to second transverse impact modulator 10 where it is further amplified, with another reversal in sign, and fed to the power stage 11.

The power stage 11 includes the paralleled transverse impact modulators 12 and 13 constructed in the same manner as the impact modulators 9 and 10 and interconnected to the supply pressure in a similar manner. Additionally, they have a common input line 35 connected to the corresponding transverse nozzles. A common output line 36 connects their collectors to the output line 14. The power stage 11 again reverses the sign of its input signal and provides a correspondingly related amplified output pressure signal. The feedback restrictor 15 interconnects the output line 14 to nozzle 16 of the summing impact modulator 1 to produce negative feedback.

The overall performance of the universal amplifier is now developed as follows.

The output (P_{osim}) of the summing impact modulator 1 which equals $(P_1 - P_2)K_{sim}$ as previously discussed, constitutes the input to the negative gain amplifier formed by the impact modulators 9, 10, 12 and 13, as more fully developed hereinafter. The output signal, P_o , at the line 14 is therefore equal to $(P_1 - P_2)K_{sim}$ (the input pressure signals at nozzles 16 and 17 times the negative gain $(-K)$ of the forward gain amplifier. The equation can be written as $P_o = (-K)(P_1 - P_2)$ with the $(-K)$ including both of the previously noted gains. Further, in summation form, the signal

$$P_1 = \frac{P_{1j} + P_o}{G_{T1}}$$

where P_{1j} refers to the respective input signal to restrictors 6 and 7 and all other restrictors which may be provided to the nozzle 16, R_{1j} refers to the fluid resistance of the input restrictors 6 and 7 and all other restrictors

which may be provided, R_f refers to the fluid resistance of the feedback restrictor 15 and where the conductance

$$G_{T1} = \frac{1}{R_{N1}} + \frac{1}{R_{11}} + \dots + \frac{1}{R_{1n}} + \frac{1}{R_f}$$

R_{N1} is the fluid resistance of the orifice of nozzle 16. Similarly, in summation form signal

$$P_2 = \sum \frac{P_{2j}}{R_{2j}} / G_{T2}$$

where conductance

$$G_{T2} = \frac{1}{R_{N2}} + \frac{1}{R_{21}} + \dots + \frac{1}{R_{2n}} = \frac{1}{R_{N2}} + \frac{1}{R_2} + \frac{1}{R_3}$$

Substitution of the equations for P_1 and P_2 in the equation for P_o gives the expression for the universal amplifier performance function in terms of the input signals at the terminals of the universal input amplifier and the noted passive elements as:

$$P_o = \frac{G_{T1}}{G_{T2}} \sum \frac{R_f}{R_{2j}} P_{2j} - \sum \frac{R_f}{R_{1j}} P_{1j} \frac{R_f(G_{T1} + 1)}{K}$$

By employing a forward gain amplifier having a sufficiently high gain K , the performance equation becomes, with the approximation or closed loop error related directly to the accuracy of dropping the denominator:

$$P_o = \frac{G_{T1}}{G_{T2}} \sum \frac{R_f}{R_{2j}} P_{2j} - \sum \frac{R_f}{R_{1j}} P_{1j}$$

It can be similarly shown that with the summing impact modulator 1 and a forward gain amplifier having a positive gain and with the feedback restrictor connected to the positive gain nozzle 17 to maintain negative feedback, a similar performance equation is:

$$P_o = \frac{G_{T2}}{G_{T1}} \sum \frac{R_f}{R_{1j}} P_{1j} - \sum \frac{R_f}{R_{2j}} P_{2j}$$

In the above equations, the overall performance is defined by the passive elements only. Further, in accordance with the special construction of modulator 1, the performance equations can be further simplified by elimination or simplification of the conductance terms in the equations. As previously noted, modulator 1 is formed such that fluid resistance of the modulator input orifices is very small and consequently the conductance $1/R_{N1}$ and $1/R_{N2}$ can be made very large relative to the sum of the input restrictor conductances

$$\frac{1}{R_{11}} + \frac{1}{R_{12}} + \dots + \frac{1}{R_{1n}}$$

and

$$\frac{1}{R_{21}} + \frac{1}{R_{22}} + \dots + \frac{1}{R_{2n}}$$

for a reasonable or limited number of inputs. The conductance ratios in the above equations can therefore closely approximately be reduced to:

$$\frac{G_{T1}}{G_{T2}} = \frac{R_{N2}}{R_{N1}} \text{ and } \frac{G_{T2}}{G_{T1}} = \frac{R_{N1}}{R_{N2}}$$

and by making the orifices equal, the conductance ratio becomes unity, and is so to speak eliminated from the performance function which in turn is defined by the respective positive and negative gain resistance ratios of the feedback restrictor and the individual signal restrictors.

In operation, the output of the universal amplifier is thus affected and controlled by each of the individual signals to a varying degree. The degree of sensitivity and control is defined as the gain of the universal amplifier for that input; that is, the output change in p.s.i. (pounds per square inch) for a given input change in p.s.i. at the corresponding restrictor. The gain associated with each of the inputs in the illustrated embodiment is determined

by the ratio of the feedback restrictors 15 to the corresponding input restrictors 2, 3, 6 or 7. The output pressure of the universal amplifier is, therefore, equal to the summation of the products of the individual gains and the individual input pressures.

In FIG. 1, the output signal at line 14 can be caused to be a direct or reverse acting for a given direct input signal by connection to the restrictors on the proper side of the summing impact modulator 1. Thus, if control signals are only applied to the input restrictors 2 and 3, the output at line 14 moves in the same sense or direction as the input signals. However, if the same signals are applied to restrictors 6 and 7, the output at line 14 moves in the opposite sense or direction.

The operation of the circuit can be further understood from the following descriptions of the various connections which can be made. The graphical illustrations in the drawings and presently described are simplified line drawings of actual diagrams taken from a universal fluid amplifier generally constructed as shown in FIG. 1 and operated with air as the fluid medium. In the following discussion, the performance equation is employed but with several input pressures to the restrictors and the resistances of the restrictors identified by a subscript corresponding to the identifying number of the restrictor. For example, the input signal to the restrictor 3 is identified as P_3 and the corresponding fluid resistance as R_3 .

If a positive gain input restrictor 3 and a negative gain input restrictor 6 are tied together and connected to a common signal source 37, orifices 2 and 7 being closed or connected to suitable fixed set point pressures, and the fluid resistance of restrictor 3 is identical to that of restrictor 6 such that they have same individual gains, the output at line 14 remains constant with variations in the common signal of source 37; that is, the difference between the two output signals remains zero. The effect of this is shown in the graph of FIG. 4 where the input pressure signals in p.s.i.g. are shown on the horizontal axis with respect to the output signal in p.s.i.g. shown on the vertical axis. Two constant pressure output lines 38 for varying input signals are shown and correspond to different adjustments of the calibrating restrictors 4 and 8 and/or the restrictors 2 and 7, if not closed, which may provide the initial set point pressures to nozzles 16 and 17.

The output as in FIG. 4 is also shown by the output equation:

$$P_o = P_3 \frac{R_f}{R_3} - P_6 \frac{R_f}{R_6} = P_3 K_3 - P_6 K_6$$

where the subscripts refer to the corresponding elements. However, as can be seen, K_6 equals K_3 because R_6 equals R_3 , therefore, $P_o = K_3(P_3 - P_6)$. As the inputs are tied together, the difference is zero and P_o should remain at the preset value as correctly shown in FIG. 4, lines 38.

If on the other hand the restrictors 2 and 6 are tied to a common input as shown, but the positive gain K_3 or the negative gain K_6 is made to predominate by proper adjustment of restrictors 3 and 6, the input-output relationship selectively provides an output characteristic, shown by the positive slope lines 39 or the negative slope lines 40 of FIG. 4. The modulator 1 is adjusted through the calibrating restrictors 4 and 8, or by use of restrictors 2 and 7 as set point controls, to establish an output level for a selected input pressure. The input signal from source 37 is assumed to vary about the point. If restrictor 6 is decreased in fluid resistance, its gain

$$\left(K_6 = \frac{R_f}{R_6} \right)$$

increases and the negative slope, line 39, through the set point is then typical of the performance of the universal amplifier.

If restrictor 2 is decreased, or restrictor 6 increased, the positive gain predominates and the gain line 40 having

the positive slope similarly typically defines the characteristic.

The slopes of lines 39 and 40 also follows from an analysis of the above performance equation

$$P_o = P_3 K_3 - P_6 K_6$$

P_6 and P_3 are the same as a result of the connection to a common signal. Therefore, $P_o = P_6(K_3 - K_6)$. If K_6 increases and predominates, the negative gain characteristic must be obtained. If K_3 increases and predominates, the positive gain characteristic must be obtained.

Characteristic of the amplifier operating as an operational amplifier with the input signals contributing to the pressure at nozzle 17 and the signal at the other nozzle 16 varying, as a result of signals from the corresponding restrictors is shown in FIG. 5. The characteristic is shown where the set point output pressure is obtained with one or more of the input signals contributing to the pressure at nozzle 17. The negative gain lines 41 and the positive gain lines 42 are shown. For the negative gain curves, as the signal pressure decreases the output pressure increases, with the rate of change determined by the ratio of the feedback restrictor to the input restrictor. Assuming signals only at the input to restrictors 3 and 6 for purposes of simplifying the equation, the output equation of $P_o = P_3 K_3 - P_6 K_6$ again defines the two sets of lines 41 and 42 as follows. If the pressures contributing to P_6 are selected at fixed values and the variable signal, feeding into restrictor 3, the characteristics are shown by the positively sloped lines 42. Thus, as P_3 , for instance, decreases, the output pressure P_o decreases also. Conversely, if pressures P_3 are fixed to determine a desired set point output pressure the amplifier performance is defined by the negatively sloped lines 41. Thus, as P_6 decreases, the output pressure P_o will increase.

FIG. 6 illustrates an operation or function similar to FIG. 5 except that the set point at which the mean output pressure is obtained, corresponds to an intermediate input pressure. The set point can be established by proper adjustment of the calibrating restrictors 4 and 8 as well as by employing one or more fixed input signals to the input summing restrictors.

The universal amplifier will function with characteristics defined by negative slope lines 43 or by the positive slope line 44 depending upon the gains and pressures as defined by the general equation, again assuming for purposes of simplicity the presence of only input signal restrictors 3 and 6:

$$P_o = P_3 K_3 - P_6 K_6$$

If P_3 is fixed and only P_6 varies, the negative slope lines 43 define the characteristics. Similarly, lines 44 define the characteristic when P_3 varies and P_6 is fixed.

Further, to show the universality of the present invention, a bootstrap fluid integrator may be formed as shown in FIG. 7 where a negative forward gain amplifier is shown in an appropriately labeled block 45 and the other elements corresponding to FIG. 1 are similarly numbered. In FIG. 7, a positive feedback restrictor 46 is connected to the positive input side at restrictor 2 with an additional restrictor 47 connected between the signal input and the summing restrictor 2. A fluid tank or capacitor 48 is connected to the junction of 47 and 2. Resistor 47 and capacitor 48 constitute the RC-time constant of the bootstrap integrator similarly to the teaching of the copending application entitled, Pure Fluid Integrator, Ser. No. 414,812, referred to previously. The integral action is illustrated in FIG. 8 where a generally sawtooth output trace 49 is obtained for a square wave input signal at the resistor 47.

Differentiation is obtained by lead-lag action employing the comparator action of the universal amplifier as shown in the simplified circuit of FIG. 9 where the forward gain amplifier is shown as in FIG. 7 and the corresponding elements of FIG. 1 are otherwise similarly numbered. The input side of restrictors 3 and 6 is tied

together to form a common input 50. Additionally, a delay capacitor 51 connects the restrictor 6 to ground. A square wave input signal at input 50 is immediately effective through restrictor 3 whereas the effect through restrictor 6 is delayed by the capacitor 51. As a result, the output will be generally as shown in FIG. 10. When a positive step is impressed at input 50 the output increases rapidly along the leading edge 52 of a pulse as a result of the signal path through restrictor 3. The output is reset or returned to the set value along the trailing edge 53 in accordance with the nullifying effect of the signal at the restrictor 6 and delayed by the capacitor 51. Pure "differentiation" is obtained by having the negative gain, established by restrictor 6, and the positive gain, established by restrictor 3, equal. A proportional plus rate action is obtained by having unequal gains. Proportional plus rate action is typically shown by the offset of the signal curve 54 with respect to the original output pressure level 55.

Additionally, if it is desired to provide a reset plus rate plus proportional action, the integrating and differentiating systems of FIGS. 7 and 9 may be combined as shown in FIG. 11 and corresponding elements in the several figures are similarly numbered. As shown in FIG. 11, the positive feedback restrictor 46 is connected to the positive input restrictor 2, as in FIG. 7, and the input sides of the positive gain restrictor 3 and the negative gain restrictor 6 are tied to the common input 50 with the delay capacitor 51 connecting the output side of restrictor 6 to ground. The input to the integrating leg and the differentiating leg are tied together to form a single input 56. A typical characteristic trace 57 is generally shown in FIG. 12 for a square wave input.

There is a predominance of the positive gain established by restrictor 3 relative to the negative gain established by restrictor 6 to provide for the proportional action. In FIG. 12, the positive portions of the input square wave (not shown) are longer in duration than the negative portions. The increased positive integration time is shown by the greater length of the positive related lines 58 with respect to the negative related lines 59 and the resulting gradual upward movement of the trace. The latter trace clearly shows the proportional action with the rate action provided by the differentiation and reset action provided by the integration superimposed thereon.

The universal fluid amplifier of the present invention provides for great flexibility when applied to fluid controls not only because of the ability to perform the noted proportional action, rate action and reset action but also because of the unique capability of adding and subtracting an appreciable number of different inputs such that its output can be made to depend on a great number of variables including various feedback circuit arrangements.

Referring particularly to FIG. 13, an alternative or special construction of the universal amplifier, identified by applicant's assignee as a controlling receiver, and constructed in accordance with the present invention is shown incorporated in a water temperature control system for a hot water heating system. Generally, in FIG. 13, a universal amplifier 60 has its output connected to control a steam valve 61 which in turn controls the flow of steam through a steam input line 62 to a heat exchanger 63 of any suitable construction for providing hot water to a hot water output line 64. The hot water line 64 is connected in a closed heating loop with a pair of radiators 65. A pump 66 is provided in the line 64 to circulate the water through the radiators 65 and heat the adjacent area. Water valves 67 are connected one each in series with each of the radiators 65 and controlled by a separate control thermostat 68 to control the circulation of water. The temperature of the water in the line 64 is controlled through the use of a temperature sensor 69 connected as an input to the universal amplifier 60 to generate an error signal which is reflected at the output of the universal amplifier for selective and proper positioning of the steam

valve 61 to maintain the temperature of the water line at a set point.

In FIG. 13, the universal amplifier 60 includes a summing impact modulator 70 constructed in accordance with the modulator 1 of FIG. 1 and corresponding elements are similarly numbered. A three terminal modulator 71 (as shown in the copending application previously referred to) interconnects the output of the modulator 70 to a pair of transverse impact modulators 72 and 73 corresponding to the transverse impact modulators 9 and 10 of FIG. 1. The three terminal modulator 71 has a main stream nozzle 74 connected to the supply through a restrictor 75 and an aligned collector nozzle 76. A transverse nozzle 77 deflects the main stream from nozzle 76 to vary the output pressure. The three terminal modulator 71 forms a buffer stage to match the characteristic of the summing impact modulator 70 to that of the transverse impact modulator 9. The output of the second stage transverse impact modulator 73 is connected directly to the input of a well known pneumatic relay 78 which in turn has its output connected to control the steam valve 61 and the feedback resistor 15.

The pneumatic relay includes a body portion having a main air chamber 79 connected to an air supply. A flapper valve 80 is biased to normally close an opening from chamber 79 to an output chamber 81. The flapper valve 80 is selectively positioned by a diaphragm actuated member 82 which projects upwardly through a reference chamber 83 and the output chamber 81. The member 82 is stepped in cross section and includes a relatively large base secured to a diaphragm 84 forming the upper wall of a control chamber 85. A diaphragm 86 forming the lower wall of chamber 81 is connected to a reduced portion of member 82. The output of the final stage impact modulator 73 is connected to the control chamber 85 to provide a (biasing) pressure therein proportional to the output of the summing impact modulator 70. As illustrated, the effective area of the member 82 at diaphragm 84 is substantially larger than the effective area secured to the output chamber diaphragm 86. Consequently, amplification generally in the ratio of these effective areas may be obtained with regard to the input (biasing) control pressure and the output pressure.

Thus, the mean output pressure holds the member 82 upwardly engaging the flapper valve 80 and throttling the supply air through the output chamber 81 and to the steam valve 61. This will provide the desired flow of steam to the heat exchanger for the given normal standby condition and thus will directly compensate for the heat loss in the hot water line 64 in accordance with predetermined conditions. If the temperature of the water decreases, or increases, sensor 69 will generate a signal which is applied to the universal amplifier 60.

In FIG. 13, the three input restrictors 87, 88 and 89 are connected as parallel inputs to a single input line 90 which is connected selectively by a diverting pneumatic valve or coupling 91 to the nozzle 16 or 17 of the summing impact modulator 70. Ganged with the coupling 91 is a second coupling 92 which is connected at one side in series with a calibrating restrictor 93 to a pressure regulator 94. The opposite side is selectively connected to the nozzle 16 or 17 inversely with the first coupling 91. Therefore when the first coupling connects the restrictors 87-89 to the nozzle 17 as shown in full line, the coupling 92 connects the opposite nozzle 16 to the calibrating restrictor 93 to provide a balance between the input signals and the calibrated signal. The one stream is thus an artificially created input signal through the calibrating resistor 93 to oppose the total of the input signal streams applied through the three paralleled restrictors.

The restrictor 89 hereinafter identified as the control point restrictor is connected in series with a pneumatic transmitter 95 which is connected to and actuated by the sensor 69 to vary the signal to the restrictor 89 in accordance with the temperature in the hot water line 64.

The restrictor 88 hereinafter defined as a set point restrictor, is connected in series with a pneumatic gradual switch 96 which provides an adjustable regulated input pressure to permit adjustment of a set point signal.

The input restrictor 87 hereinafter identified as a master signal restrictor is connected through a ratio adjusting restrictor 97 to a pneumatic transmitter which is connected to a remote temperature sensor 99 located to sense either outdoor or "room" temperature.

The set point is adjusted to provide a signal which when added to the signals at the restrictors 89 and 97 maintains the hot water temperature in accordance with this set point and the outdoor temperature in relation to a schedule; this schedule in part being adjustable by the adjustable restrictor 97 and in part by the ratio of the sensitivities of the temperature transmitters 95 and 98. The calibrating resistor 93 which connects the nozzle 16 to the regulated air supply is adjusted to provide the desired balance by comparator action such that the output signal for a given set of signals at 98, 96 and 95 is at a predetermined desired value.

Thus, either room or outdoor temperature can regulate the water temperature entering the room heat-exchangers; i.e. it is a temperature servo system.

The system clearly illustrates the flexibility of the universal amplifier. It not only provides for an adjustable forward loop gain of the servo system (this is accomplished by changing the feedback resistance 15) but also serves as the system (summing) error junction, by adding the system feedback signal through resistor 89 to the system set point and system input signals through resistors 88 and 87 respectively.

The controlling receiver version of the universal amplifier shown in FIG. 13 can always provide for the correct loop sign of the system control loop by means of the switching mechanism 91 and 92 as explained above.

In the illustrated embodiments of the invention, called a controlling receiver in FIG. 13, a reverse acting temperature servo system is provided in that as the outdoor or room temperature decreases the output of the relay increases to close the valve 61. The system's negative feedback is here provided by the controlling receiver in that an increasing signal at any of the input resistors 87-89 will decrease the relay output. In accordance with the illustrated embodiment of the invention, a direct action can be obtained by merely reversing the connection of the couplings 91 and 92, in which case negative feedback must be provided by other loop elements such as either the valve 61 or the temperature transmitter 95.

It is also obvious to people skilled in the art of automatic control systems, how the comparator action of the universal amplifier can be utilized with great benefit to create "error" signals by signal subtraction as previously described, and where (if desired) various system loop gains can be attained simply by an adjustable weighted subtraction.

In general, such a servo system will require compensating actions such as reset, rate or a combination thereof, which can be provided by the universal amplifier in the manner previously discussed with respect to the embodiment of FIG. 11. The parallel pure fluid power elements 12 and 13 of FIG. 1 may be replaced by a pneumatic relay for instance, similar to the power stage of the controlling receiver, while retaining all of the other functions as explained in regard to the embodiment of FIG. 1.

The summing impact modulator 1 may be constructed in any suitable arrangement. An actual construction satisfactorily employed as a part of a universal amplifier included similar supply nozzle orifices of .016 inch which were identically spaced from a control orifice of .018 inch by .005 inch. The summing impact modulator 1 generally has been satisfactorily operated with the nozzle input pressures above the reference pressure in the order of as little as 33 hundred thousandths pounds per square inch (.000033 p.s.i.) and up to 60 p.s.i.

In the systems, each subsequent modulator has its reference pressure selected to be less than its input pressure from the preceding modulator by at least a similar pressure difference. An actual construction of a transverse impact modulator employed in the same system had the following significant dimensions. The supply orifices were .007 inch, the control orifice was .008 inch and the transverse nozzle orifice was .010 inch. The control orifice was spaced from the nozzle means within the output chamber by .005 inch and from the opposite nozzle by .055 inch. The transverse nozzle was spaced with its center line .005 inch from the adjacent nozzle which had its center line similarly spaced .005 inch from the end of the transverse nozzle.

Thus, the present invention provides a highly versatile and universal type fluid amplifying unit which can be designated for special applications as in the embodiment of the controlling receiver and which can be readily formed of a plurality of basic modules consisting essentially of the summing impact modulator and other fluid pressure sensitive amplifying means for the active elements of which the illustrated transverse impact modulators are particularly suitable together with such passive elements as restrictors, capacitors, etc. The power stage may be either a pure fluid power unit, a conventional relay unit or the like. Although the invention has been illustrated with negative feedback, specific applications such as switching systems may desirably employ positive feedback.

Various modes of carrying out the invention are contemplated as being within the scope of the following claims particularly pointing out and distinctly claiming the subject matter which is regarded as the invention.

I claim:

1. In a universal fluid amplifier, a summing impact modulator having a pair of opposed and spaced nozzle means having orifice means for defining impacting controllable signal streams within a control orifice means mounted therebetween, said signal streams and said control orifice being selected such that no significant pressure drop occurs in the nozzle orifice means, said control orifice means forming a part of a reference chamber to one side thereof and an output chamber to the opposite side thereof, input signal restrictor means connected to said nozzle means to selectively modulate the streams to both said nozzle means and thereby modulate the output of the summing impact modulator, a fluid amplifier having a fluid input terminal connected to the output chamber and having a fluid output terminal, and a feedback means connected to the fluid output terminal and to the nozzle means to produce negative feedback.
2. In a universal fluid amplifier, a summing impact modulator having a pair of opposed and spaced nozzle means having orifice means for defining impacting controllable signal streams within a control orifice means mounted therebetween, said control orifice means forming a part of a reference chamber to one side thereof and an output chamber to the opposite side thereof, input signal restrictor means connected to said nozzle means to selectively modulate the streams to both said nozzle means and thereby modulate the output of the summing impact modulator, a fluid amplifier having a fluid input terminal connected to the output chamber and having a fluid output terminal, and a feedback means connected to the fluid output terminal and to the nozzle means to produce negative feedback.
3. In a universal fluid amplifier, a pair of opposed and spaced nozzle means with nozzle orifice means for defining impacting signal streams

- within a control orifice means mounted therebetween, said signal streams being selected such that the total flow cannot establish an appreciable pressure drop across the corresponding nozzle orifice means, said control orifice means defining a pair of chambers to opposite sides of the orifice with the nozzle means terminating therein and one of said chambers constituting an output chamber,
- input signal restrictor means connected to said nozzle means for selectively modulating the streams to both said nozzle means,
- a fluid amplifier having a fluid input terminal connected to the output chamber and having a fluid output terminal, and
- a feedback means connected to the fluid output terminal and to the nozzle means to produce negative feedback.
4. In a universal fluid amplifier,
- a pair of opposed and spaced nozzle means having nozzle orifice means for defining impacting signal streams within a control orifice means mounted therebetween, said signal streams being selected such that the flow through the corresponding nozzle orifice means is incapable of producing a noticeable pressure drop, said control orifice means forming a part of a reference chamber to one side thereof and an output chamber to the opposite side thereof,
- input signal restrictor means connected to said nozzle means to selectively modulate the streams to both said nozzle means,
- a fluid amplifier having a fluid input terminal connected to the output chamber and having a fluid output terminal,
- a feedback means connected to the fluid output terminal and to the nozzle means to produce negative feedback,
- a positive feedback means connected to the fluid output terminal and to the input restrictor means to produce positive feedback, and
- an integrating restrictor means and fluid capacitor means connected in common to the positive feedback means and the corresponding input restrictor means.
5. In a universal fluid amplifier,
- a pair of opposed and spaced nozzle means for defining impacting signal streams within a control orifice means mounted therebetween, said control orifice means forming a part of a reference chamber to one side thereof and an output chamber to the opposite side thereof,
- input signal restrictor means at least one of which is connected to a first of said nozzle means and a second of which is connected to a second of the nozzle means,
- a fluid amplifier having a fluid input terminal connected to the output chamber and having a fluid output terminal,
- a feedback means connected to the fluid output terminal and to the nozzle means to produce negative feedback,
- means connecting the first and second input restrictor means to a common input signal source, and
- a fluid capacitor connected to the negative gain nozzle means.
6. In a universal fluid amplifier,
- a summing impact modulator having a pair of opposed nozzle means for defining impacting streams within a control orifice means mounted therebetween, said control orifice means forming a part of a reference chamber to one side thereof within which one nozzle means terminates and an output chamber to the opposite side thereof within which the other nozzle means terminates,
- a plurality of cascaded transverse impact modulators connected to the output chamber and producing an amplified output signal,

- a fluid power amplifier connected to the output of said cascaded transverse impact modulators having an output means, and
- a feedback restrictor means connected between the output of the power amplifier and the nozzle means of the summing impact modulator to produce a negative feedback.
7. The universal fluid amplifier of claim 6 having a first plurality of input restrictors having separate input connections for different signals and connected to the first nozzle means and a second plurality of input restrictors connected to the second nozzle means.
8. The universal fluid amplifier of claim 7 wherein at least one of each of said pluralities of restrictors is variable to permit calibration of the amplifier.
9. In a universal fluid amplifier,
- a summing impact modulator having a pair of opposed nozzle means for defining impacting streams within control orifice means mounted therebetween, said control orifice means forming a part of a reference chamber to one side thereof and an output chamber to the opposite side thereof,
- a plurality of cascaded transverse impact modulators connected to the output chamber and producing an amplified output signal,
- a pair of paralleled transverse impact modulators connected to the output of said cascaded transverse impact modulators and producing an operating output signal, and
- a feedback restrictor means connected between the output of the paralleled transverse impact modulators and one of the nozzle means of the summing impact modulator to provide a negative feedback.
10. In a universal fluid amplifier unit,
- a summing impact modulator having a pair of opposed nozzle means for defining impacting signal streams within control orifice means mounted therebetween, said control orifice means forming a part of a reference chamber to one side thereof and an output chamber to the opposite side thereof,
- a fluid amplifier connected to the output chamber and having an output terminal means for producing an amplified output signal,
- a pneumatic relay having a low signal input connection to the output terminal of the fluid amplifier and a high pressure output line, and
- a feedback restrictor connected to the output line and to the nozzle means of the summing impact modulator to create negative feedback.
11. The universal fluid amplifier unit of claim 10 wherein said fluid amplifier includes a plurality of cascaded transverse impact modulators connected to the output chamber and producing an amplified output signal.
12. In a universal fluid amplifier,
- a summing impact modulator having a pair of opposed nozzle means for defining impacting signal streams within control orifice means mounted therebetween, said control orifice means defining a pair of similar chambers to the opposite side of the orifice means within which the nozzle means terminate and one of said chambers having an output connection means, a plurality of paralleled input restrictors having a common end to produce a total signal which is the sum of the input individual signals,
- coupling means to selectively connect the common end to said nozzle means to form one of said streams,
- a calibrating restrictor,
- coupling means to selectively connect the opposite nozzle to the calibrating restrictor to produce the other of said streams,
- a fluid amplifier connected to the output connection means of the summing impact modulator, and
- a feedback restrictor means connected to the output of the amplifier and to the nozzle means of the summing impact modulator to provide negative feedback.

17

13. The universal fluid amplifier of claim 12 wherein said coupling means are interconnected to simultaneously reversely connect the restrictors to the nozzle means.

14. In a universal fluid amplifier,
a summing impact modulator having a pair of opposed 5
nozzle means for defining impacting streams within
control orifice means mounted therebetween, said
control orifice means defining a pair of similar cham-
bers to the opposite side thereof within which the
nozzle means terminate and one of said chambers 10
having an output connection means,
a plurality of paralleled input restrictors having a com-
mon end to produce a total signal which is the sum
of the individual signals,
means to selectively connect the common end to said 15
nozzle means to form one of said streams,
a calibrating restrictor,
means to selectively connect the opposite nozzle to the
calibrating restrictor to produce the other of said
streams, 20
a fluid amplifier connected to the output connection
means of the summing impact modulator,
a pneumatic relay having an input connected to the
output of the fluid amplifier and having an output
means, and 25
a feedback restrictor connected to the output means of
the pneumatic relay and to the nozzle means of the
summing impact modulator to produce negative
feedback.

15. In a control system, 30
a summing impact modulator having a pair of opposed
and spaced nozzle means with a control orifice means
mounted therebetween and defining a pair of cham-
bers within which the nozzle means terminates, one
of which constitutes a reference chamber and the 35
other of which constitutes an output chamber,
a plurality of input restrictor means having separate
input connections for different signals and connected
to the nozzle means,
a high gain fluid amplifier means connected to the out- 40
put chamber and having an output means,
a feedback restrictor means connected to the output
means and to the nozzle means to produce negative
feedback,
a pneumatic actuator connected to the output means to 45
regulate a load,
a load sensing means for establishing a fluid signal re-
lated to predetermined load conditions, and
means connecting said load sensing means to the one
of said input restrictors to provide negative feedback. 50

16. The control system of claim 15 including a plu-

18

rality of preselected fluid signal sources connected to others of the plurality of input restrictors.

17. A summing impact modulator comprising,
a pair of opposed nozzles terminating in spaced rela-
tion within an enclosure and defining a pair of im-
pacting streams,
a dividing wall within the enclosure spanning the gap
between the nozzles and having a control orifice
aligned with the nozzles, said wall defining similar
confining chambers to selectively constitute a ref-
erence chamber and an output chamber,
passageway means connected to said respective cham-
bers for establishing a reference pressure within the
reference chamber and for sensing an output pressure
in the pressure chamber, and
input flow means connected to said nozzles each ter-
minating in a nozzle orifice and including flow re-
strictors reducing the pressure and flow of the signal
through the corresponding nozzle such that the total
flow through the nozzle orifices cannot produce a
significant pressure drop relative to the reference
pressure.

18. An impact modulator for operation with a plural-
ity of predetermined inputs comprising,
a pair of opposed nozzle means having orifices for de-
fining a pair of impacting streams, said orifices being
selected such that the total flow of all input flows of
said predetermined inputs is insufficient to develop a
significant pressure drop through the orifice,
an enclosure concentrically secured to the nozzles to
enclose said streams and having a central dividing
wall with a control orifice aligned with the impact-
ing streams, said wall defining essentially identical
chambers to selectively constitute a reference cham-
ber and an output chamber, said wall being symmetri-
cally tapered outwardly from a sharp edge at the
orifice, and
passageway means connected to said respective cham-
bers for establishing a reference pressure within the
reference chamber and for sensing an output in the
output chamber.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,388,713

June 18, 1968

Bjorn Gerhard Bjornsen

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 6, line 36, "benefically" should read -- beneficially --; line 60, "means" should read -- mean --; line 66, "etch" should read -- each --. Column 7, line 2, "means" should read -- mean --; line 36, "The" should read -- This --. Column 12, line 69, "resistor" should read -- restrictor --. Column 13, line 37, "embodiments" should read -- embodiment --. Column 14, line 17, "designated" should read -- designed --. Column 18, line 40, after "output" insert -- pressure --.

Signed and sealed this 2nd day of December 1969.

(SEAL)

Attest:

Edward M. Fletcher, Jr.

Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents