

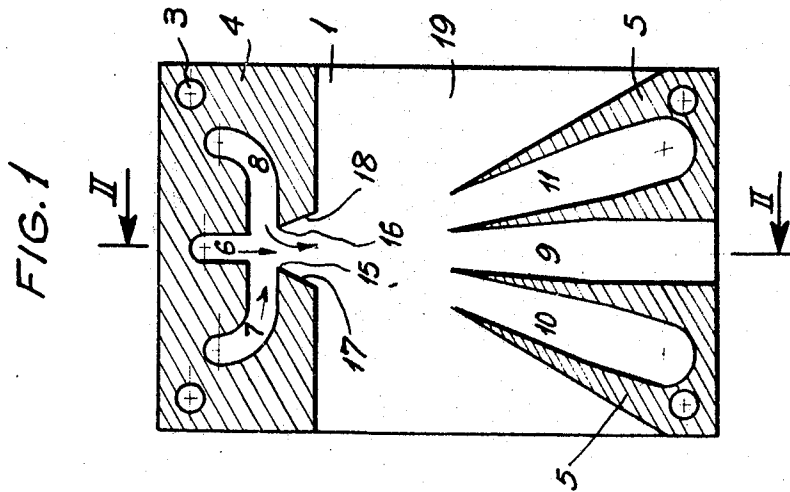
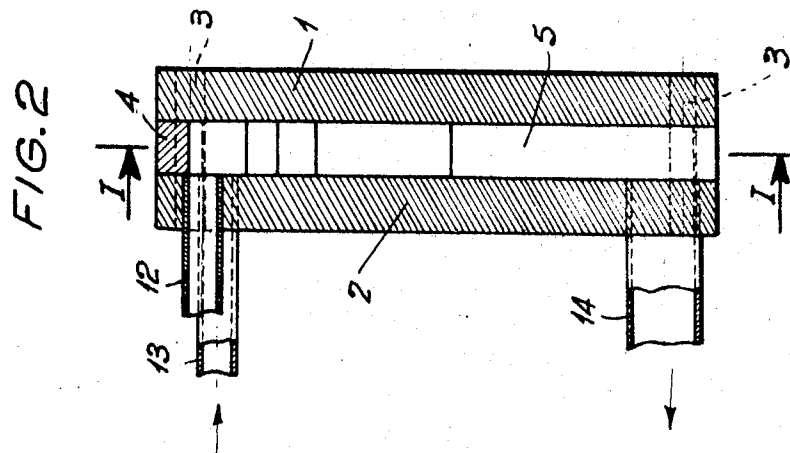
July 22, 1969

C. F. PAVLIN
FLUID AMPLIFIERS

3,456,665

Filed Oct. 21, 1965

8 Sheets-Sheet 1



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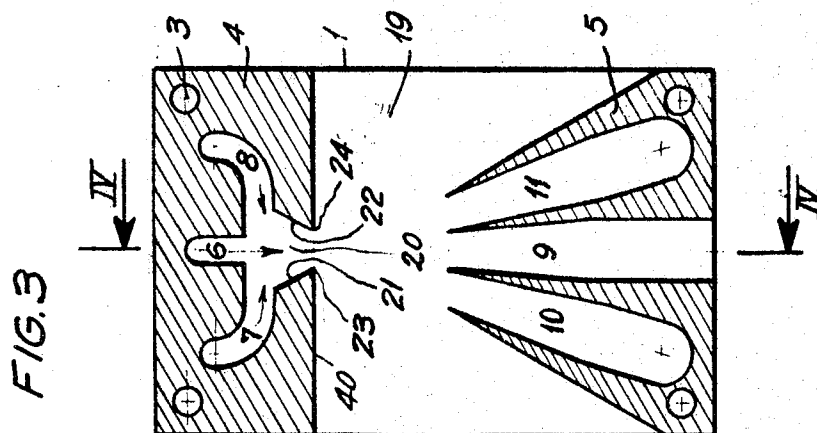
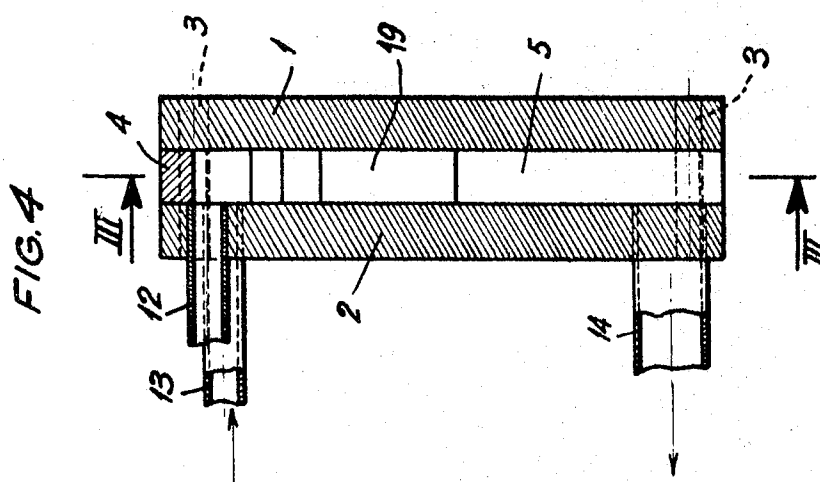
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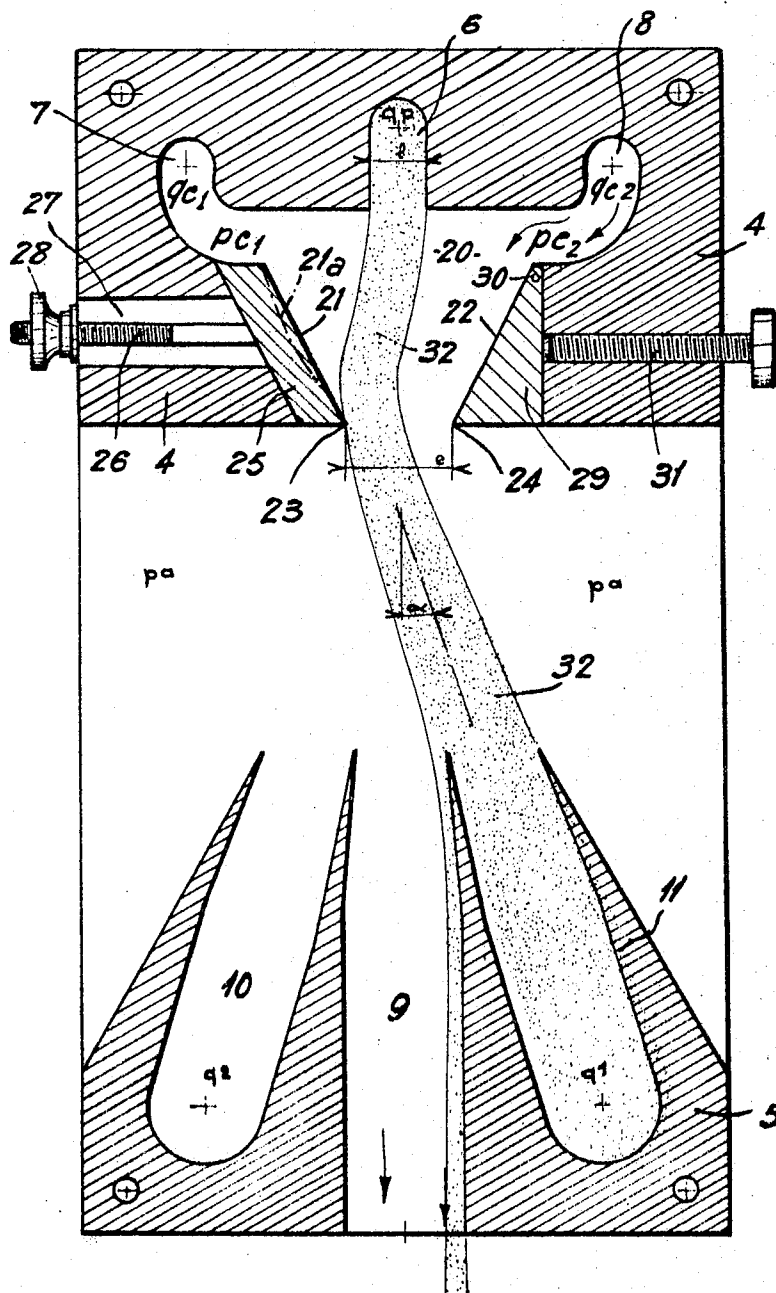
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8 Sheets-Sheet 3

FIG. 5



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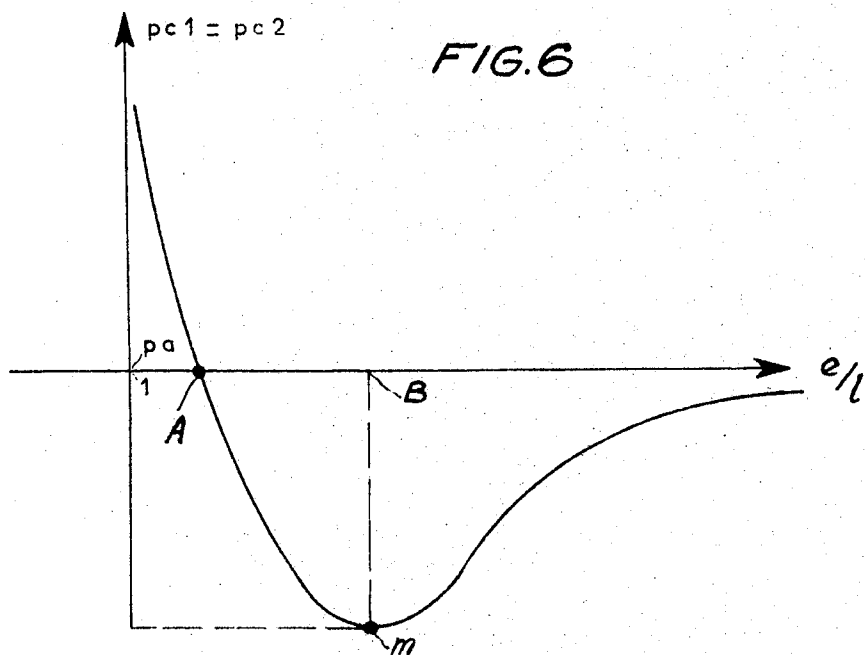
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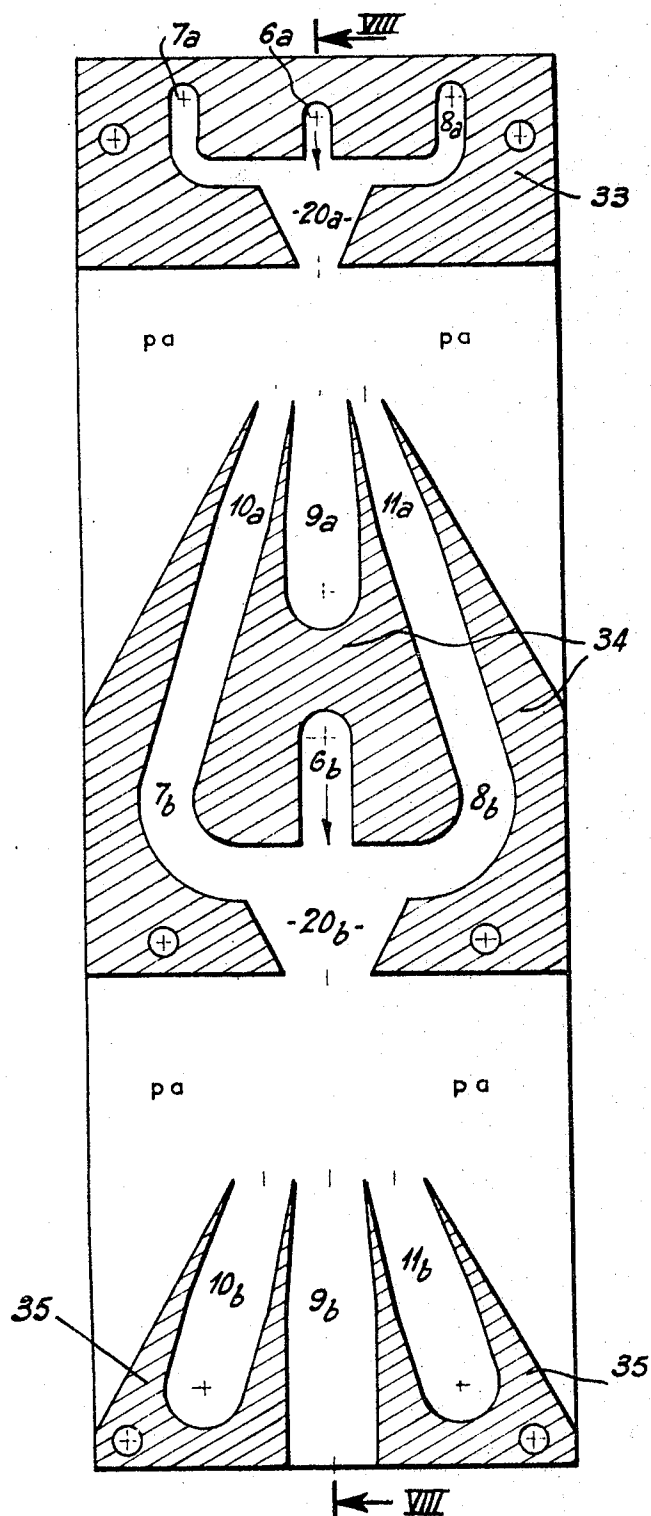
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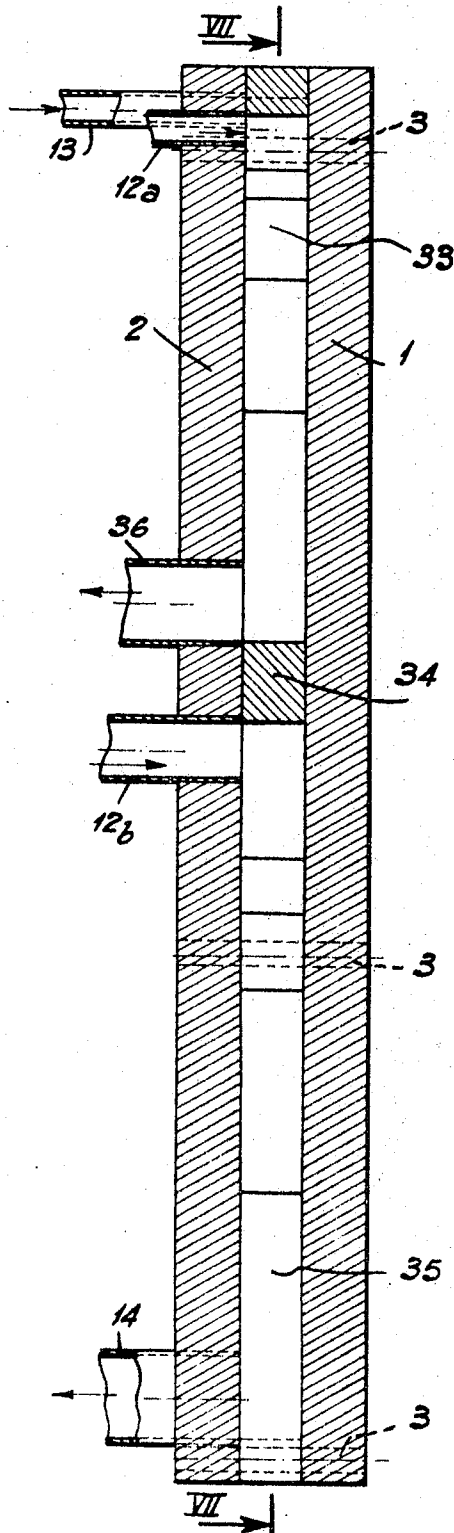
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8 Sheets-Sheet 7

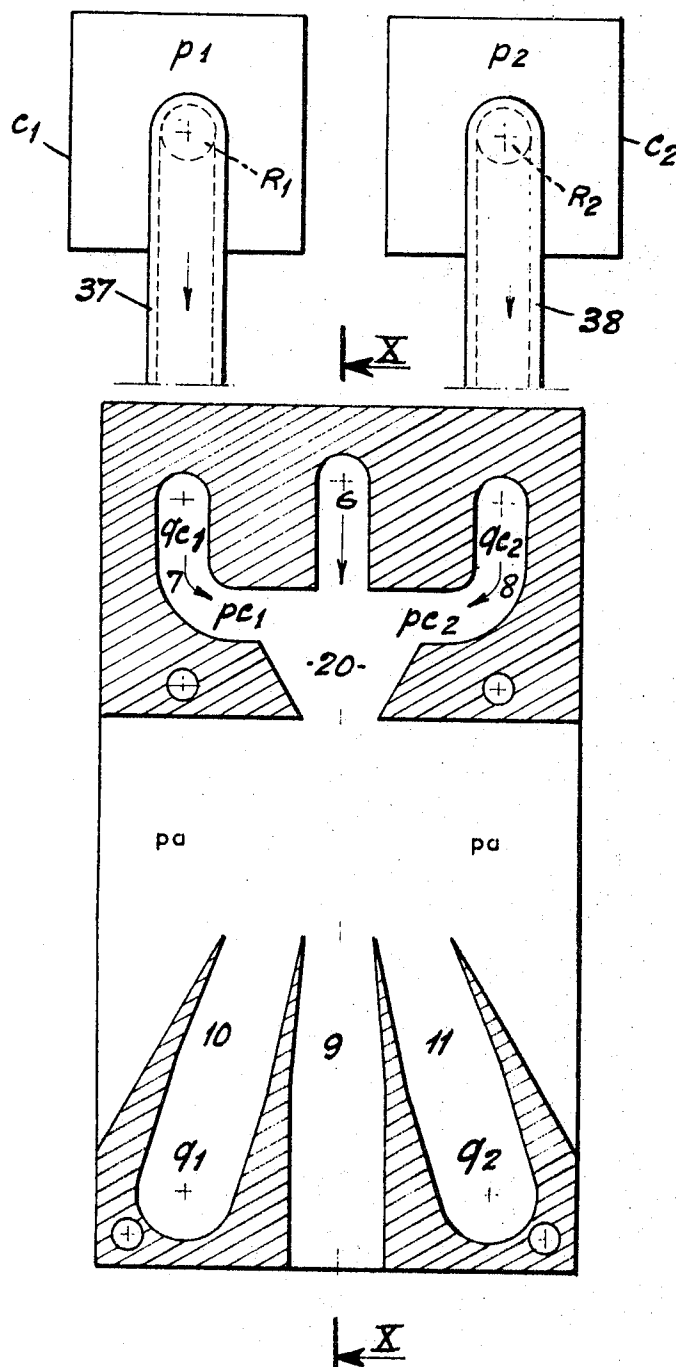


FIG. 9

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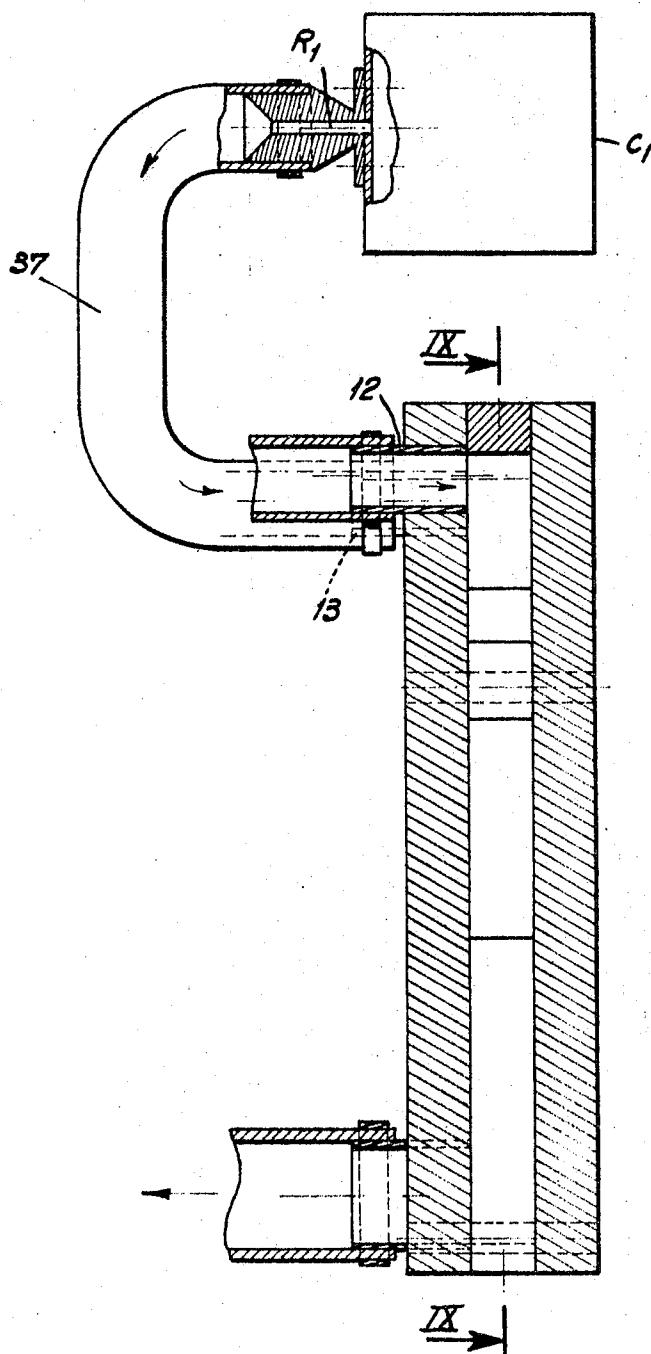
C. F. PAVLIN
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FIG. 10



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FLUID AMPLIFIERS

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9 Claims

ABSTRACT OF THE DISCLOSURE

A fluid amplifier of the jet deflection type, in which the power jet issues from an inlet port into a central chamber, which chamber is defined by an upstream transverse wall in which said inlet port opens, and lateral walls extending downstream from the respective ends of said transverse wall and converging downstream and ending with relatively sharp free edges spaced from each other, said edges defining the sides of a discharge orifice. The inlet port is disposed substantially centrally of the upstream transverse wall wherefore the power jet defines two separate spaces in the central chamber. At least one control jet inlet is provided into at least one of said two separate spaces to increase the pressure therein whereby the power jet is displaced toward the side wall bounding the other space and is reflected by the last-mentioned side wall before issuing from the discharge orifice defined by said sharp edges.

As is well-known, a fluid amplifier essentially comprises a power stream which is normally directed towards a central exhaust or vent outlet and can be diverted toward a selected one of a set of lateral outlets, by the effect of control jets which may be projected laterally against the power stream as it issues out of its inlet nozzle. The deflection of the power stream is produced by the difference in linear momentum of the control jets. When this difference is zero, substantially the whole of the power stream passes through the central exhaust outlet; as the difference in momentum increases in one or the other sense, a correspondingly large proportion of the fluid issues through one or the other of the side outlets.

FIGS. 1 and 2 of the attached drawings schematically illustrate a fluid amplifier of conventional type. FIG. 1 is a section on line I—I of FIG. 2 and FIG. 2 is a section on line II—II of FIG. 1.

The fluid amplifier comprises a pair of flanges 1 and 2 connected by means of screws 3 on opposite sides of spacer blocks 4 and 5. The spacer block 4 is formed with cutouts defining a power inlet channel 6 from which the power stream issues and two side channels 7 and 8 for the control jets, while block 5 is formed with cutouts defining a central exhaust outlet 9 and side outlets 10 and 11.

The channels 6, 7 and 8 and the outlets 10 and 11 are respectively connected to input and output tubes 12, 13 and 14 (FIG. 2). The outlet 9 is vented to the atmosphere in this embodiment.

As clearly shown in FIG. 1, the side channels 7 and 8 are defined by sharp edges 15 and 16 at their ends adjacent to the channel 6 and positioned downstream with

2

respect to the power stream, said sharp edges being followed by diverging surfaces 17 and 18 formed in the spacer block 4. The angle of divergence of the wall faces 17 and 18 has always been selected quite large in order to prevent the power stream from locking on to either of said faces.

The spacing between the edges 15 and 16 is greater than the width of the outlet of power channel 6. If the momentum of the control jet issuing from channel 7 predominates over the momentum of the jet from channel 8, the power stream is deflected rightward (as shown in FIG. 1) and hence tends to issue through outlet 11. In the reverse case the stream would tend to issue from outlet 10.

Thus the power stream is deflected away from the predominant control jet. It retains the direction imparted to it within the constant-pressure zone 19, here shown as vented to atmosphere, situated between the spacer blocks 4 and 5.

The channels 6, 7 and 8 are formed with rectangular cross sections wherein the height dimension is preferably at least twice as large as the width, so that the jets can be regarded as substantially bidimensional or flat. The central exhaust outlet has a width such that most or all of the power stream will pass through it in the absence of a difference between the momentum of the control jets. The side outlets are separated from the central exhaust outlet by thin edges which will sharply divide the power stream. Said outlets diverge slightly to provide for an optimal re-compression of the portions of the power stream flowing therethrough.

Essential objects of the present invention are to provide improvements in fluid amplifiers of the type specified, in the following chief respects:

- 35 Increase the amplification or flow gain-factor;
- Make it possible to match the input or control pressure level with a preselected value whereby to facilitate the serial interconnection of a plurality of fluid amplifier stages;
- 40 Provide fluid-amplifier apparatus possessing good linearity over a wide range of output flow values;
- Improve stability; and
- Ensure satisfactory frequency-response.

With the above objects in view an improved fluid amplifier according to the invention may include a chamber connected with the power stream channel and also having the control jets opening into it, said chamber having converging wall surfaces at its downstream end defining an exit passage for the power stream.

The converging wall surfaces may be flat or arcuate. The wall surfaces desirably are formed at their outlet ends with sharp edges or at any rate with portions of relatively small curvature radius to prevent tendency to stream locking.

The wall surfaces may be made adjustable in angle and/or position.

The presence of such converging wall surfaces on opposite sides of the power stream profoundly modifies the operation of the fluid amplifier. Whenever the action of one of the control jets predominates over that of the other, the power stream is first deflected toward the wall opposite the predominating control jet, but is then reflected back from said wall toward the side outlet positioned on the same side as the predominant control channel. The resulting assembly behaves approximately after the fashion of

an aerodynamical lever device, resulting inter alia in a considerable improvement both in the flow gain and in linearity.

The edges of the wall surfaces defining the limits of the chamber may be provided very close to the outgoing power stream so that the flow section area provided for the stream may be greatly restricted. For this reason the apparatus according to the invention will retain high performance characteristics even when all of its dimensions are greatly reduced. In prior-art efforts to miniaturize fluid amplifier equipment, difficulty has been encountered in retaining adequate values of momentum for the fluid jets because of the relatively increased influence assumed by viscosity effects. In this connection an important advantage of the invention is that it takes advantage of viscosity effects occurring in the reflection of the deflected power stream from the converging wall surfaces, to overcome the above limitation.

Exemplary embodiments of the invention will now be disclosed for purposes of illustration but not limitation with reference to the accompanying drawings, wherein:

FIGS. 3 and 4 are views similar to the prior-art FIGS. 1 and 2 earlier referred to, but illustrating a modified fluid amplifier device constructed according to the invention.

FIG. 5 is a large-scale view generally similar to FIG. 3 but showing certain modified features of the invention;

FIG. 6 is a graph wherein the pressure in the control channels at zero control flow is plotted against the ratio of chamber width to power inlet channel width;

FIGS. 7 and 8 are views generally similar to FIGS. 1 and 2 respectively, relating to a two-stage fluid amplifier according to the invention;

FIGS. 9 and 10 are further views generally similar to FIGS. 1 and 2 illustrating a fluid amplifier device according to the invention connected for operation as a pressure detector device.

The exemplary embodiment of the invention shown in FIGS. 3 and 4, includes the same basic components already described with reference to the conventional device of FIGS. 1 and 2, and designated with similar reference numerals.

An essential difference over the conventional device, however, lies in the fact that the power channel 6 opens into a central chamber 20, into which the control channels 7 and 8 also deliver. Chamber 20 is defined by an upstream transverse wall 40 and by converging lateral wall surfaces 21 and 22 symmetrically related with respect to the medial plane of the apparatus and which terminate at their downstream ends with sharp edges 23 and 24.

The said wall surfaces may be planar, or they may be curved as shown by way of example in chain lines at 21a in FIG. 5. They may be fixed or they may be adjustable. On the left side of FIG. 5 a first modification is illustrated wherein the wall surface 21 or 21a is part of a block 25 secured to a threaded rod 26 extending through an elongated port 27 formed in spacer block 4. A nut 28 threaded on rod 26 allows the block 25 to be adjusted in position so as to move the edge 23 of wall surface 21 toward and away from the midplane of the apparatus and thereby adjust the width of the outlet orifice of chamber 20.

The right side of FIG. 5 illustrates another modification wherein the wall surface 22 forms part of a vane-like member 29 hinged on a pivot 30 and displaceable by actuation of an adjusting screw 31 threaded through a hole in spacer block 4 for purposes similar to those above described.

The operation of the fluid amplifier is simple.

If the flow rates qc_1 and qc_2 of the jets in both control channels 7 and 8 are equal, the power stream 32 is not deflected and all or most of it flows out through central exhaust outlet 9.

Any increase in the flow through one of the control channels, such as an increase in the flow qc_2 through channel 8, first causes a deflection of jet 32 towards the opposite wall surface 21 and this wall surface then reflects the

power stream back towards the side at which the control flow was increased, as shown in FIG. 5. The net effect is therefore seen to be the reverse from what occurs in the conventional apparatus of FIGS. 1 and 2. The improved fluid amplifier of the invention generates a so-called aerodynamical lever effect, which results in a substantially greater amount of deflection for a given value of the difference between control jet momenta. Thus, it becomes possible for example to obtain flow variations in the outlet conduits or channels 10 and 11 within a range of from 0 to 100% with respect to the main or power flow rate, with the flow gain factors varying over a range of 10:1 to 100:1 and remaining comparatively constant.

Remarkably, it is found that the pressures pc_1 and pc_2 in the control channels vary relatively little when the control flow rates qc_1 and qc_2 are varied and the difference $pc_1 - pc_2$ between them remains extremely small. This can be ascribed to the fact that any pressure variations as between the two sides of the chamber 20 separated by the power stream 32, tend to cancel out as a result of the dual curvature assumed by the power stream.

A further remarkable feature of the improved fluid amplifier device of the invention is that with zero control flow, that is with both channels 7 and 8 cut off in this example, the pressures pc_1 and pc_2 can be adjusted to values that may be higher than, equal to or lower than the ambient pressure, in this instance, atmospheric pressure. Such adjustments can conveniently be made by modifying the width of the space between the edges 23 and 24 of the exit passage from chamber 20.

FIG. 6 illustrates the variations of $pc_1 = pc_2$ against the ration e/l (where e is the width of the passage between 23 and 24 and l is the width of the power inlet channel), with both flow rates qc_1 and qc_2 being zero.

It is seen that when e/l is less than a critical value A greater than unity and depending on the specific characteristics of the system used, the control pressure is greater than atmospheric pressure pa . The device then tends to discharge through the control nozzles.

For $e/l = A$, the control pressure equals the ambient pressure.

As e/l exceeds A the control pressure first falls off until it reaches a minimum m for a value B of said ratio, then rises slowly as the edges 23 and 24 are moved further away from each other until it gradually approaches atmospheric pressure.

The possibilities for adjustment thus made evident are of great interest. In the first place, it becomes possible to couple a plurality of fluid amplifier devices in series with the output stream from one stage serving as the control jet in the next. Such a multistage coupling provides a power multiplication effect which can only operate in a fully precise manner if the zero-flow control pressure in one stage exactly equals the ambient pressure in the preceding stage. Otherwise the control channel that is not supplied with fluid from the preceding stage would draw in or discharge fluid from or into the outlet channel supplying it.

For such an application, the ratio e/l would be adjusted in each of the appropriate stage or stages at the critical value A .

As another possibility, in those applications where the apparatus is to detect and amplify fluid pressures in one or more enclosures, it may be desirable to maintain a certain degree of negative pressure in the control channels, thereby making it possible to connect the apparatus differentially with two enclosures at different pressures p_1 and p_2 . In such a case, the ratio e/l would be adjusted to a value preferably within the range from A to B .

FIGS. 7 and 8 illustrate a two-stage fluid amplifier device according to the invention wherein the parallel walls 1 and 2 have three spacer blocks interposed between them. In one spacer 33 are formed the input channels 6a, 7a, 8a of a first stage including a chamber 20a; a second spacer 34 includes the central exhaust 9a

and the side outlets 10a and 11a from the first stage as well as the power inlet 6b, control inlets 7b and 8b connected with the first-stage outlets 10a and 11a, and the chamber 20b of the second stage; and the third spacer block 35 provides the central exhaust 9b and side outlets 10b and 11b from the second stage (see FIG. 7).

The power inlets 6a and 6b are supplied with fluid through nozzles 12a, 12b, the first-stage control inlets are supplied through nozzles 13; the primary exhaust is connected with an exhaust nozzle 36 and the secondary outlets are connected with outlet nozzles 14 (FIG. 8).

FIGS. 9 and 10 illustrate an application of the invention to pressure detection.

In this example the nozzles 13 connected with the control channels 7 and 8 are respectively connected with the capacities C_1 and C_2 wherein pressures p_1 and p_2 obtain, by way of pipes 37, 38 and connectors R_1 , R_2 which embody pneumatic resistance.

If the values of said resistance are high, i.e. the connectors have narrow flow section areas, the device will detect the pressure level in one container, p_1 or p_2 , with respect to the other pressure serving as a reference.

If on the other hand the resistance values are low, the device will only respond to the difference $p_1 - p_2$ and will be capable of detecting small pressure differentials.

In either case the difference between the flow rates from the amplifier is a function of the difference between the pressures p_1 and p_2 and can accordingly be used as a pressure feedback control.

Generally speaking the time constant of the fluid amplifier is the resultant of a number of elementary time constants including propagation time of the control jet flows qc_1 and qc_2 , time required to establish a steady flow pattern in chamber 20, fluid transit time through the outlet orifices, and the like. A reference velocity for all the phenomena involved is the velocity of sound, and accordingly the over-all time constant is comparatively short, being on the order of one millisecond.

What I claim is:

1. A fluid amplifier comprising:

- (a) a central chamber (20) provided with
- (b) an inlet (6) to deliver a power jet (32) into said central chamber, said power jet defining two separate spaces in said chamber;
- (c) said chamber being bounded by
 - (1) an upstream transverse wall in which said inlet port opens and which has a substantial extent with respect to the width of said port;
 - (2) and partly by two opposite jet reflecting sidewalls (21, 22) extending downstream of said upstream transverse wall, converging downstream, each of said walls being shaped in the form of an acute angle defining relatively sharp free edges (23, 24) for preventing stream attachment with said sidewalls, said edges being spaced from each other and defining partly a discharge orifice;
- (d) said inlet port being arranged in said upstream transverse wall in laterally spaced relationship with respect to the upstream ends of said downstream converging sidewalls;
- (e) and at least one aperture (7 or 8) to admit pressure fluid into one of said two separate spaces to increase the pressure therein;
- (f) whereby said power jet is displaced by the increase of pressure in one of said two spaces toward the sidewall bounding the other space and is reflected by the sharp edge of the last mentioned sidewall in the direction of said one of said two spaces before issuing from said discharge orifice.

2. A fluid amplifier as claimed in claim 1 further comprising a duct (9) having an inlet spaced from said free edges and designed to admit at least a part of said power

jet when the direction of the latter remains unchanged in said central chamber.

3. A fluid amplifier as claimed in claim 1 further comprising at least one duct (10 or 11) having an inlet spaced from said free edges and designed to admit at least a part of said power jet when reflected by one of said sidewalls.

4. A fluid amplifier as claimed in claim 1 further comprising means to vary the distance between said free edges, the angular setting of said sidewalls remaining unchanged.

5. A fluid amplifier as claimed in claim 1 further comprising means to vary the angular setting of at least one of said sidewalls.

6. The combination defined in claim 1, wherein the spacing between the outlet ends of said wall surfaces is so determined in relation to the width of said power stream inlet that the pressure in the control inlets in the absence of control jets is substantially lower than the ambient pressure into which said power stream exhausts.

7. The combination defined in claim 1, further including a pair of different pressure sources and means connecting the respective sources with respective ones of said control jet inlets for indication by said device of the difference between said pressures; and wherein the spacing between the outlet ends of said wall surfaces is so determined in relation to the width of said power stream inlet that the pressure in the control inlets in the absence of control jets therein is substantially lower than the ambient pressure into which said power stream exhausts.

8. The combination defined in claim 7, including fluid resistance means interposed in said connecting means.

9. In a multistage fluid amplifier apparatus wherein each stage includes a power stream inlet; a plurality of power stream outlets; control jet inlets positioned to direct control jets at opposite sides of the power stream adjacent said inlet thereof so as to selectively direct the power stream into a corresponding one of said outlets; and wherein said power stream outlets of at least one of said stages are connected to supply fluid to control jet inlets of a next following stage; the improvement consisting in that each stage includes:

- (a) a central chamber (20) provided with
- (b) an inlet (6) to deliver a power jet (32) into said central chamber, said power jet defining two separate spaces in said chamber;
- (c) said chamber being bounded by
 - (1) an upstream transverse wall in which said inlet port opens and which has a substantial extent with respect to the width of said port;
 - (2) and partly by two opposite jet reflecting sidewalls (21, 22) extending downstream of said upstream transverse wall, converging downstream, each of said walls being shaped in the form of an acute angle defining relatively sharp free edges (23, 24) for preventing stream attachment with said sidewalls, said edges being spaced from each other and defining partly a discharge orifice;
- (d) said inlet port being arranged in said upstream transverse wall in laterally spaced relationship with respect to the upstream ends of said downstream converging sidewalls;
- (e) and at least one aperture (7 or 8) to admit pressure fluid into one of said two separate spaces to increase the pressure therein;
- (f) whereby said power jet is displaced by the increase of pressure in one of said two spaces toward the sidewall bounding the other space and is reflected by the sharp edge of the last mentioned sidewall in the direction of said one of said two spaces before issuing from said discharge orifice;
- (g) the spacing between the downstream edges of said reflective wall surfaces of each stage being so adjusted in relation to the width of said power inlet of such stage that the pressure in the control inlets of

each succeeding stage, in the absence of control jets therein, is substantially equal to the exhaust pressure of the preceding stage.

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