Nov. 8, 1966 C. P. WRIGHT 3,283,767

JET FLUID AMPLIFIER

Filed May 31, 1963

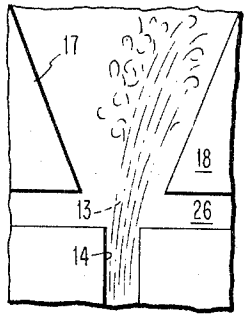


FIG. 2

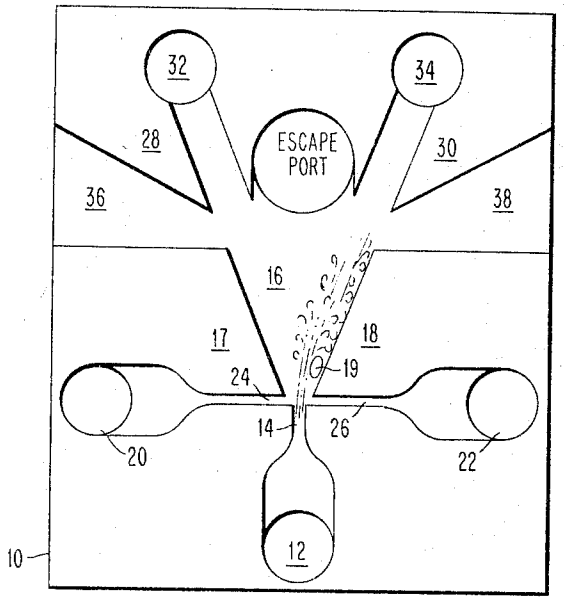


FIG. 1

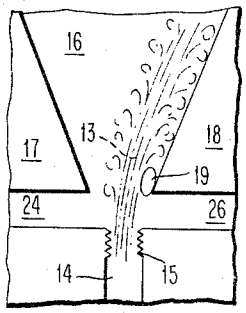


FIG. 3

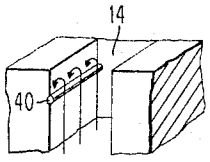


FIG. 4

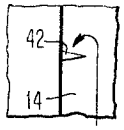


FIG. 5

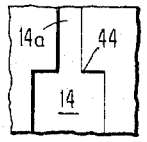
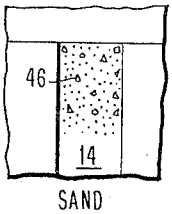
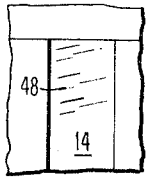


FIG. 6



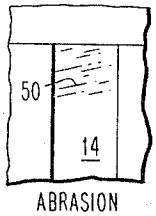
SAND

FIG. 7



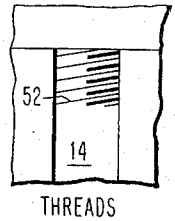
MACHINING

FIG. 8



ABRASION

FIG. 9



THREADS

FIG. 10

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JET FLUID AMPLIFIER

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4 Claims. (Cl. 137—81.5)

The present invention relates generally to fluid logic and it has reference in particular to pure fluid jet amplifiers.

Fluid switches, amplifiers and the like have been developed wherein all mechanical elements are eliminated and a fluid stream to be called the "power stream" is switched to one or the other of two or more outlets by directing the flow of one or more low energy streams of the same fluid known as "control streams" transversely against the power stream. This method of control permits small, low-pressure control streams to direct the path of a high energy power stream. By utilizing a setback in the power stream channel wall in the region of the control streams, the deflected power stream is caused to more positively lock on to the wall of the channel to which it is deflected and remain there even though the deflecting control stream is discontinued. However, this type of operation is closely dependent on the pressure of the source of the power stream, and below Reynolds numbers in a predetermined range, positive lock-on of the switched stream after the controlled stream is discontinued cannot be always relied upon, because the stream will attach only if turbulent and the critical point of turbulence can vary over a wide range of Reynolds numbers dependent upon pressure surges.

Generally stated, it is an object of the present invention to provide an improved and more reliable jet fluid amplifier.

More specifically, it is the object of the present invention to provide in a pure fluid amplifier for facilitating transition of the flow in outer layers of the jet stream from laminar to turbulent further upstream or sooner, so as to permit reliable proper switching action at lower values of supply pressures that may be lower than usual to reduce the power requirements of the device.

It is an important object of this invention to provide for using means such as surface irregularities in the nozzle of a power stream for generating a turbulent boundary layer in the power jet stream prior to acting on it with a control jet, so that the control jet is more effective and turbulent reattachment of the power stream may be effected at a lower than usual value of Reynolds number.

Another object of this invention is to provide for introducing a sharp protrusion at the edge of a power stream immediately prior to acting on it by a control stream, so as to facilitate turbulent reattachment of the main stream under lower supply pressure conditions than are otherwise possible.

Yet another object of the invention is to provide for roughening the walls of a supply passage or nozzle in a jet fluid amplifier ahead of a control port so as to facilitate switching the power stream by producing turbulent flow of the power stream sooner or further upstream than otherwise possible.

It is also an object of the invention to provide in a fluid amplifier for using corrugations in the supply or inlet nozzle of a main stream ahead of a control nozzle to induce turbulence and make switching of the main stream by a control stream less critical.

Another important object of the invention is to provide for using random surface irregularities in an inlet port of a main or power jet just ahead of a control port in a fluid amplifier for generating a turbulent boundary layer in the main jet and facilitating proper switching of a main jet at much lower supply pressures than usual.

It is furthermore an imporant object of this invention to provide for using mechanical means for producing turbulent reattachment of a power stream in a fluid device with the use of less setback and at a lower Reynolds number than heretofore considered possible.

Yet another object of the present invention is to provide for improving and making more reliable the operation of fluid amplifiers at low supply pressures.

The foregoing and other objects, features and advantages of the invention will be apparent from the following and more particular description of the preferred embodiments of the invention as illustrated in the accompanying drawings.

In the drawings:

FIG. 1 is a plan view of a pure fluid amplifier of the general type previously proposed;

FIG. 2 is an enlarged partial plan view of the amplifier of FIG. 1 showing the transition of a laminar jet stream to turbulent flow under low pressure conditions;

FIG. 3 is an enlarged partial plan view of a control amplifier modified in accordance with the invention to show the turbulence effect of corrugations in the throat on the power stream flow under low pressure conditions;

The following FIGURES 4–10 illustrate different modifications of the invention as disclosed in FIG. 3;

FIG. 4 is a partial isometric view of a portion of the throat wall incorporating the use of a trip wire on the wall for producing turbulence;

FIG. 5 is a diagrammatic representation of a portion of the wall in the throat of the main nozzle illustrating the use of spikes of sharp protrusions to produce eddies in the boundary layer, which propagate turbulence;

FIG. 6 is a diagrammatic representation of a throat nozzle illustrating the use of a suddent constriction to produce eddies;

FIG. 7 is a diagrammatic showing of a portion of the throat surface illustrating the use of particles of sand or the like to produce eddies;

FIG. 8 is a diagrammatic representation of a portion of a throat showing the use of machined marks on the surface of the throat;

FIG. 9 is a diagrammatic representation of a portion of a throat showing the use of the abrasions or scratches in the throat for producing eddies; and,

FIG. 10 is a diagrammatic representation of a portion of the throat showing the utilization of threads for producing eddies.

Referring particularly to FIG. 1, the numeral **10** designates a body or plate of plastic or the like of which a bistable fluid amplifier is formed by machining or by an etching process in a manner well known in the art. As shown, a supply port **12** connected to a source of fluid pressure has an inlet passage, throat or nozzle **14** which opens into a receiving chamber or a reception region **16** defined by divergent side walls **17** and **18** on either side of a main or power stream **13** of jet fluid emitted from the nozzle **14**. Control ports **20** and **22** are disposed on opposite sides of the throat **14**, and are connected to the reception region **16** by means of control nozzles **24** and **26** which are substantially transverse of the passage of the main power stream **13** emitted from the throat **14**. Substantially, in line with the divergent walls **17** and **18**, divergent outlet passages **28** and **30** are provided connecting to outlet ports **32** and **34**. Exhaust or escape ports **36** and **38** which vent to the atmosphere are provided in the side walls **17** and **18** adjacent the beginning of the outlet passages **28** and **30**.

As is well known in the art, the inlet port **12** may be connected to a source of fluid under pressure for emitting a stream **13** of fluid such as air through the nozzle **14** into the reception region **16**. The walls **17** and **18** are set back adjacent the exit of the nozzle **14** so as to pro-

vide for producing a turbulent boundary layer condition as the stream leaves the throat **14**. Boundary turbulence causes a lower pressure area and a separation bubble **19** to a form adjacent one wall or the other and results in the locking on or turbulent reattachment of the power stream **13** to the wall **18**, for example, so that the associated outlet port **34** receives a relatively large flow of fluid. Switching of the stream to the other outlet port **32** is produced by a control jet from the control port on the side to which the power stream is attached, which inflates the separation bubble **19**, enlarges it and drives it downstream, releasing the power stream from the one wall and causing a pressure differential which creates a lower pressure area adjacent wall **17** and permits turbulent reattachment to cause the power stream to lock on the other wall **17** so as to supply a major portion of the fluid to the other outlet port **32**.

As shown in FIG. 2, when the walls of the nozzle **14** are smooth, the stream **13** therefrom has substantially smooth or laminar flow for an appreciable distance from the nozzle **14**. Typical dimensions of the nozzle may be, for example, .030 inch wide and .040 inch deep. With normal supply pressures on the order of ½ pound per square inch, boundary layer turbulence of the main stream occurs soon enough for the main stream to lock onto the adjacent wall **18**. Switching to the other wall **17** is effected by a control stream from passage **26**. Turbulence normally occurs at a predetermined value of Reynolds number in the region of 3000 when supply pressures are on the order of ½ pound per square inch of greater, and air is supplied at a rate of approximately 3500 cubic centimeters per minute. However, when the supply pressures are lower than normal, the transition point of laminar to turbulent flow occurs too far downstream of the main jet for turbulent reattachment to the walls to be effective, so that reliable switching of the main stream is not attained.

Referring to FIG. 3, it will be seen that the throat of the nozzle **14** is provided with a mechanical means such as a plurality of corrugations **15** adjacent its entrance into the reception region **16**. These corrugations **15** tend to induce boundary turbulence in the outer layer of the otherwise laminar flow stream from the nozzle, so that the necessary transition from laminar to turbulent flow in the outer layers of the power stream occurs sooner or further upstream, and turbulent reattachment of the power stream to the wall **18** occurs soon enough for the attachment to be effective and lock the stream to wall **18**, even at supply pressures that would otherwise be too low to effect turbulent reattachment.

The power stream **13** is switched by a control jet from control nozzle **26** which inflates the separation bubble **19**, increases the pressure therein, and moves it downstream until the power stream **13** separates from the wall **18** and transfers to wall **17** because of the change in pressures on opposite sides of the stream. It has been found that by utilizing corrugations and the like that turbulent reattachment may be effected for a Reynolds number on the order of 2000 or less, for supply pressures as low as one quarter of a pound per square inch.

Rferring to FIG. 4, the reference numeral **40** designates other mechanical means such as a trip wire or the like secured to the surface wall of the throat **14** by soldering, welding or brazing for producing eddies as is indicated by the curved arrows on the downstream side side of the wire, which initiate the formation of a turbulent boundary layer in the power stream, thus expediting control of the power stream by a control stream at lower values of Reynolds numbers.

Referring to FIG. 5, the numeral **42** designates a sharp protrusion such as a spike located, for example, in one or both of the side walls of the nozzle **14**, which is likewise effective to produce eddies as indicated by the curved arrow on the downstream or outlet side of the protrusion, thus expediting the formation of a turbulent boundary layer and effective control of the power stream at lower than normal values of supply pressure.

Referring to FIG. 6, it will be seen that a sudden reduction in the size of the nozzle **14** to a smaller passage **14***a* produces a sharp entrance constriction **44** which is likewise effective to produce eddies in the boundary layers of the power stream and expedite the formation of a turbulent boundary condition which facilitates turbulent reattachment of the stream at lower values of supply pressure under the control of a control stream.

Referring to FIG. 7, the reference numeral **46** designates a random roughness produced by a number of grains of sand or the like secured to the side walls of the throat or nozzle **14** by means of a suitable cement or the like, for purpose of producing a turbulent condition in the boundary layers of the stream similar to those produced by the corrugations of FIG. 3.

FIG. 8 illustrates another method of mechanically producing turbulence by roughening the surface of the nozzle **14** to produce turbulent boundary conditions in the power stream, such as by machine marks or cuts **48** on the surfaces of the throat.

FIG. 9 illustrates still another method of providing surface irregularities or roughness in the throat or nozzle **14** by means of scratches **50** produced by abrasion of the surface walls. Still another method of using surface roughness is effective to provide turbulent boundary layer conditions in the power stream is the provision of threads **52** as shown in FIG. 10.

Fluid amplifiers embodying the present invention may be readily produced by using an optical etching process with a suitable photopolymer. The body may, for example, comprise a layer of photopolymer used with an aluminum backing plate in a manner known in the art. The photopolymer is subjected to ultraviolet light through a suitable mask defining the desired flow pattern. This hardens the exposed regions and the masked areas may be removed or washed away by a sodium hydroxide solution or the like. Roughening of the throat areas may be readily produced by placing the desired roughness characteristics on the mask so that they are transferred to the body.

From the above description and the accompanying drawings, it will be seen that providing either random or uniform roughness or other mechanical means in the throat or nozzle of the power stream of a fluid amplifier facilitates the transition of a laminar to a turbulent flow in the boundary layers and enables turbulent reattachment of the power stream to take place at lower than usual supply pressures. In addition, by effecting more reliable switching of the power stream, better separation of the outlet ports is permitted. Spillover between the output ports is prevented and either the angle of divergence of the walls of the reception region may be varied and/or the distances between the power nozzle and the output ports may be varied without materally altering the efficiency of the fluid amplifier. This means that manufacturing tolerances need not be so close, so that production of amplifiers is greatly expedited.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that the changes in form and detail may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. In fluid control apparatus:

(a) a main nozzle connected to a source of fluid under pressure for producing a fluid power stream,

(b) a divergent wall disposed on at least one side of the power stream,

(c) an outlet port disposed adjacent said wall for receiving a portion of said stream,

(d) a control jet disposed on the other side of the stream for directing a transverse control stream to control said power stream, and

(e) means including a plurality of random surface protrusions on an inner wall of the nozzle adjacent the end thereof for inducing turbulence in the outer portions of the stream to insure turbulent reattachment and provide for control of the main stream by the control stream at lower supply pressures.

2. Fluid control apparatus comprising:

(a) a main power nozzle connected to a source of fluid under pressure for providing a main fluid power stream,

(b) divergent wall means disposed along opposite sides of said stream,

(c) an outlet passage disposed along each of said wall means,

(d) transverse control ports located on the opposite sides of the stream adjacent the nozzle for directing control streams to alter pressure conditions on opposite sides of the main stream and deflect the main stream in a plane through the control ports, and

(e) means in the nozzle providing an abrupt projection into the power stream to induce turbulent boundary flow in outer portions of the laminar power stream before it is impinged on by the control stream for achieving turbulent reattachment of the power stream to one of said divergent side walls at values of Reynolds numbers on the order of 2000 or less for power stream source pressure below ½ lb. per square inch.

3. A fluid control device comprising:

(a) a main nozzle connected to a source of fluid under pressure for producing a main fluid power stream,

(b) a pair of divergent walls one on either side of the main stream defining a reception region,

(c) a pair of fluid outlet ports located one along each of said walls,

(d) a pair of control nozzles disposed one on each side of the main stream adjacent the end of the main nozzle for selectively directing a control stream into the reception region toward the main stream, and

(e) means providing a sharp constriction in the main nozzle adjacent the reception region to induce turbulence in the boundary layers of the main stream prior to entering the control stream portion of the reception region to produce turbulent reattachment of the main stream to their respective walls at a lower Reynolds number whereby the control streams are rendered effective to control the power stream.

4. In a fluid control device:

(a) a main power nozzle connected to a source of fluid under pressure for providing a main flow power stream,

(b) a pair of divergent side walls defining a reception region adjacent the end of the nozzle,

(c) a pair of outlet ports disposed one along each of said side walls,

(d) a pair of control ports one on each side of the power stream connected to a source of fluid under pressure to provide control streams transversely of said main stream for shifting turbulent reattachment of the power stream to the wall on the other side of the power stream, and

(e) one or more wires disposed along the walls of the main nozzle normal to the power stream and ahead of the control streams for inducing turbulent boundary flow therein whereby the control streams are rendered effective to change turbulent reattachment of the main stream from one side wall to the other at lower values of pressure of the power source.

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