March 17, 1964 K. E. WOODWARD **3,124,999**

FLUID OSCILLATOR

Filed Feb. 1, 1963 2 Sheets-Sheet 1

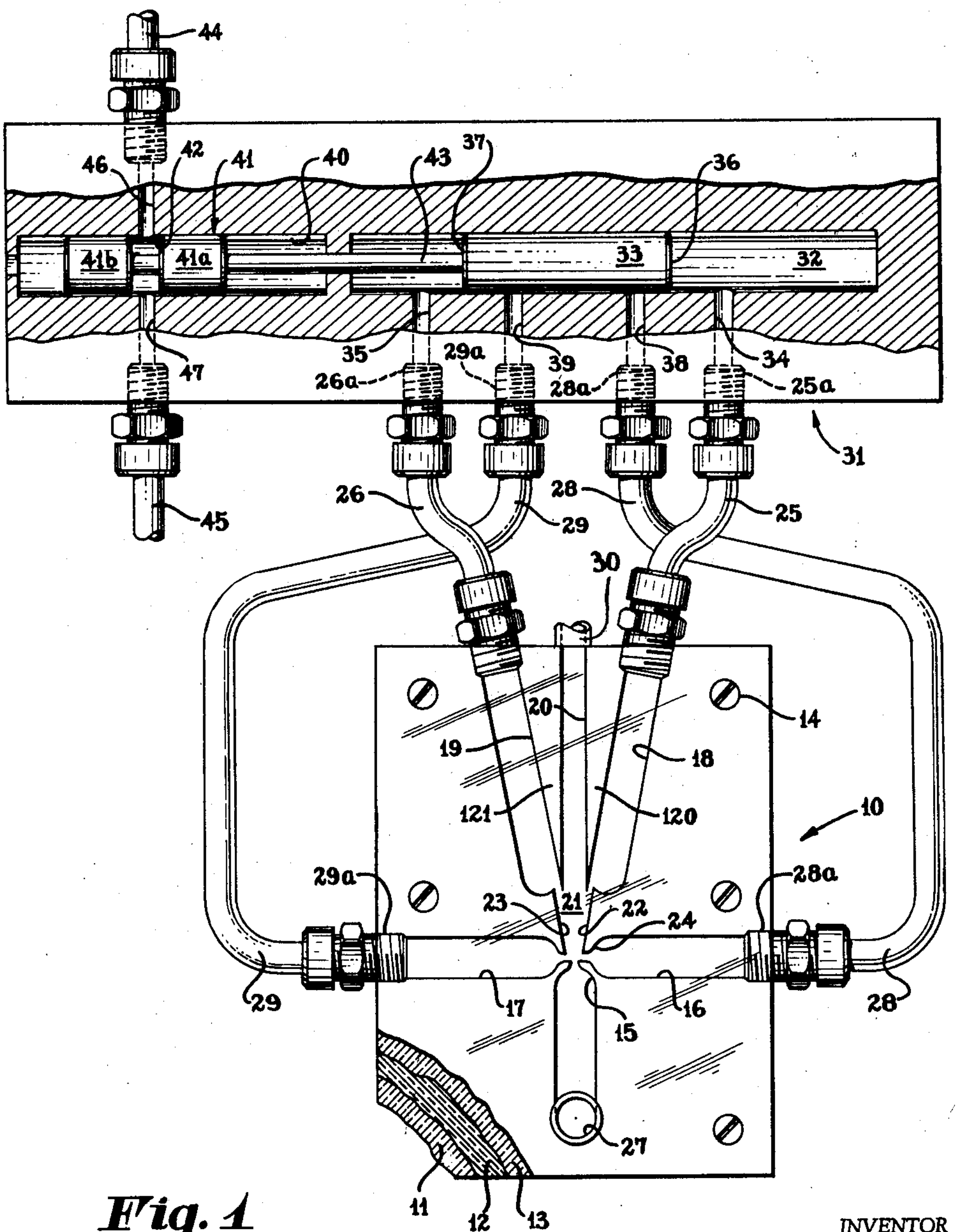

Fig. 1

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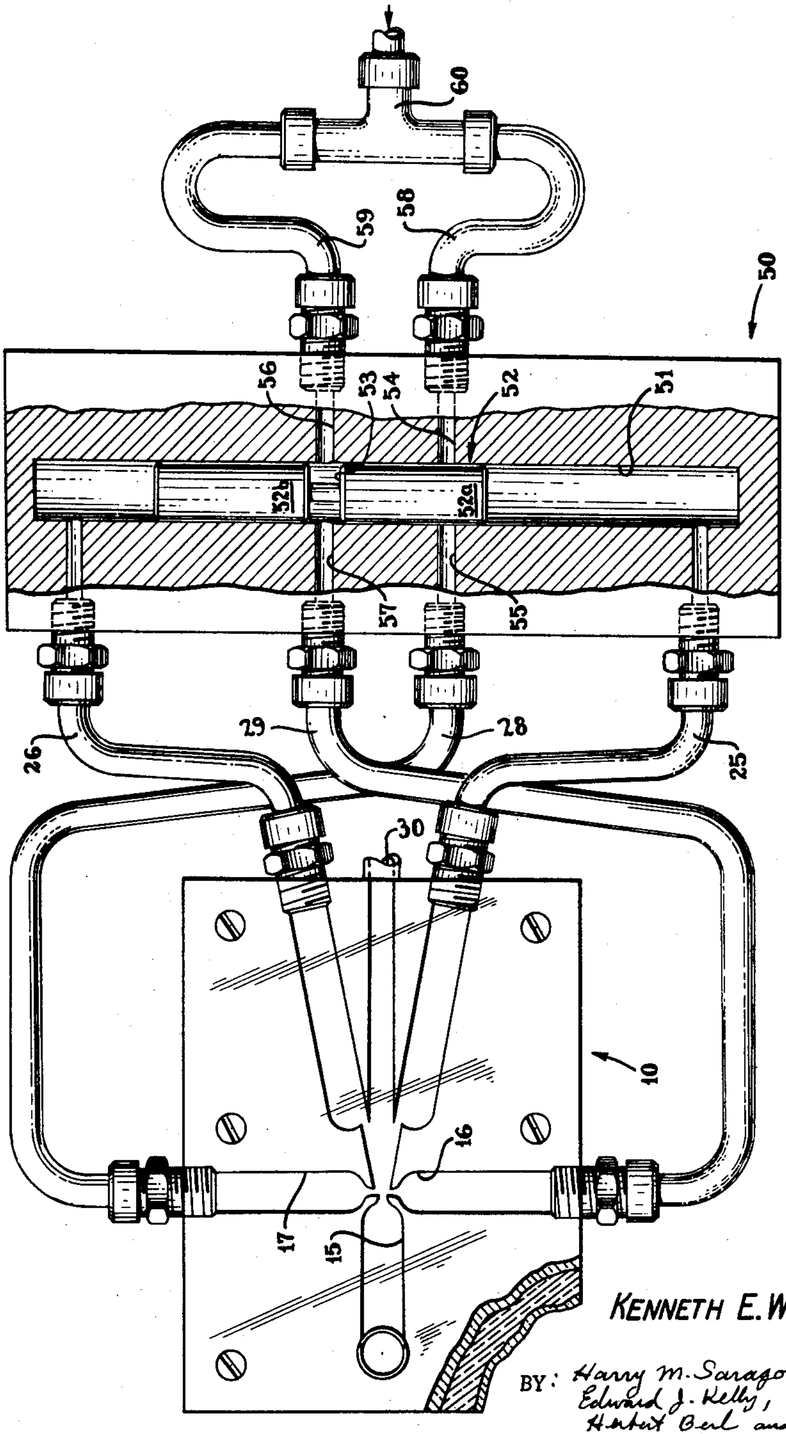

Fig. 2

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3,124,999

Patented Mar. 17, 1964

3,124,999

FLUID OSCILLATOR

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Filed Feb. 1, 1963, Ser. No. 256,217
5 Claims. (Cl. 91—3)
(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States for governmental purposes without the payment to me of any royalty thereon.

This application is a continuation in-part of my copending application serial No. 102,905 filed April 13, 1961, now abandoned, for Fluid Oscillator.

This invention relates generally to a fluid system for oscillating a piston in which the movement of the piston generates fluid pulses. These pulses ultimately determine the rate of oscillation of the piston and accordingly, the output of the system.

Prior art fluid actuated systems require the use of at least two moving elements to produce oscillation of one of the elements. The latter element is usually a piston which is slidable in a chamber and capable of actuating a suitable load device by means of a rod or similar linkage connected to the piston. The former element is usually some type of flow reversing valve which must also oscillate in order to permit alternating flow of fluid into opposite ends of the chamber housing the piston.

Such prior art systems have two main disadvantages. First, they have high time constants because of the inertia and friction of the moving valve and piston. Second, since at least two moving elements are required, these systems are not as systems which require lesser numbers of moving elements.

Recently, pure fluid oscillators have been developed. These oscillators require no moving parts to produce an oscillating output fluid pulse. Basically such oscillators comprise a fluid amplifier and some means for storing and feeding back to the amplifier fluid energy in order to cause alternating deflections of the power jet of the fluid amplifier. Using pure fluid oscillators, the piston is driven directly by the oscillating output fluid pulses. The piston can be employed to produce a pulse fluid output signal. The piston can also be employed to control the entrance of a secondary fluid source to furnish control pulses to the fluid amplifier.

It is an object of this invention to utilize the oscillation of a piston driven by the output flows from a fluid amplifier to control the sonic pulses or flow to the control nozzles of the amplifier thereby governing the rate of oscillation of the amplifier.

Another object of this invention is to provide a fluid amplifier in combination with a single moving piston which can actuate a load device, and which also serves to convert the amplifier to an oscillator.

Still another object of this invention is to provide a fluid oscillator which has a pulsed fluid output signal.

A further object of this invention is to provide a fluid oscillator in which a secondary fluid source is utilized for the control signal pulses.

According to this invention, a piston housed in a fluid receiving chamber is driven by fluid from the output tubes of a conventional fluid amplifier. Tubes connected to the control nozzles of the amplifier are also connected to ports in the chamber. These ports are alternately covered and uncovered by movement of the piston so that sonic pulses or flows from the output tubes enter the tubes connected to the control nozzles. As a result, alternating fluid pulses are received by the control nozzles and these pulses ultimately oscillate the power jet flowing through the amplifier. The frequency of oscillation depends primarily upon the spacing of the ports and the length and mass of the piston and the volumetric flow rate.

In fluid amplifier systems of the type with which the present invention is concerned, a power jet of fluid, which is well defined in space, is deflected by means of a pressure differential established approximately transverse to the normal direction of movement of the power jet. The differential in pressure established across the power jet may be employed to deflect the jet to one of various positions at which load devices may be situated. These devices may convert a portion of the energy of the fluid stream to useful work. Alternately, the energy, pressure or mass flow of the deflected stream may be employed as an input signal to a further fluid amplifier or a fluid amplifier system to increase the overall amplification of the system or to perform switching functions. Amplification is achieved by the fluid amplifier as a result of the fact that a relatively small control fluid flow is required to deflect a high energy fluid stream so as to produce a relatively large variation in energy, pressure or mass flow, delivered to an output location.

A typical single stage amplifier, chosen for purposes of ease of explanation only, may comprise a main fluid nozzle extending through an end wall of an interaction region defined by a sandwich type structure consisting of an upper plate and a lower plate (which serve to restrict fluid flow to an approximately two-dimensional flow pattern between the two plates), and end wall, two sidewalls (hereinafter referred to as the left and right sidewalls), and one or more dividers disposed at a predetermined distance from the end wall. The leading edges or surfaces of the dividers are disposed relative to the main fluid nozzle centerline so as to define separate areas in a target plane. The sidewalls of the dividers in conjunction with the interaction region sidewalls establish the receiving apertures which are entrances to the amplifier output channels. Completing the description of the apparatus, left and right control orifices may extend through the left and right sidewalls, respectively. In the complete unit, the region bounded by top and bottom plate, sidewalls, the end wall, receiving apertures, dividers, control orifices and a main fluid nozzle, is termed an "interaction region or interaction chamber region." The unit described above is capable of operation as one of several subtypes of fluid amplifier units depending upon the specific arrangement of the unit.

Two broad classes of pure fluid amplifiers are: Class I, based on stream interaction or momentum exchange; and Class II, based on boundary layer control. Class I amplifiers include devices, in distinction to the devices of Class II, in which there are two or more streams which interact in such a way that one or more of these streams (control stream) deflects another stream (power stream) with little or no interaction between the side walls of the interaction region and the streams themselves. Power stream deflection in such a unit is continuously variable in accordance with control signal amplitude. Such a unit is referred to as a continuously variable amplifier or computer element. In an amplifier or computer element of this type, the detailed contours of the side walls of the interaction chamber are of secondary importance to the interacting forces between the streams themselves. Although the side walls of such units can be used to contain fluid in the interacting chamber, and thus make it possible to have the streams interact in a region at some desired ambient pressure, the side walls are so placed that they are somewhat remote from the high velocity portions of the interaction streams and the power stream does not approach or attach to the side walls. Under these conditions the power stream flow pattern within the interacting chamber depends primarily upon the size, speed and direction of the power stream and control streams and upon the density, viscosity, compressibility and other properties of the fluids in these streams. A typical Class I amplifier is disclosed in the June 1960 edition of "Science and Mechanics Magazine," pages 81–84, inclusive.

The present invention also relates to the second broad class (Class II) of fluid amplifier and computer elements; that is, boundary layer control units. This second broad class of fluid amplifier and computer elements comprises units in which the main power stream flow and the surrounding fluid interact in such a way with the interaction region sidewalls that the resulting flow patterns and pressure distributions within the interaction region are greatly affected by the details of the design of the chamber walls.

The power stream deflection effect in boundary layer units is the unit of transverse pressure gradient due to a difference in the effective pressures which exist between the power stream and the opposite interaction region sidewalls; hence, the term "boundary layer control." In order to explain this effect, assume initially that the fluid stream is issuing from the main nozzle and is directed toward the apex of a centrally located divider. The fluid issuing from the nozzle, in passing through the chamber, entrains some of the surrounding fluid in the adjacent interaction regions and removes this fluid therefrom. If the fluid stream is slightly closer to, for instance, the left sidewall than the right sidewall, it is more effective in removing the fluid in the interaction region between the stream and the left wall than it is removing fluid between the stream and the right wall since the former region is smaller. Therefore, the pressure in the left interaction region between the left sidewall and power stream is lower than the pressure in the right interaction region, and a differential pressure is set up across the power jet tending to deflect it towards the left sidewall. As the stream is deflected further toward the left sidewall, it becomes even more efficient in entraining fluid from the left interaction region and the effective pressure in this region is further reduced. In those units which exhibit "lock-on" features or characteristics, this feedback-type action is self-reinforcing and results in the fluid power stream being deflected toward the left wall and predominantly entering the left receiving aperture and outlet channel. The stream attaches to and is then directly deflected by the left sidewall as the power stream effectively intersects the left sidewall at a predetermined distance downstream from the outlet of the main orifice, this location being normally referred to as the "attachment location." This phenomenon is referred to as boundary layer lock-on. The operation of this type of apparatus may be completely symmetrical in that if the stream had initially been slightly deflected toward the right sidewall rather than the left sidewall, boundary layer lock-on would have occurred against the right sidewall.

Control of these units can be effected by controlled flow of fluid into the boundary layer region from control orifices at such a rate that the pressure in the associated boundary layer region becomes greater than the pressure in the opposing boundary layer region located on the opposite side of the power stream and as a result the stream is switched towards this opposite side of the unit.

The control flow may be at such a rate and volume as to deflect the power stream partially by momentum interchange so that a combination of the two effects may be employed. However, it is not essential, and in many cases is undesirable, that the control flow have a momentum component transverse to the power stream when the control fluid issues from its control orifice.

In both classes of amplifiers, only a small amount of energy is required in the control signal fluid flow to alter the power jet path so that some or all of the power jet becomes intercepted by the load device or output channel. For a continuously applied control signal, the power gain

of this system can be considered equal to the ratio of the change of power delivered by the amplifier to its output channel or load to the change of control signal power required to effect this associated "change of power" delivered to the output channel or load. Similarly, the pressure gain can be considered equal to the ratio of the change of output pressure to the change of control signal pressure required to cause the change, and the mass flow rate gain can be defined as the ratio of the change of output channel mass flow rate to the associated change of control signal mass flow rate.

In the discussion a two dimensional configuration has been described for purposes of clarity. However, the invention and description relative thereto are also inclusive of configurations which are three dimensional in nature, as for example, axially symmetric units which result from rotation of a plan view about an axis coincident with the power nozzle centerline.

The specific nature of the invention, as well as other objects, uses, and advantages thereof, will clearly appear from the following description and from the accompanying drawings in which:

FIGURE 1 is a plan view of an embodiment of the fluid oscillator constructed in accordance with this invention.

FIGURE 2 is a plan view of a second embodiment of this invention.

Referring now to FIG. 1, there is shown a fluid amplifier **10**. Amplifier **10** is a Class II type amplifier discussed above, and although it will be evident that a Class I amplifier may also be used, I have found it preferable to employ the former type of amplifier. Amplifier **10** is formed by three flat plates **11**, **12**, and **13**. Plate **12** is positioned between plates **11** and **13** and is tightly sealed between these plates by an adhesive or other suitable means such as machine screws **14**. Plates **11**, **12** and **13** may be composed of any suitable material such as metal, ceramic or plastic. Also, for purposes of illustration the plates are shown composed of a transparent plastic material such as lucite. Plates **11** and **13** prevent spreading of the power and control streams received by amplifier **10** in a direction normal to the deflecting plane.

The substantialy Y-shaped configuration cut or etched from plate **12** provides a power nozzle **15**, control nozzles **16** and **17**, fluid receiving channels **18** and **19**, fluid bleeding channel **20**, and an interaction chamber **21**. Nozzles **15** and **16** are adjacent to each other and are at substantially right angles. Control nozzle **17** is positioned opposite nozzle **16**. Channel **20** bleeds off chamber **21** so that pressures developed in chamber **21** will be limited.

Output tubes **25** and **26** are threadedly connected to the ends of channels **18** and **19** and receive fluid therefrom. Tube **27** is threadedly connected to power nozzle **15** while tubes **28** and **29** are each threadedly connected at ends **28***a* and **29***a* to control nozzles **16** and **17**, respectively. The connections between the tubes and the nozzles as well as the tube connections to the channels should be made tight enough to prevent leakage.

A source of pressurized fluid (not shown) may be connected to tube **27**. The source of fluid may be air, gas, water or other liquids. The gas or liquid may have small solid particles or bubbles entrained therein. If necessary, a fluid regulating valve (not shown) may be used to regulate the amount of fluid entering tube **27**.

When fluid under pressure is applied to the power nozzle **15**, there is flow through the power nozzle which results in the creaction of a power jet. Initially the power jet passes through chamber **21** substantially undeflected. As a result of viscous interaction between the power jet fluid and the surrounding fluid, the surrounding fluid is accelerated in the power jet direction as a result of momentum exchange. The entrainment of the fluid surrounding the stream transports the fluid on each side of the power jet out of chamber **21**. The action lowers the pressure on each side of the power jet and counterflow fluid flowing down and from channel **20** enters chamber **21** to replace the fluid entrained and removed by the power jet.

The power stream flow through chamber **21** creates a turbulence in the chamber and therefore differential pressure perturbations will exist transverse to the power jet. The pressure perturbations deflect the power jet slightly to an asymmetric flow configuration. The effect becomes asymmetrical to a degree which increases with increasing sidewall length.

Assume for purposes of discussion that because of perturbations in flow, deflection is towards sidewall **22**. This deflection reduces the area between power stream and sidewall **22** and reduces the pressure in the right boundary region, defined by right sidewall **22**, the interaction chamber end wall **24**, and the power stream, which region is being evacuated by the power stream entrainment.

As the gap between sidewall **22** and the power stream is further reduced, the net flow to the right boundary layer is further modified. This modification results in decrease of the right side effective pressure while the left boundary region effective pressure tends to increase towards the ambient fluid pressure level in chamber **21**. The resulting transverse force inclines the power stream toward wall **22**. When the sidewalls **22** or **23** are sufficiently close to the leading edges of the dividers **120** and **121**, the cumulative action results in the power stream contacting wall **22** at an "attachment location." When this happens the power stream establishes a sealed boundary region along the sidewall **22**, causing the power stream to completely lock-in to wall **22** and flow out channel **18** and tube **25**.

Should control nozzle **16** issue fluid into the boundary layer, the pressure in the boundary layer will increase until there is no tendency for the stream to remain locked-on to wall **23**. Fluid will then issue from output tube **26**.

It will be obvious that jets issuing from control nozzles **16** and **17** in an alternating manner will cause oscillation of the power jet between tubes **25** and **26**.

Numeral **31** refers generally to the above-referred to valve system. System **31** comprises a hollow cylinder **32** in which piston **33** reciprocates.

Tube ends **25*a*** and **26*a*** are threadedly connected to ports **34** and **35** communicating with cylinder **32**. System **31** is of the double acting type wherein the pressure is applied alternately to the chambers formed by the opposed heads **36** and **37** of the piston and cylinder **32**. Another pair of ports **38** and **39** are formed in the chamber walls and are threadedly connected to the tube ends **28*a*** and **29*a***. These ports are located substantially intermediate the length of the cylinder as shown and are spaced apart a predetermined distance. As can be seen from FIG. 1, when fluid flow from tube **25** drives the piston a distance sufficient to uncover port **38** fluid will travel as flow or as a sonic pulse into this port, into tube **28**, and finally into the control nozzle **16**. Fluid issuing from the control nozzle will deflect the power jet in amplifier **10** into tube **26** from whence it will drive piston **33** towards the right (as viewed in FIG. 1), uncovering port **39** and permitting some of this fluid to enter tube **29**. Fluid entering tube **29** also issues as a jet from control nozzle **17** which deflects the power jet in amplifier **10** from tube **26** to tube **25**. The described cycle thereafter continues and the rate of oscillation of piston **33** will depend upon the length and mass of the piston, the volumetric flow rate, and the spacing between the ports, as will be apparent to those skilled in the art. The relative lengths of cylinder **32** and piston **33** should be such that fluid is issuing from either tube end **25*b*** or **26*b*** as the piston approaches that end of the cylinder. The piston will thereby be cushioned by fluid at all times during reciprocation.

Channel **20** is connected to a control bleeder tube, referred to by numeral **30**. The inside diameter of this tube determines the loading character of the amplifier, as will be evident to those skilled in the art. The fluid bled off by tube **30** can be fed back into the sump (not shown) which supplies fluid to the power jet, or can be fed into the atmosphere as shown in FIG. 1.

Piston **33** provides the only moving element in my system and performs the dual function of providing a reciprocating movement and governing the frequency of oscillation of the system. When the piston is increased in length, the frequency of oscillation decreases. Decreasing the piston length increases the frequency of oscillation. The frequency of oscillation can also be varied by varying the distance between ports **38** and **39**. Increasing the distance between the ports decreases the rate of oscillation, while decreasing the distance between ports increases the rate.

The reciprocation of piston **33** can be utilized to drive a rod linkage or the like, or the piston may drive another member so as to produce a pulsed output to a continuous high pressure stream of fluid. The last mentioned function may be achieved by providing a second cylinder **40**, coaxial to cylinder **32**. Piston **41** having sections **41*a*** and **41*b*** and an annular groove **42** therebetween reciprocates in cylinder **40** as a result of being connected to the cylinder by rod **43**. A pair of opposed tubes **44** and **45** communicate with cylinder **32** by means of parts **46** and **47**. Tubes **44** and **45** are designed to convey streams of fluid at high pressure. Flow between tubes **44** and **45** occurs when groove **42** is opposite ports **46** and **47** and ceases when sections **41*a*** and **41*b*** block these ports. By varying the rate of oscillation of piston **41** or by varying the length of groove **42** and the piston sections, continuous flow through one tube **44** or **45** may be converted to a pulsed output flow from the other tube at any desired frequency.

FIG. 2 illustrates a system in which the piston controls the flow of fluid at high pressure from an external source to the control nozzles of amplifier **10** in order to effect oscillation of the piston. As shown in that figure, system **50** comprises a cylinder **51** in which piston **52** reciprocates. The piston can be alternately driven by fluid issuing into the ends of chamber **51** by flow from tubes **25** and **26**.

Piston **52** is divided into two sections **52*a*** and **52*b*** by annular groove **53**. Ports **54**, **55**, **56** and **57** are, respectively, positioned opposite each other and provide communication between tubes **58** and **59** and tubes **28** and **29**. Tubes **58** and **59** join at T-junction **60**. These tubes are designed to receive fluid at high pressure from any conventional source (not shown).

When groove **53** is opposite ports **56** and **57**, as shown in FIG. 2, tube **59** will supply fluid to tube **29** and to control nozzle **16**, causing the power jet from nozzle **15** to issue from tube **26**. Fluid issuing from tube **26** drives piston **52** until section **52*a*** no longer blocks ports **54** and **55**. At that time, section **52*b*** will move to a position where it blocks ports **56** and **57** so that fluid no longer flows to control nozzle **16**, but rather flows through tube **58**, port **54**, piston slot **53**, port **55**, tube **28** to nozzle **17** deflecting the power jet from nozzle **15** into tube **25**. Fluid from tube **25** drives piston **52** to the left, as viewed in FIG. 2, until groove **53** is again opposite ports **56** and **57**, at which time ports **54** and **55** will be blocked and fluid from tube **59** will again flow into nozzle **16**. The pulsing of fluid through T-junction **60** can be employed as a source of timed pulse signals by means (not shown) intermediate the source and the T, or in one of the control tubes **28** or **29**.

As is the case with the system disclosed and shown in FIG. 1, for any fluid pressure level the rate of oscillation of the piston will depend upon the spacing of the ports, the length and position of the groove in the piston as well as the piston mass.

As will be apparent to those in the art, windshield wipers and other types of devices which are required to perform oscillating or reciprocating functions may be connected to and driven by the piston, or the piston may be employed to valve hot or cold gases or liquids under high pressure, or to deliver exact amounts of fluids to be canned, such as beer.

It will be apparent that the embodiments shown are only exemplary and that various modifications can be made in structure and arrangement within the scope of the invention as defined in the appended claims.

I claim as my invention:

1. In a fluid oscillator;

(*a*) a fluid power source;

(*b*) a fluid amplifier comprising a power nozzle connected to said fluid power source,

(*c*) said power nozzle issuing a power jet,

(*d*) a pair of opposed control nozzles positioned to direct fluid jets against said power jet in such a manner as to cause amplifier displacement of said power jet,

(*e*) a pair of opposed output tubes positioned to receive said power jet as a result of displacement by fluid issuing from said control nozzles; and

(*f*) oscillating means adapted to periodically direct fluid flow into a predetermined combination of ports formed in said oscillating means,

(*g*) said control nozzles and output tubes communicating with said oscillating means by means of said ports,

(*h*) said ports being arranged such that fluid issuing from one output tube is directed by said oscillating means into that control nozzle which is positioned to deflect said power jet into the output tube opposite the tube issuing fluid.

2. In a fluid oscillator as recited in claim 1, said oscillating means including a piston having two ends wherein said ends direct said power jet into the proper control nozzle when properly positioned.

3. In a fluid oscillator as recited in claim 1,

(*a*) said oscillating means including a piston having a central channel therein,

(*b*) said power source connected to two of said ports in said oscillating means and said ports which communicate with said control nozzles being alternately connected to one of said power source ports when the central channel of said piston is properly positioned.

4. In a pulse generator,

(*a*) a fluid power source for producing a fluid power stream,

(*b*) a fluid amplifier having wall lock-on characteristics,

(*c*) an oscillatory body means having an oscillatory body therein,

(*d*) first conduit means connecting said fluid power source to said fluid amplifier,

(*e*) second and third conduit means connecting said fluid amplifier to said oscillatory body means for providing fluid power thereto,

(*f*) fourth and fifth conduit means connecting said oscillatory body means to said fluid amplifier for providing control signals to said fluid amplifier for selection of directing the power stream from said fluid

power source into one of said second and third conduit means.

5. In a pulse generator;

(*a*) a fluid power source for issuing a power stream;

(*b*) a fluid amplifier having wall lock-on characteristics including a power nozzle means,

(*c*) a right and a left control nozzle means,

(*d*) and a right and a left receiver means;

(*e*) an oscillatory body means including a piston means,

(*f*) means for confining the movement of said piston means to a single plane,

(*g*) and first, a second, a third and a fourth port means in said means for confining said movement;

(*h*) first conduit means connecting said fluid power source and said power nozzle means,

(*i*) second conduit means connecting said left control nozzle means to said second port,

(*j*) third conduit means connecting said left receiver means to said first port,

(*k*) fourth conduit means connecting said right receiver means to said fourth port,

(*l*) fifth conduit means connecting said right control nozzle means to said third port,

(*m*) said four ports being positioned to provide said power stream to move said piston with said first and fourth ports being positioned beyond the limits of travel of the ends of the piston,

(*n*) and said second and third ports being positioned intermediate said first and fourth ports so that said third port is uncovered by said piston when said piston is at its limit of travel near said first port and said second port is uncovered by said piston when said piston is at its limit of travel near said fourth port,

whereby application of said power stream through said power nozzle, said left receiver means, said third conduit means and said first port will force said piston toward said fourth port until said second port is uncovered and said power stream is then directed through said second port,

said second conduit means and said left control nozzle to redirect said power stream from said left receiver means to said right receiver means and through said fourth conduit means,

said fourth port to return said piston toward said first port until said third port is uncovered and said power stream is then applied through said third port,

said fifth conduit means and said right control nozzle to return said power stream from said right receiver means to said left receiver means.

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