

June 11, 1963

R. W. WARREN
FLUID-OPERATED TIMER

3,093,306

Filed June 5, 1961

4 Sheets-Sheet 1

FIG. 3

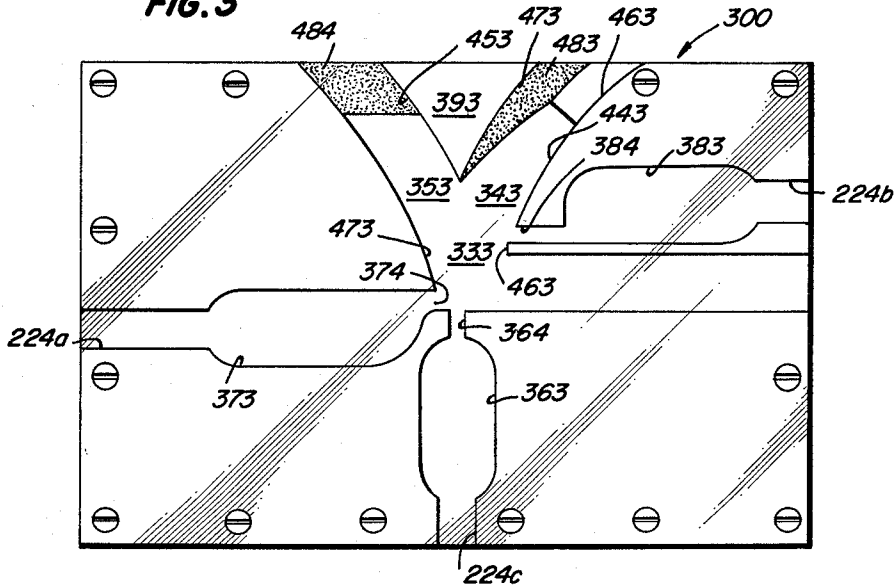


FIG. 1

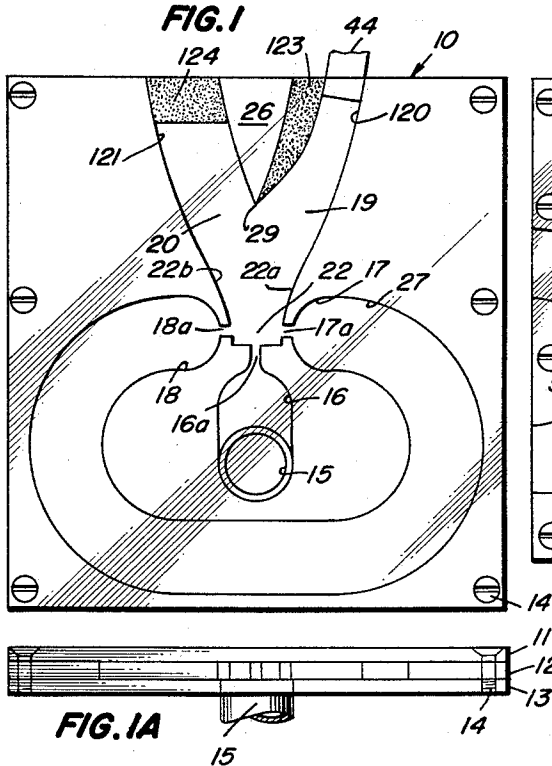


FIG. 5

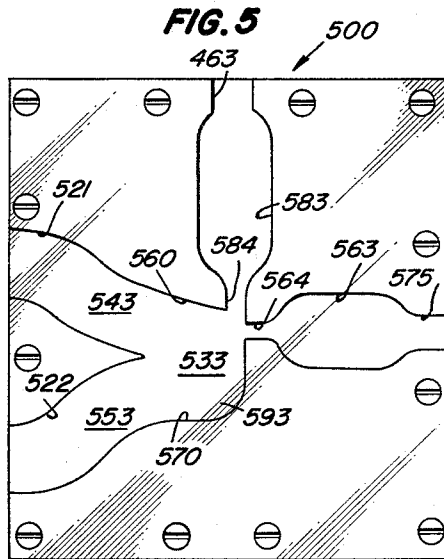


FIG. 1A

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4 Sheets-Sheet 3

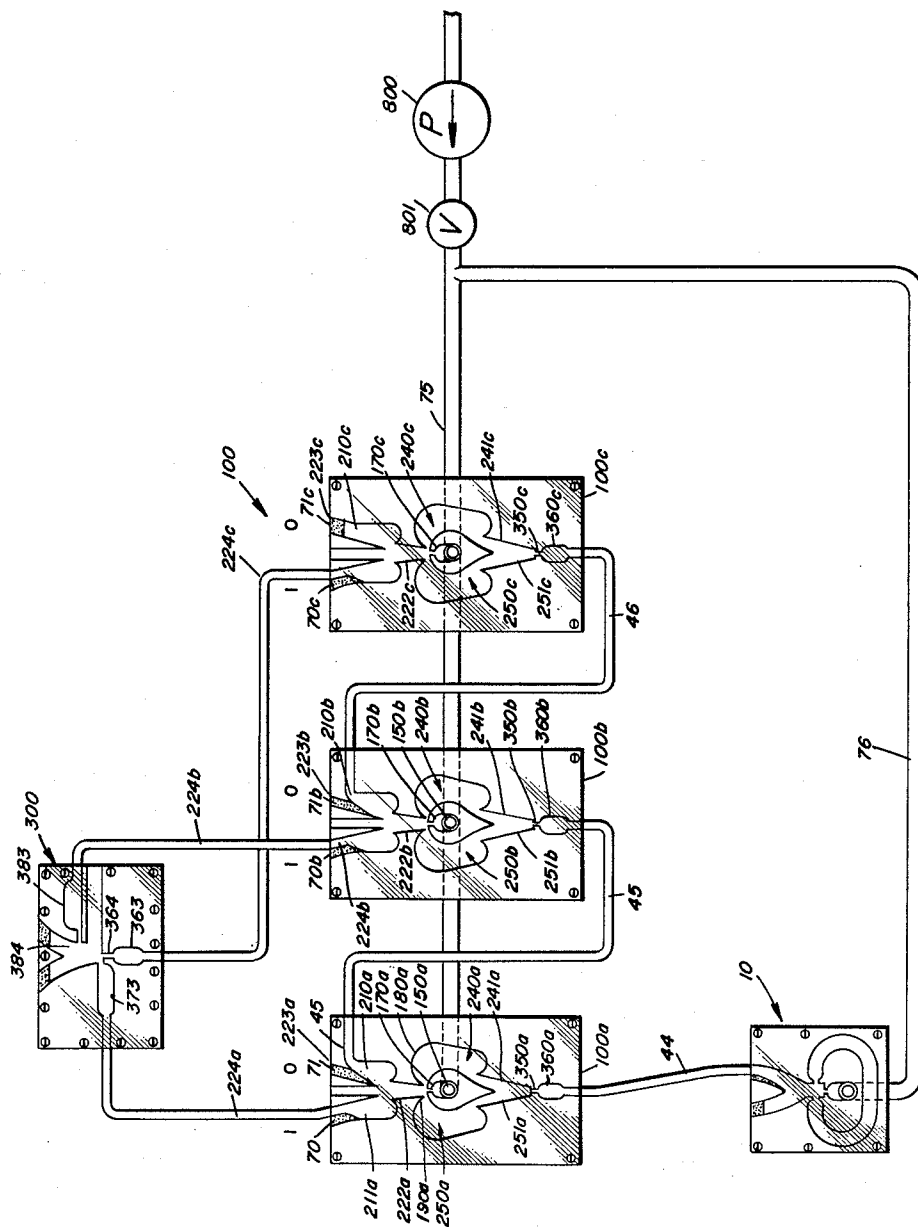


FIG. 4

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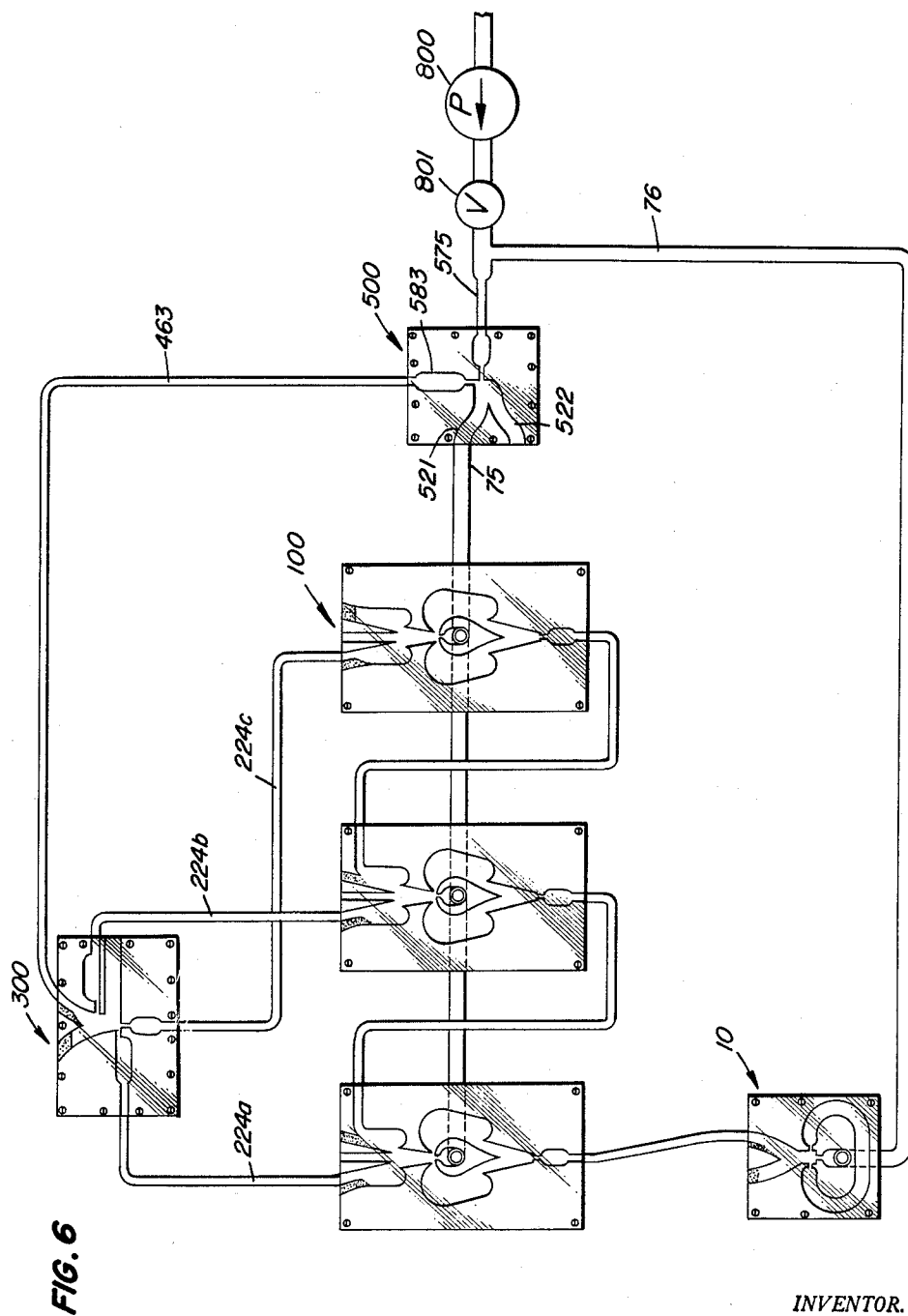
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1

3,093,306

FLUID-OPERATED TIMER

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3 Claims. (Cl. 235-61)

(Granted under Title 35, U.S. Code (1952), sec. 266)

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

This invention relates to a fluid-operated timer which is capable of indicating predetermined time intervals.

There are many kinds of timing devices in existence today. Electrical, electronic and mechanical timers are, of course, among the most well known. There are disadvantages inherent in each type of timer. Known mechanical timing devices have the disadvantage of requiring numbers of moving parts in order to achieve a timing function. Wear, friction and thermal expansion constantly affect the functioning of these timing devices as well as their accuracy.

Electrical or electronic timing devices on the other hand, require substantially constant sources of electrical power. Such sources of power may not be either available or the most desirable type of power under particular operating conditions. Also such timing devices do not have long operating lives.

In computers in particular, and in control systems in general, large numbers of timing devices are utilized. The basic types of timers, that is, electrical, electronic and mechanical are employed almost exclusively. This is so primarily because of the lack in the art of a suitable fluid-operated timer.

The inherent ruggedness and reliability of fluid systems as well as the availability of air or water as a power source are among the reasons why fluid operated systems are also desirable and may often be employed in lieu of pure mechanical, electrical or electronic systems. In order to satisfactorily utilize fluid in fluid-actuated systems some satisfactory means for achieving amplification of a fluid input signal had to be developed because of the energy losses occurring when the fluid is conveyed from one component to another in the system. Without means to amplify the fluid signal the size of the power source becomes excessively large. Amplification of fluid input signals was achieved by systems with numerous moving pistons and valves. Unfortunately, such systems have rather low response times because of the inertia of the moving valves or pistons.

The fluid-operated timer of this invention incorporates the combination of a fluid-operated oscillator, a fluid-operated binary counter and a fluid-operated AND component. The fluid oscillator, counter and AND component require no moving parts other than the working fluid employed therein for their operation.

A basic component of the fluid-operated timer is a fluid oscillator. One type of fluid oscillator incorporates a fluid amplifier and a feedback system which communicates with the amplifier and feeds back energy to control fluid flow from the amplifier. This type of oscillator, known and referred to herein as a sonic oscillator, utilizes the effect of waves which travel at the speed of sound. It should be distinguished from a relaxation type oscillator discussed hereafter which depends upon the filling and emptying of a fluid capacitance or inertance to provide the desired timing or phase relationship.

The frequency of a sonic oscillator varies with the length of the feedback path and the speed of sound. The speed of sound varies as

2

$$C = K \sqrt{\frac{P}{\rho}}$$

for perfect gases or $C = \sqrt{KRT}$

where

R = gas constant

T = temperature in degrees Kelvin

C = speed of sound (feet per second)

K = ratio of specific heats

P = pressure in pounds per square inch

ρ = density.

During the operation of a sonic oscillator K varies between narrow limits and as P increases, ρ increases. Consequently, the speed of sound for slight variations in pressure and temperature is relatively constant. The length of the feedback path can easily be lengthened or shortened to provide any desired frequency of oscillation within the physical limits of the system. A fluid amplifier is employed in the sonic oscillator and is preferably of the type which utilizes boundary layer lock-on control. The following description is an aid in understanding some of the control principles involved in this type of fluid amplifier.

In a boundary-layer-controlled fluid amplifier, a high energy power jet is directed towards a receiving aperture system by the pressure distribution in the power jet boundary layer region. This pressure distribution is controlled by the wall configuration of the interaction chamber, the power jet energy level, the fluid transport characteristics, the back-loading of the amplifier output passages and the flow of control fluid to the boundary layer region. In this type of fluid amplifier special design of the interaction chamber configuration causes the power jet to lock-on to one side wall and remain in the locked-on flow configuration without a control fluid flow. When the power jet is suitably deflected by a control fluid flow it can lock-on to the opposite side wall and remain in the locked-on flow configuration even after the control fluid flow is stopped. Fluid amplifiers of the boundary layer control type control the delivery of energy of a main stream of fluid to an outlet orifice or utilization device by means of control fluid flow issuing from a control nozzle generally at right angles to the main stream. The proportion of the relatively high energy main stream delivered to an orifice may be varied as a linear or non-linear function of the relatively low energy of a control stream interacting herewith. Since the energy controlled is larger than the control energy supplied, an energy gain is realized and amplification in the conventional sense is realized.

A fluid oscillator of the relaxation type requires in addition to a fluid amplifier and a feedback system or loop, some means for storing fluid energy. Such oscillators may store fluid energy in two forms, as potential and kinetic energy. Potential energy is energy associated with a "fluid capacitance." The term "fluid capacitance" can be defined as that class of fluid energy storage means which stores fluid potential energy. In general the energy stored in a fluid capacitance increases as a result of introduction of additional fluid therein. Fluid capacitance may take one or more of the following forms: compression of the fluid to a greater density, change of thermodynamic state of the fluid, change of elevation of the fluid, change of fluid internal energy level, compression of a second fluid separated from the first fluid by a flexible wall, compression of a second fluid in contact with the first fluid, deformation of elastic walls which restrain the fluid, change of elevation of the fluid, change of elevation of a weight supported by the fluid, and compression

of bubbles or droplets of one fluid entrained in another.

Fluids in motion have a kinetic energy which represents a second form of stored energy. The method of storing energy in this form is to accelerate the fluid to a higher speed. "Fluid inertance" is a measure of the pressure required to accelerate a mass of a fluid in a passageway or tube and is normally associated with the fluid flow through a tube.

The rate of oscillation of this type of oscillator varies with the pressure due to the change in rate at which the capacitance or inertance fills and discharges. Although the sonic oscillator, discussed above, is preferred as a source for timed fluid pulses and is disclosed in detail in this application, oscillators of the relaxation type may also be used as a source of timed pulses.

The second component of the timer of this invention consists of a fluid binary counter. Such a counter comprises a series of fluid pulse converters capable of performing functions analogous to those performed by scalars or flip-flops in electronic computers which are connected together to form a fluid binary counter. Successive series of input fluid signals cause determinable fluid flow patterns to occur in the pulse converters. Such flow patterns are utilized to actuate a fluid-operated readout system.

The third element comprising the fluid-operated timer of the instant invention is a fluid readout component. This component preferably takes the form of a fluid AND component. The fluid-operated AND component of this invention utilizes the amplifying and quick response capabilities of the fluid amplifiers of the afore-described boundary layer control type. Such components produce a fluid output signal from a certain output tube when two or more input fluid signals of same minimum magnitude or energy level are received by the component at substantially the same time.

According to this invention the pulsed fluid output signals from a fluid oscillator are conveyed to a fluid-operated binary counter and hence to a fluid-operated AND component connected thereto. When the AND component is properly connected to the counter the AND component will issue fluid pulses after predetermined intervals of time have elapsed. The instant invention also includes an AND component for resetting the counter after any time interval has elapsed so that a time cycle of any duration can be produced.

Broadly, it is an object of this invention to provide a fluid-operated timer in which all elements comprising the timer except the working fluid remain stationary during operation thereof.

More specifically, it is an object of this invention to provide a fluid-operated timer which comprises the combination of a source of timed fluid pulses, means for counting these pulses and fluid operated readout means responsive to certain of such pulses.

Another object of this invention is to provide a fluid timer comprising a fluid-operated counter and fluid-operated means for resetting the counter so that any desired time interval can be produced.

Another object in accordance with the above object, is to provide a fluid AND logic component as the fluid-operated means for resetting the counter.

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 drawing, in which:

FIG. 1 is a plan view of a fluid oscillator for providing timed output fluid pulses.

FIG. 1A is an end view of FIG. 1.

FIG. 2 is a plan view of a fluid pulse converter for converting successive fluid pulses into alternating fluid output pulses.

FIG. 2A is a sectional side view of FIG. 2, taken through section lines 2A—2A.

FIG. 3 is a plan view of a fluid AND logic component for reading out fluid pulses from a fluid pulse converter.

FIG. 4 is a plan view of the fluid-operated timer of the instant invention.

FIG. 5 is a plan view of another embodiment of a fluid AND component which is employed to reset the timer of this invention.

FIG. 6 is a plan view of the fluid operated timer of this invention which is capable of producing timed fluid pulses of any predetermined duration.

The term "input signal" as used herein is the fluid signal which is intentionally supplied to the fluid component for the purpose of instructing or commanding the component to provide a desired output signal or flow pattern. The term "output signal" used herein is the fluid signal or flow pattern which is produced by the component at its output. The input and output signals can be in the form of time or spatial variations in pressure, density, flow velocity, mass flow rate, fluid composition, transport properties, or other thermodynamic properties of the input fluid individually or in combination thereof.

Referring now to FIG. 1 there is shown stable fluid-oscillator 10 formed by three flat plates 11, 12, and 13 (FIG. 1A). Plate 12 is positioned between plates 11 and 13 and all three plates are fixed together by machine screw 14. These plates may be composed of any metallic, plastic, ceramic or other suitable material. For the purpose of illustration the plates are shown composed of clear plastic material, such as Lucite.

The configuration cut from plate 12 provides a jet interaction chamber 22, feedback passage 27, fluid power nozzle 16, apertures 19 and 20 and output tubes 120 and 121. The feedback passage is provided with oppositely disposed nozzles 17 and 18 and orifices 17a and 18a which communicate with chamber 22. The term "orifice," as used herein, includes orifices having parallel converging or diverging walls of any conventional shape. Input tube 15 communicates with nozzle 16 and can be threadedly fixed in plate 13. Nozzle 16 forms orifice 16a which communicates with one wall of chamber 22. Apertures 19 and 20 are normally symmetrically spaced relative to orifice 16a. Flow divider 26 is substantially symmetrical to orifice 1a. Tip 29 of divider 26 defines one side of apertures 19 and 20 which have identical cross-sectional areas. A pair of oppositely diverging walls 22a and 22b forming chamber 22 join the outer walls of tubes 120 and 121, respectively and define the opposite side of the apertures. The end of input tube 15 extending from plate 13 can be connected to any conventional source of fluid under pressure indicated by reference numeral 800 in FIG. 6.

Tube 44 inserted in tube 120 scoops off a portion of the fluid flowing into that tube. Tube 44 can be threadedly or otherwise fixed into the end of tube 120. Porous plug resistors 123 and 124 may be inserted into the ends of tubes 120 and 121 in order to achieve or maintain stable oscillation.

When power nozzle 16 initially issues fluid, the resulting power jet entrains particles adjacent to its flow and tends to evacuate the chamber through which it flows. If there is a chamber wall such as wall 22a and 22b near one side of the stream the wall will impede the flow of particles to the stream. Thus the space between the stream and the wall tends to become evacuated. The pressure of particles on the opposite side of the stream tend to force the stream towards the wall. As the stream moves toward the wall the evacuation process becomes more efficient. This action which produces boundary layer lock-on is regenerative and the stream is forced against the wall.

As the power jet issues from the orifice 17a it strikes the divider 26. The stream is slightly turbulent so more of it goes on one side of divider 26 than the other. This causes a stronger boundary layer condition on one side than the other so all of the stream will be contained in

5

either aperture 19 or 20. The stream tends to evacuate the entire chamber 22, but is more effective in evacuating the region between the stream and the closest wall. Assume, for purposes of illustration, that because of stream turbulence, power jet is more efficient in evacuating fluid from wall 22a than from wall 22b.

As the power jet flows out aperture 19 and tube 120 a counter flow is induced in tube 121. Initially fluid will be evacuated from both orifices 17a and 18a and flow out feedback passage 27. However, since more fluid is flowing across orifice 17a, the fluid is evacuated more efficiently from that orifice so the flow at the orifice 18a will reverse and a pressure wave will proceed from orifice 18a to orifice 17a at the speed of sound in the local medium.

Similarly a rarefaction wave will proceed from orifice 17a to orifice 18a reducing the differential pressure which tends to force the stream towards orifice 17a. The rarefaction wave arrives at orifice 18a at the same time the pressure wave arrives at orifice 17a. The combined effect of a reduced pressure at 18a and an increased pressure at 17a occurring in phase with the stream issuing from nozzle 16 is to shift the stream from aperture 19 to aperture 20. Then there is a sudden reversal of flow. Where the fluid flow was flowing into tube 121 it is now flowing from that tube and where the fluid was flowing from tube 120 it is now flowing into that tube. Consequently, where the flow was flowing from orifice 17a of feedback passage 27 it is now flowing into that orifice. This fluid also creates a pressure wave which travels at the speed of sound in the medium through the feedback passage 27 to orifice 18a where it issues as a jet to cause the power jet to shift into aperture 19 again.

Three factors control the frequency of oscillation and these are: the speed of sound in the fluid at the particular pressure temperature and density; the length of the feedback loop; and the transit time for the power jet to flip from one chamber wall to the other.

As the speed of sound and the transit time of the power jet only change slightly for moderate changes of pressure temperature and density, the frequency of oscillation is mainly governed by the length of the feedback loop. The frequency of oscillation is very stable if changes in the ratio of the power jet pressure to the outlet pressure are slight and the temperature and density are substantially constant.

It has been determined that oscillation is most readily obtained if the apex of the flow divider or splitter is from three to eight orifice widths downstream. This is a region where the power jet is readily flipped from one side to the other by blocking the stream outlet.

As would be expected from the above, the tendency to oscillate is also enhanced by partially blocking the stream outlets because by partially blocking the outlet the pressure which feeds down the boundary layers between the bounding wall and the power jet is raised. This raised pressure assists the signal in the feedback loop to flip the power jet.

Beveling the exit end of the bounding walls facilitates the counterflow in the boundary layer and increases the tendency to oscillate. While the unit is shown with a feedback loop, a well constructed oscillator will oscillate at its highest frequency with the feedback loop removed and the control passages open to the atmosphere. Presumably the waves are transmitted through the shortest path in the atmosphere instead of being required to follow a longer path through the feedback loop.

There are several things which decrease the tendency of the unit to oscillate or prevent it from oscillating. These items fall into two classes

- (1) Attenuating or reflecting the rarefaction and compression waves and,
- (2) Increasing the "memory" of the bistable element, that is decreasing its tendency to switch when the outlet is blocked.

Under the first category, the tendency to oscillate is de-

6

creased by a feedback loop which expands and contracts under the action of the rarefaction wave and the compression wave. This effect will produce greater attenuation of the waves and extends the wave front. Long narrow passages have a similar effect. Sharp bends and right angle turns reflect the rarefaction and compression waves. By this means the waves can be prevented from reaching the opposite orifice in the correct phase relationship. Such means can thus be used to effectively prevent oscillation.

Under the second heading placing the apex of the flow divider or splitter twelve or more orifice widths downstream from the exit of the power jet enhances the stability of the unit. With the splitter in this region, it is extremely difficult to make the unit oscillate. If hooks are provided in the chamber walls vortices, created within these hooks by fluid flowing thereover will tend to prevent feedback down the boundary layer adjacent the hook. As a consequence the memory characteristic is increased and the tendency to oscillate decreased.

Oscillator 10 is employed for producing constant successive fluid output pulses so that tube 44 can receive such pulses and convey them to a second component, fluid binary counter 100.

It will be understood that any fluid pulsing means can be used for producing constant pulses and that, oscillator 10 is merely one example of fluid oscillator suitable for use as a source of constant fluid pulses. However, since it is an object of this invention to eliminate moving parts it is preferable that the sonic oscillator employed be one which has no moving parts.

Fluid-operated binary counter 100 (FIGS. 4 and 6) consists of a series of three fluid pulse converters 100a, 100b and 100c. Converter 100a (FIG. 2) consists of a fluid memory system 150, encompassed by phantom lines as shown, and a tube and nozzle connection referred to by numeral 160.

Fluid memory system 150 includes a fluid supply or power nozzle 170, a pair of control nozzles 180 and 190 and apertures 210 and 211. Orifices 181 and 191 formed by control nozzles 180 and 190 respectively, communicate with chamber 220. Fluid is supplied to system 150 by nozzle 170. System 150 is basically a fluid amplifier with a memory characteristic.

The term "memory" refers to the characteristic of the fluid stream from nozzle 170 to persist in trying to exhaust into that aperture 210 or 211, through which it is initially directed by fluid flow from one of the control nozzles 180 or 190, respectively, even after the control fluid flow has ceased from the control nozzles and despite partial or total blockage of discharge from the output tube associated with aperture 210 or 211.

In memory system 150 the flow divider blade is split in half forming two sections 261 and 262. The memory feature is achieved in system 150 by spacing the tips 391 and 392 of sections 261 and 262 respectively, a substantial vertical distance as viewed in this figure from orifice 171. This distance should be at least equal to twelve widths of orifice 171. Such spacing of the tips of the flow dividers from the orifice 171 will ensure that the fluid stream from nozzle 170 will remain locked-on to the chamber wall 221 or 222 against which it was initially deflected even though the output tube from which the stream would issue is heavily backloaded. Alternatively, the chamber walls may be provided with sharp changes of slope in order to achieve greater lock-on and memory.

Orifice 171 should preferably be positioned slightly closer to one chamber wall 221 or 222 than the other, depending upon which aperture 210 or 211 is to initially receive fluid from nozzle 170. The asymmetrical positioning of orifice 171 with respect to chamber wall 221 or 222 insures that when flow is initiated in nozzle 170, it will always flow into one aperture. Flow into one pre-selected aperture 210 or 211 can also be effected by inclining the nozzle slightly or by rounding one side of the

orifice 171. The fact that flow from nozzle 170 can be directed initially into one of the apertures permits "reset" of converter 100a. The "reset" feature will be discussed in greater detail hereafter.

Control nozzles 180 and 190 are respectively connected to the ends of tubes 240 and 250 which form the uppermost ends of the nozzle and tube connection 160. Peripheral walls 241 and 251 define the outer walls of the tubes 240 and 250 which terminate at orifice 350 formed by nozzle 360. Walls 241 and 251 are setback from orifice 350 so that fluid issuing from nozzle 360 will lock-on to either of these walls in accordance with the boundary layer control principle discussed above.

While walls 241 and 251 are setback from either side of orifice 350, their respective opposite inner walls 242 and 252 intersect to form a flow divider 260 as shown. The tip 390 of divider 260 is vertically aligned, as viewed in the figure, with the center of orifice 350 formed by input nozzle 360. Tube 44 is the single input tube which communicates with input nozzle 360 and with the output tube 121 of oscillator 10.

It is desirable to have nozzle orifice 350 and walls 241 and 251 symmetrical so that slight flow from tubes 250 and 240, or vice-versa, induced by a pressure differential in the tubes will positively influence the fluid jet from input nozzle 360 into the proper tube.

The required pressure differential induced in tubes 240 and 250 is created when the fluid stream from nozzle 170 is deflected against wall 222 of chamber 220 by a jet from nozzle 180, for example. A lower pressure region will consequently be created across orifice 191, in nozzle 190, and in tube 250 as a result of fluid flow over wall 222, than exists across orifice 181, in nozzle 180 and in tube 240. When the fluid stream from nozzle 170 is deflected against chamber wall 221 by fluid issuing from control nozzle 190, a lower pressure region will be created in nozzle 180 than exists in nozzle 190.

The vacuums which can be successively created across the orifices of the control nozzles and in the control nozzles themselves as fluid successively flows over opposite chamber walls create pressure differentials in tubes 240 and 250 which are utilized to produce alternating switching of the fluid stream, as will be evident from the following description.

As the fluid stream issues from nozzle 170 it will entrain fluid in chamber 220. The fluid stream from nozzle 170 can be positioned slightly closer to wall 222 than to wall 221, by for example, positioning nozzle 170 slightly closer to wall 222, inclining nozzle 170 slightly toward wall 222 or otherwise, as discussed above. If the fluid stream is slightly closer to wall 222 than to wall 221 the pressure on the side of the fluid stream toward wall 222 will be slightly lower than on the side of the fluid stream toward wall 221. This difference in pressure causes the fluid stream to move slightly toward wall 222 and the movement towards wall 222 causes a further reduction in pressure on the side of the fluid stream toward wall 222. The stream bends until it finally locks-on to this wall.

With the fluid stream from nozzle 170 locked-on to the chamber wall 222 the pressure in nozzle 190 and tube 250 will be lower than the pressure in nozzle 180 and in tube 240. The difference in pressure in tubes 240 and 250 will induce a small fluid stream to flow from 180 around tip 391 to nozzle 190. The velocity and mass flow induced is insufficient to unlock the fluid stream issuing from nozzle 170 from the wall 222. If a fluid pulse is thereafter fed to nozzle 360 the lower pressure existing in tube 250 and the small fluid stream flowing from 240 to 250 causes all the fluid from nozzle 360 to flow into tube 250. Fluid flowing into tube 250 issues from nozzle 190. This flow supplies fluid to the boundary layer along wall 222b. Sufficient fluid is supplied to the boundary layer to raise the pressure therein until the differential in pressure is no longer sufficient to hold the

stream onto wall 222. Consequently, the stream from nozzle 170 will swing to the center of chamber 220 evacuating fluid between it and wall 221 until the decrease in pressure between the stream and wall 221 causes the stream to lock-on to that wall. Thus, the stream issuing from nozzle 170 will switch from aperture 211 into aperture 210. A bistable switching action occurs between apertures 210 and 211 since memory system 150 will cause a definite switching of the fluid stream from the power nozzle 170 as a result of alternating fluid jets issuing successively from each of the control nozzles 180 and 190.

Since the fluid stream from power nozzle 170 is now issuing from aperture 210, a lower pressure region is created across orifice 181 of control nozzle 180 with the result that after tube 250 ceases to supply fluid to nozzle 180, tube 240 will be at a lower pressure than tube 250. Consequently, the next fluid pulse from input tube 44 will flow into tube 240 where it can issue from nozzle 180, thereby switching the fluid stream into output aperture 211.

As described above with regard to the operation of oscillator 10, where the fluid stream from nozzle 170 is switched from aperture 210 to 211 or vice versa compression and rarefaction waves are induced in tubes 240 and 250. These waves arrive between walls 241 and 251 at the same time. The waves reflect from the wall and are intermingled in the region between divider 390 and nozzle 350. The phase relationship of the original waves is also distorted. The combined result is that the waves do not have sufficient magnitude or the proper phase relationship to switch the fluid stream issuing from nozzle 170 from one outlet aperture to the other.

Slot 65, formed between the opposite edges of divider sections 261 and 262 is open to the atmosphere or to a capacitance and resistance, if required, and insures stability of the deflected stream under heavy backloading because flow from the atmosphere down slot 65 will always allow a higher pressure to exist on the side of the fluid stream opposite the boundary layer region. This is so because ordinarily the pressure in the amplifier and in the boundary layer region will always be less than atmospheric. The combined effect of the lower-than-atmospheric pressure in the boundary layer region and the atmospheric pressure on the other side of the fluid stream in chamber 220 ensures that the stream will be held against the chamber wall 221 or 222 towards which it was deflected by a control jet even though output tubes 223 and 224 are heavily loaded by tubing or valves. If the pressure in the amplifier is greater than the surrounding atmosphere a closed container forming a fluid capacitance should be connected to slot 65. The capacitance will periodically store fluid and issue it into slot 65 so as to aid the stability of deflection of the power jet.

The fluid signal supplied to tube 44 will be a series of fluid pulses from oscillator 10 while the fluid stream issuing from nozzle 170 will be alternately deflected from one aperture to another in system 150, and thus from output tube 223 to tube 224 as a consequence of the induced pressure differential in the nozzle and tube connection 160. Tubes 240, 250 and nozzle 360 thusly cooperate to convert sequential fluid pulses received from oscillator 10 into alternating fluid pulses. It should be noted that no moving parts are required to perform the conversion function. Also because of the memory characteristic system 150, once the fluid stream locks-on to one wall of the chamber 220, it remains locked-on to that wall in the absence of the fluid from both control nozzles 180 and 190. Since memory system 150 is basically a pure fluid amplifier, the large energy stream from nozzle 170 will be deflected by jets from the control nozzles 180 or 190 having lesser energy.

Pulse converters 100b and 100c (FIGS. 4 and 6) are identical in shape and size to converter 100a described above and are modified by the addition of tubes 45 and 46.

Tubes 45 and 46 are designed and positioned to scoop off a portion of the fluid stream entering the apertures of converters 100a and 100b respectively. Tubes 45 and 46 communicate with each input nozzle 360b and 360c of converters 100b and 100c, respectively, causing deflection of the fluid stream issuing from the power nozzles 170b and 170c. Also successive pulses of fluid entering nozzles 360b and 360c of converters 100b and 100c will cause successive deflections of the stream issuing from these nozzles into opposite tubes 240a, 250a, 240b, 250b, 240c and 250c of the tube connection, as discussed above with regard to converter 100a. Fluid resistors which may take the form of porous plugs 70a, 71a, 70b, 71b, 70c, 71c, are fitted into the output tubes in order to insure proper backloading of the output tubes and deflection of the fluid into those tubes.

Tube 75 is connected to source 800 and to each input tube 150a, 150b and 150c of the converters. Tube 76 is connected to tube 75 and to input tube 15 of oscillator 10. When valve 801 is turned on fluid will be fed from source 800 to the oscillator and to each converter of counter 100.

Source 800 may be any source of pressurized liquid or gas or combination thereof. The orifice of each power nozzle in each converter 100a, 100b and 100c is positioned slightly closer to one chamber wall than the other. If the orifices are closer to walls 222a, 222b and 222c than to walls 221a, 221b and 221c, after valve 801 is turned on the fluid stream issuing from nozzles 170a, 170b and 170c will lock-on to walls 222a, 222b and 222c and issue from output tubes 224a, 224b and 224c. This is known as the "turn-on" position of the counter.

If a single pulse of fluid from oscillator 10 is received by nozzle 360a in converter 100a, it will issue from tube 250a and thus from nozzle 190a. Fluid from nozzle 190a will deflect the stream from nozzle 170a into aperture 210a and hence into tubes 223a and 45. Fluid entering tube 45 issues from nozzle 360b of converter 100b. The fluid output of converter 100b will be flipped from tube 224b to tubes 223b and 46. Fluid entering tube 46 is conveyed to nozzle 360c of converter 100c. The output of converter is thusly deflected from tube 224c to tube 223c.

If the fluid stream supplying nozzle 360a is interrupted by a second pulse, the flow pattern in counter 100 will change again. Since the pulsing of the fluid stream entering nozzle 360a of converter 100a causes switching of the fluid stream from tube 45 to tube 224a fluid will issue from output tube 224a. Since neither converter 100b nor 100c can receive a fluid pulse from converter 100a, these latter converters continue to issue fluid from tubes 223b and 223c.

When the flow to nozzle 360a in converter 100a is interrupted or pulsed for the third time, the flow in converter 100a is switched from tube 224a to tube 223a and 45. Fluid flowing through tube 45 causes the fluid issuing from nozzle 170b in converter 100b to switch from tube 223b to tube 224b. In the absence of a pulse to nozzle 360c converter 100c continues to issue fluid from tube 223c.

When the fourth fluid pulse is supplied to converter 100a converters 100a and 100b have the same flow pattern as they did when the first pulse was received by the counter, whereas the fluid issuing from converter 100c is caused to switch from tube 223c to tube 224c.

Counter 100, as shown, is capable of counting up to seven successive fluid pulses before it resets. As will be evident, the reset occurs on the seventh pulse after the initial or turn-on pulse is received. Those in the art will appreciate that by merely increasing the number of fluid converters counter 100 may count any number of successive fluid pulses before the counter resets.

In order to facilitate understanding the flow characteristics of the binary counter, the value "1" has been assigned to represent fluid flow from each output tube 224a,

224b and 224c, and the value "0" has been assigned to represent fluid flow from each output tube 223a, 223b and 223c.

Referring now to Table I below, there is shown the output fluid patterns of the various pulse converters 100a, 100b and 100c which comprise counter 100. The left-hand column of the table lists the successive oscillations of oscillator 10. The values "1" and "0" represent that output tube of each converter from which fluid is flowing. For any given number of oscillations of oscillator 10 the characteristics of the counter can be determined. The term "oscillation," as used herein, refers to one complete cycle of deflection of the fluid stream in the oscillator from either output tube.

Table I

	Output of Fluid Pulse Converters		
	100a	100b	100c
Signal Turn-On	1	1	1
1st Oscillation	0	0	0
2nd Oscillation	1	1	0
3rd Oscillation	0	0	0
4th Oscillation	0	0	1
5th Oscillation	1	0	0
6th Oscillation	1	1	1
7th Oscillation	0	0	0
8th Oscillation	1	0	0
9th Oscillation	0	1	0
10th Oscillation	0	0	1
11th Oscillation	1	0	0
12th Oscillation	1	0	1
13th Oscillation	1	1	1
14th Oscillation	1	1	1

At signal turn-on that is, when valve 801 is turned so that fluid from source 800 is supplied to tube 70 and hence, to each fluid nozzle 170a, 170b and 170c, fluid flow will issue from tubes 222a, 222b and 222c. Since the value "1" has been assigned the flow output of these tubes the output characteristics of the converters will be "1," "1," "1." After the first oscillation of oscillator 10, since the fluid will issue from tubes 221a, 221b and 221c the output flow characteristic is represented by three "0's." At the second oscillation, fluid will issue from tubes 222a, 222b and 222c, as stated above, and hence the counter characteristics will be "0," "0" and "1." At the seventh oscillation, the counter will reset and the cycle repeats.

Tabulating the output flow characteristics of the counter such as shown in table I is helpful since once the output flow characteristics of the counter are known fluid-operated readout components can be suitably connected to the output tubes of the counter which will read-out any arrangement or sequence of numbers "1" and "0."

As stated above, for any given number of oscillations of oscillator 10, the counter will have an overall output characteristic as indicated by the table. It is possible to connect to the output tubes of the counter a fluid-operated readout unit in the form of a fluid AND component 300 which will detect and indicate by means of a fluid output pulse from one output tube of the AND component when any particular combination of pulses issues from counter 100. The particular combination of pulses is of course related to the time required before oscillator 10 produces enough pulses to produce that particular flow characteristic in the counter. The particular connection of the input tubes of the AND component to the output tubes of the counter will depend upon the characteristic of the output flow pattern.

For example, if it were desired to detect the occurrence of the sixth oscillation which, as shown, has a "1," "0," "1" output flow pattern, the AND component 300 might be used to indicate the presence of this pattern by a pulse from one output tube thereof.

Component 300 consists of three input nozzles 363, 373, and 383 and input tubes 224a, 224b and 224c which feed fluid input signals into respective input nozzles. Ori-

fices 364, 374, and 384 are formed by nozzles 363, 373 and 383, respectively, and communicate with jet interaction chamber 333. Apertures 343 and 353 also communicate with jet interaction chamber 333, as shown. Output tubes 443 and 453, see FIG. 3, communicate with apertures 343 and 353. Tubes 443 and 453 are the AND and NOT output tubes respectively, of component 300. Tube 443 divides to form two tubes 463 and 473. Porous plugs 483 and 484 may be inserted as shown in order to provide proper backloading of the AND component.

As the fluid stream issues from nozzle 363 it will entrain fluid in chamber 333. The fluid stream from nozzle 363 may be positioned closer to wall 473 than to wall 463, for example, by positioning orifice 364 substantially closer to wall 473 or by inclining nozzle 363 towards wall 473. Orifice 364 may be positioned to the right of the tip of divider 393 to facilitate shifting the stream since wall 463 can be setback far enough from orifice 364 to prevent boundary layer lock-on from occurring. As fluid issues from nozzle orifice 364, because wall 473 is closer to the stream than wall 463, the pressure on the side of the fluid stream toward wall 473 will be lower than on the side of the fluid stream toward wall 463. This difference in pressure causes the fluid jet from nozzle 363 to move toward wall 473 and the movement towards this wall causes a further reduction in pressure on the side of the fluid stream toward that wall. The stream bends until finally it locks-on to this surface. Fluid from nozzle 363 will never lock-on to wall 463 because this wall is setback far enough from orifice 364 to prevent boundary layer lock-on from occurring.

As the pressure in the boundary layer between the fluid stream and the wall 473 decreases, the tendency of the fluid stream to remain locked-on to that wall increases, as will be apparent. Consequently, in the absence of an input signal from nozzle 373 the stream from 363 flows along wall 473 into aperture 353 and out NOT tube 453.

If tube 224a does not receive a fluid signal while tube 224c is receiving such a signal, the jet from nozzle 363 enters aperture 353 since wall 463 is too far away from orifice 364 to provide a surface upon which the stream can lock-on to.

Fluid flowing into tube 224a issues as a jet from orifice 374. This jet supplies fluid to the boundary layer between 473 and the fluid stream from nozzle 363. Sufficient fluid must be supplied to the boundary layer to raise the pressure therein until the differential in pressure is no longer sufficient to hold the stream onto wall 473. As the magnitude of the input signal increases the stream from nozzle 363 will be deflected to the right of chamber 333. Thus, the stream issuing from nozzle 363 will switch from aperture 353 into aperture 343 in the absence of flow from nozzle 383.

Nozzle 383 is positioned to issue fluid from orifice 384 to deflect the fluid stream into aperture 353 if tube 224b receives fluid. Thus only if there is no flow into tube 224b will fluid issue from tube 463.

The presence of both input signals to nozzles 363 and 373 and the absence of a signal to nozzle 383 will be indicated by fluid flowing from output tube 463.

Fluid capacitances and/or fluid resistances in the form of porous plugs, for example may be included in the tubes of the system to shape and regulate the pulses as is known to those skilled in the art.

If additional pulse converters are incorporated into the system additional AND-NOT components will be needed to detect the increased number of signals forming a particular pattern. However, the signals from the additional AND-NOT components can be combined by means of other AND-NOT units to form a single output if desired.

It will be evident from the foregoing that output tube 463 will only issue a fluid pulse when a "1," "0," "1" pattern is produced by counter 100.

Binary counter 100 has a natural repetitive cycle of seven oscillations. Reset occurs after the seventh oscilla-

tion. If the timer is to have a longer or shorter repetitive time cycle, then reset must occur after a greater or lesser number of pulses have been received from oscillator 10.

If desired an additional AND component 500, FIG. 5, may be employed to effect resetting of counter 100 after a predetermined number of oscillations of oscillator 10. In this component also, boundary layer lock-on is utilized to achieve the AND or NOT function. As can be seen from FIG. 5, component 500 consists of two input nozzles 563 and 583 and associated input tubes 575 and 463 which feed fluid input signals into respective input nozzles. Orifices 564 and 584 are formed by nozzles 563 and 583, respectively, and communicate with jet interaction chamber 533. Apertures 543 and 553 also communicate with chamber 533, as shown. Output tubes 521 and 522 communicate with apertures 543 and 553. Tubes 521 and 522 are the NOT and AND output tubes respectively, of component 500. Tube 75 is connected to tube 521 so as to receive fluid therefrom as shown in FIG. 6.

Fluid flowing into tube 463 issues as a jet from orifice 584. This jet supplies fluid to the boundary layer between wall 560 and the fluid stream issuing from nozzle 563. Source 300 supplies fluid to tube 575. Sufficient fluid must be supplied to the boundary layer to raise the pressure therein until the differential in pressure is no longer sufficient to hold the stream from nozzle 563 onto wall 560. As the magnitude of the input signal increases the stream from nozzle 563 will be deflected to the lower portion of chamber 533 by fluid from nozzle 583. Thus, the stream issuing from nozzle 563 will switch from aperture 521 into aperture 522. In no case will fluid from nozzle 575 lock-on to chamber wall 570 since this wall is set back a considerable distance from orifice 564. The presence of both input signals will be indicated by fluid flowing from output tube 522.

Fluid flowing from nozzle 583 interrupts the flow from source 800 into tube 75. Fluid flow to counter 100 is thereby momentarily stopped and consequently flow to nozzle 583 subsequently ceases because of the absence of a signal from AND component 300. Counter 100 is thusly reset. Since component 300 is no longer issuing an output signal which would deflect flow from source 800 into tube 522, tube 75 again receives fluid flow from this source and the cycle begins once again in the counter.

Those skilled in the art will realize that fluid capacitors and fluid resistors may be used in the system to shape and regulate the number of output pulses. Such capacitors and resistors may exhaust to atmosphere or to other sources of pressure which themselves can provide predetermined pressure levels and differentials in the system.

In the absence of a fluid jet from nozzle 563, fluid issuing only from nozzle 583 will be deflected by curved wall section 593 and issue from tube 522. As an alternative to curved wall section 593, a spill-out aperture may be positioned opposite orifice 584.

Since the fluid timer consists basically of a fluid oscillator, a series of pulse converters, and a fluid AND logic component, any other suitable fluid-operated system which performs the same or an analogous function may be substituted for the components shown and described in this application. For example the fluid pulse converter may also take the form of a fluid pulse converter disclosed in my copending patent application Serial No. 60,763 filed October 5, 1960, now matured into U.S. Patent 3,001,698, issued Sept. 26, 1961. The AND component may take the form of one of the AND components disclosed in patent application Serial No. 96,623, filed March 17, 1961 of Billy M. Horton and myself.

I claim as my invention:

1. A fluid-operated timer comprising, a source of pressurized fluid, oscillating means connected to said source for producing periodic fluid pulses, means limiting said fluid within said oscillating means to a plane of oscillation of said fluid, fluid-operated means for converting said pulses into a fluid flow pattern, the characteristics of said

13

flow pattern being dependent upon the number of pulses received, means limiting said fluid flowing within said fluid-operated means to a single plane, means connected to said source and said fluid-operated means for resetting said fluid-operated means after a predetermined flow pattern is created by said fluid-operated means and means limiting said fluid flowing within said resetting means to a single plane.

2. A fluid-operated timer comprising, means for providing timed fluid pulses, fluid pulse counting means connected to said source for converting said fluid pulses into fluid flow patterns, fluid-operated readout means connected to said counting means for reproducing a fluid signal upon the occurrence of certain of such flow patterns, a fluid-operated component connecting said readout means and said counter for resetting said counting means upon receiving a fluid signal from said readout means, and fluid limiting means in each of said means for providing timed fluid pulses, said fluid pulse counting means, said fluid-operated readout means and said fluid-operated component confining said fluid to a single plane within each of said means.

3. In a fluid-operated timer, a fluid power source, a fluid oscillator means for producing timed fluid pulses, said fluid oscillator having a power input means and a pair of pulse output means, a plurality of counter means for converting said timed fluid pulses into fluid flow patterns, each of said counter means having a fluid pulse input means, a fluid power input means and a pair of flow output means, a readout means for determining a pre-selected number of fluid pulses including a plurality of flow input means and a pair of readout output means, a

14

reset means having a power input means, a readout input means, a power output means and an exhaust means, and first means for connecting said fluid power source to said power input means in said fluid oscillator means and in said reset means, second means for connecting one of said pulse output means of said fluid oscillator means to said pulse input means of a first of said plurality of counter means, third means for connecting one of said flow output means of said first counter means to the power input means of a second of said counter means, fourth means for connecting the other of said flow output means of said first counter means to a first one of said flow input means of said readout means, fifth means for connecting the other of said flow output means of said second counter means to a second one of said flow input means of said readout means, sixth means for connecting one of said pair of readout output means to said readout input means in said reset means and seventh means for connecting said power output means of said reset means to said fluid power input means in each of said counters.

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