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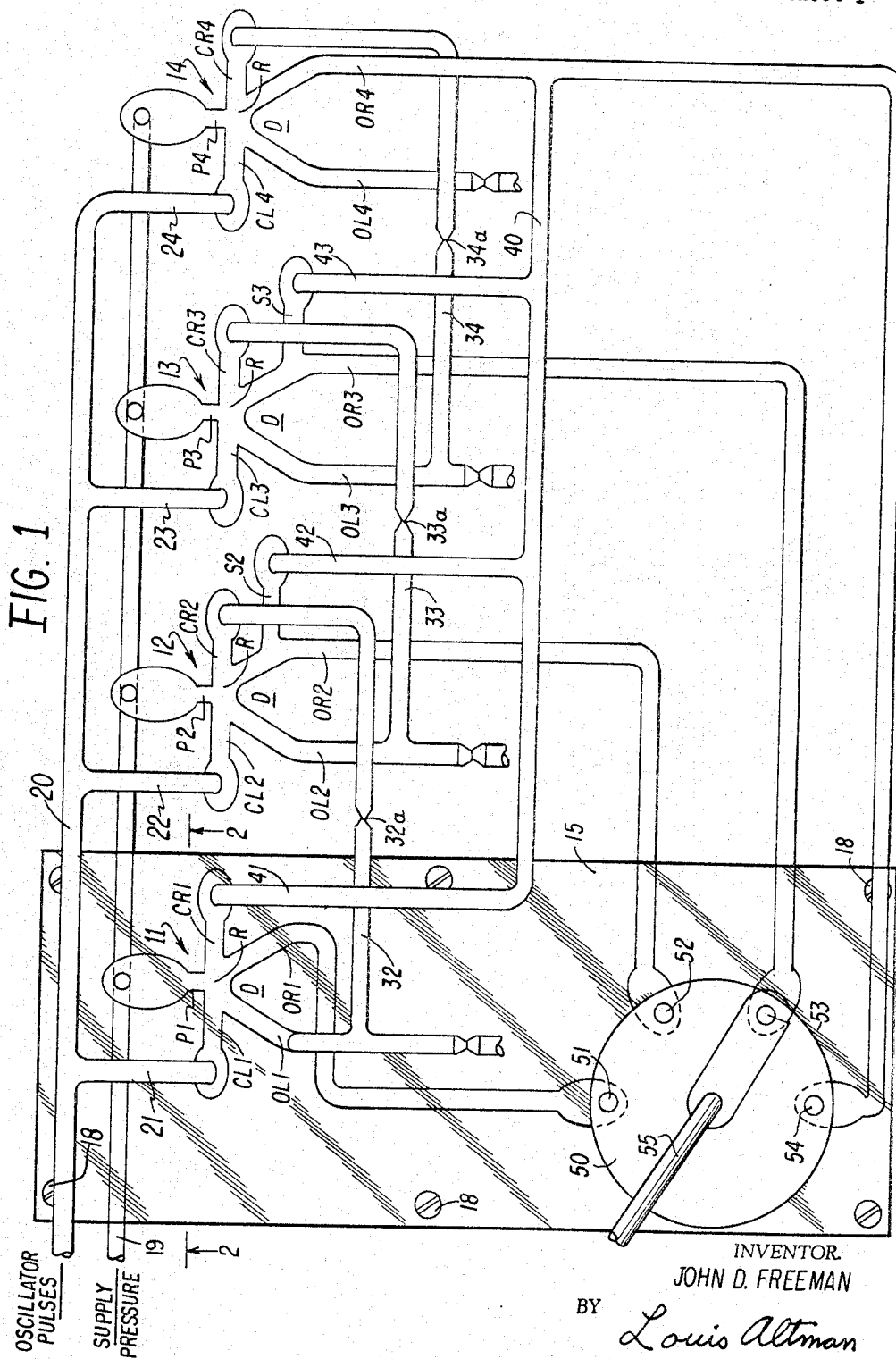
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3,276,689

FLUID OPERATED TIMER CIRCUIT

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2 Sheets-Sheet 1



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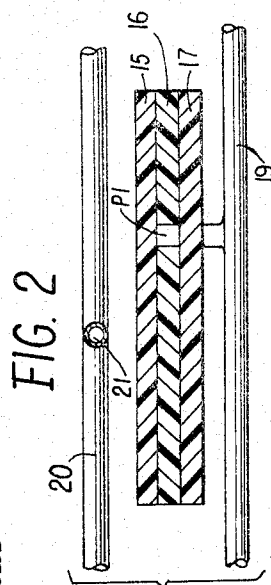
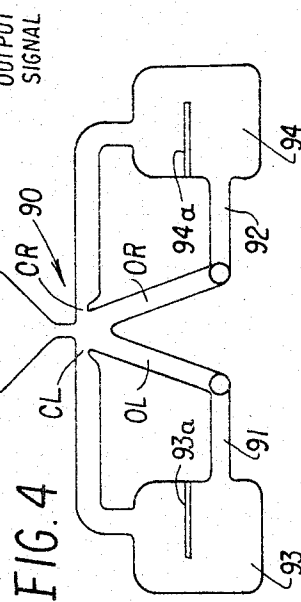
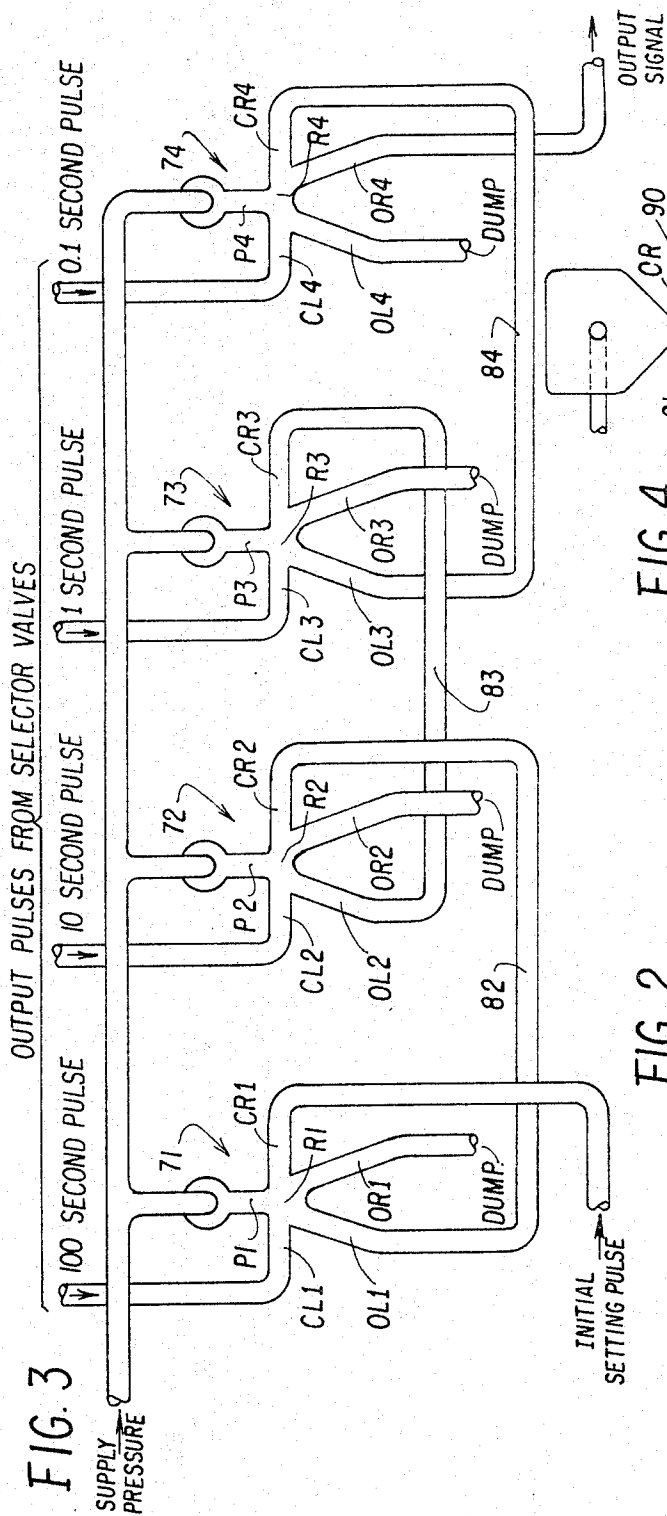
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2 Sheets-Sheet 2



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FLUID OPERATED TIMER CIRCUIT

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The present invention relates generally to fluid-operated timers, more particularly, to improved fluid-operated counter and adder circuits suitable for use in a fluid-operated timer.

It is a primary object of the present invention to provide an improved fluid-operated timer which is capable of measuring practically any predetermined time interval in relatively small increments, such as in increments of a tenth of a second or less. Another object is to provide an improved fluid-operated timer which is extremely accurate, even over relatively long time intervals.

It is a further object of the present invention to provide an improved fluid-operated timer including a plurality of fluid-operated switching elements for counting a sequence of timed fluid pulses at close intervals. A related object is to provide such a timer wherein the fluid-operated switching elements respond extremely rapidly to the fluid pulses being counted. Another related object is to provide such a timer in which the timed fluid pulses being counted are applied directly to each of the individual switching elements rather than being applied to only a single switching element and then passed sequentially through the remaining switching elements. In this connection, it is an object to provide such a timer in which the response time for any given pulse is the response time of only a single fluid-operated switching element rather than the cumulative response times of a plurality of such elements.

It is still another object of the invention to provide an improved fluid-operated timer in which each of the timed fluid pulses being counted produces a predetermined output signal from only a single fluid-operated switching element. An allied object is to provide such a timer in which each timed fluid pulse produces a predetermined output signal by the switching of only a single fluid-operated switching element. A further object is to provide such a timer in which each fluid-operated switching element is switched only once between resettings of the fluid-operated counter.

Yet another object of the present invention is to provide an improved fluid-operated timer which is positive starting and which automatically resets itself. It is another object to provide such a timer which is simple to construct, having no moving parts, and is reliable even over extended periods of operation.

A still further object of the invention is to provide an improved fluid-operated adder suitable for use in a fluid-operated timer and which has a low response time. Thus, it is an object to provide such an adder which produces the desired output signal without substantially extending the desired time interval. In this connection, it is an object to provide such an adder which substantially increases the reliability and accuracy of the present timer over fluid-operated timers of the prior art.

Other objects and advantages of the invention will become apparent upon reading the following description and appended claims and upon reference to the drawings, in which:

FIGURE 1 is a partially diagrammatic plan view of an improved fluid-operated counter circuit embodying the present invention;

FIG. 2 is a sectional side view of FIGURE 1 taken along section line 2-2;

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FIG. 3 is a diagrammatic plan view of an improved fluid-operated adder circuit embodying the present invention; and

FIG. 4 is a diagrammatic plan view of a fluid-operated oscillator suitable for use in a completely fluid-operated timer including the circuits of FIGS. 1 and 3.

While the invention will be described in connection with certain preferred embodiments, it is to be understood that the invention is not to be limited to the disclosed embodiments but, on the contrary, it is intended to cover the various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

In the practice of the present invention, there is provided an improved fluid-operated timer circuit comprising, in combination, a source of pressurized fluid, a series of fluid-operated switching elements each of which has a body defining a jet chamber having a power nozzle at one end connected to the source of pressurized fluid to produce a power jet and having first and second output tubes at the other end, first and second control nozzles on opposite sides of the power nozzle for directing the power jet toward the respectively opposite output tubes to define first and second states of operation, means for applying timed fluid pulses directly to the first control nozzle of each switching element for switching each element from the first to the second state of operation, biasing means operatively associated with the second control nozzle of each switching element for selectively controlling the switching of the elements by the timed fluid pulses, the biasing means for each element being responsive to the switching of the preceding element in the series so that the elements are switched sequentially in timed relation to said timed fluid pulses, and reset means for restoring the switching elements to the first state of operation.

Thus, referring to FIG. 1, there is provided a fluid-operated timer circuit including a series of bi-stable fluid amplifiers 11, 12, 13, and 14 preferably formed by three flat plates 15, 16, and 17, as shown in the sectional view in FIG. 2. The plate 16, which is centrally contoured, is positioned between the plates 15 and 17, and all three plates are secured together by a plurality of machine screws 18. These plates may be composed of metal, plastic, or other suitable material. For the purpose of illustration, the plates are shown composed of clear plastic material. Although the plate structure is shown only for the first amplifier 11, it will be understood that the other three amplifiers 12, 13, and 14 can be constructed in the same manner.

The configuration cut from the center plate 16 for each amplifier defines a central power nozzle P which is fed from a fluid pressure line 19. The pressurized fluid passes through the power nozzle P and issues therefrom as a high energy power jet which passes between first and second control nozzles CL and CR through a jet chamber R. At the front of the chamber for receiving the jet are first and second diverging output tubes OL and OR separated by a divider D. It is a known phenomenon in fluid-operated amplifiers of the boundary-layer-controlled type that the jet does not remain centered but tends to cling to one of the side walls of the chamber R, in accordance with the Bernoulli principle, so that the jet is directed into one of the output tubes. This represents one stable state of operation. In order to switch the amplifier to the other stable state, pressurized fluid is passed into the control nozzle CL or CR nearest the power jet so as to provide a control jet which deflects the power jet over into the other output tube. Although the boundary-layer-controlled type of fluid amplifier is preferred in this invention, it will be understood that other types of fluid amplifiers may be used.

As shown in FIG. 1, each of the intermediate amplifiers 12 and 13 between the first and last amplifiers 11

and 14, respectively, also has a secondary control nozzle S opening into the right hand output tube OR. This secondary control nozzle S operates in the same manner as the control nozzle CR, so that the power jet can be switched from output tube OR over into output tube OL by applying pressurized fluid to either the primary control nozzle CR or the secondary control nozzles.

For the purpose of actuating the bi-stable amplifiers 11 through 14, timed fluid pulses are passed through a line 20 which has a plurality of branches 21, 22, 23, and 24 each of which leads into the left hand control nozzle CL of one of the bi-stable amplifiers. Thus, it can be seen that the timed fluid pulses are continuously applied directly to the left hand control nozzle CL of all four amplifiers. Before the application of the timed fluid pulses is commenced, the power jet of each of the four amplifiers is directed to its left output tube OL. Then, when the timed fluid pulses are applied to the left hand control nozzle CL, they tend to deflect the power jet away from tube OL over into tube OR.

However, as the power jet of the first amplifier 11 is discharged through the output tube OL1, a portion of the fluid is directed through a line 32 into the right hand control nozzle CR2 of the second amplifier 12, the remainder of the fluid being dumped through the restricted portion of OL1. Similarly, fluid from output tube OL2 of the second amplifier 12 is directed through a line 33 to nozzle CR3 of the third amplifier 13, and fluid from output tube OL3 of the third amplifier is directed through a line 34 to nozzle CR4 of the fourth amplifier 14. Thus, each of the amplifiers 12, 13 and 14 is "biased" to the left by the jets emerging from the control nozzles CR2, CR3 and CR4, and the first amplifier 11 is the only amplifier that is "conditioned" for switching. In other words, amplifier 11 is the only one that is not biased. As a result, although the first fluid pulse from the line 20 is applied to all four amplifiers, it switches only the first amplifier 11 by deflecting the power jet from output tube OL1 to output tube OR1.

The right hand output tube OR1 of the first amplifier 11 is connected to a manually adjustable selector valve, as described in more detail hereinafter. Thus, switching of the first amplifier 11 from tube OL1 to tube OR1 removes the biasing fluid from control nozzle CR2, thereby conditioning the second amplifier 12 for switching. As a result, the second fluid pulse from the line 20 switches the second amplifier 12 by deflecting the power jet therein from tube OL2 to tube OR2. This in turn removes the biasing fluid from control nozzle CR3, conditioning the third amplifier 13 for switching, so that the third fluid pulse deflects the third power jet from tube OL3 to tube OR3. Finally, since the biasing fluid from control nozzle CR4 has been removed by the switching of amplifier 13, the fourth pulse switches the fourth amplifier 14 from tube OL4 to tube OR4.

It can be seen from the above description that the lines 32, 33 and 34 and the right hand control nozzles CR2, CR3 and CR4 act as biasing or conditioning means which selectively control the switching of the bi-stable amplifiers by the timed fluid pulses from the line 20. Moreover, each of these biasing or conditioning means is responsive to the switching of the preceding amplifier, so that the amplifiers are switched sequentially in timed relation to the applied fluid pulses. However, it is important to note that only the biasing of each amplifier is controlled by the preceding amplifiers in the series, and that the actual switching of the amplifiers is effected by pulses applied directly from the line 20.

In accordance with one feature of this invention, in order to insure that none of the applied fluid pulses switches two of the bi-stable amplifiers at the same time, small restrictions 32a, 33a and 34a are provided in the biasing lines 32, 33 and 34, respectively, and corresponding restrictions are provided in the ends of the output lines OL which feed the biasing lines. These restrictions

act as time delay means so that some biasing fluid will continue to flow out of the control nozzles CR for a short time after the pulses are removed.

For the purpose of resetting the four amplifiers to their original stable states, a portion of the fluid from output tube OR4 of the last amplifier 14 is directed through a reset line 40. This reset line 40 has three branches 41, 42, and 43 which direct the resetting fluid to the nozzle CR1 of the first amplifier and the secondary control nozzles S2 and S3 of the second and third amplifiers respectively. Thus, the resetting fluid deflects the power jet of each of the amplifiers 11, 12 and 13 from output tube OR over into tube OL, thereby restoring these amplifiers to their original stable states. As the power jet of amplifier 13 is deflected into output tube OL, a portion of the fluid passes through line 34 into control nozzle CR4. This resets the fourth amplifier 14 by deflecting the power jet therein from tube OR4 to tube OL4. At this point, one complete cycle of the timing operation is then completed and all four amplifiers are in their original state with the power jets being discharged through the output tubes OL. When starting up the timer, the power jet of the first amplifier 11 may be directed into its left output tube OL by means of a conventional resetting pulse supplied to the control nozzle CR1 or to a supplementary nozzle on the same side of the amplifier.

In order to provide an appropriate output signal when a certain predetermined number of fluid pulses has been applied to the amplifiers, the right hand output tube OR of each amplifier is connected to a selector valve 50. Thus, output tube OR1 is connected to port 51 of the valve 50, tube OR2 is connected to port 52, tube OR3 is connected to port 53, and tube OR4 is connected to port 54. The selector valve 50 is manually set to direct fluid from the appropriate port into outlet 55. For example, in FIG. 1 the valve is set to use the fluid from port 53 to produce an output signal, which would indicate the third pulse of each cycle. It will be apparent that these output signals may be passed into an adder, as described hereinafter, where multiple cycles are required to count the desired number of pulses. Also, while the particular counter shown in the drawings includes only four bi-stable amplifiers or switching elements, it is obvious that the circuit may be expanded to include any desired number of amplifiers.

It will be understood that in a complete fluid-timer, a plurality of counters such as that shown in FIG. 1 are connected together in a cascade arrangement, with the output signals of the various counters being fed into an adder. After the total interval indicated by the sum of the various adder input signals has elapsed, the adder triggers an appropriate output transducer to activate the particular device being timed, for example, an explosive detonator.

In accordance with a further aspect of the invention, there is provided a fluid-operated adder comprising a series of fluid-operated switching elements each of which is connected to a different fluid-operated counter so as to be switched from one stable state to the other by the timed fluid pulses from the counter, and biasing means for selectively controlling the switching of the switching elements, the biasing means for each switching element being responsive to the switching of the preceding element in the series whereby the elements are switched sequentially in timed relation to the timed fluid pulses from the counter. Thus, referring to FIG. 3, there is provided a series of bi-stable fluid amplifiers 71, 72, 73 and 74. These amplifiers are similar to those described above in connection with the counter circuit of FIG. 1, each amplifier having a power nozzle P connected to a source of pressurized fluid, a chamber R, first and second output tubes OL and OR leading away from the power nozzle P, and first and second control nozzles CL and CR opening into the first and second outlet tubes adjacent the orifice of the power nozzle P.

Assuming that the adder of Fig. 3 is to be used to add pulses from four different counters producing pulses at intervals of 100 seconds, 10 seconds, 1 second and 0.1 second, respectively, the output pulses from the four counters are passed into the left hand control nozzles CL of the four amplifiers 71, 72, 73 and 74. The pulses having the lowest frequency, i.e., the pulses with the largest intervals are applied to the first amplifier 71, while the other pulses are applied to the remaining amplifiers in the order of increasing frequency. For example, to add pulses from the arrangement of four counters mentioned above, the 100-second pulses would be applied to the first amplifier 71, the 10-second pulses would be applied to the second amplifier 72, the 1-second pulses would be applied to the third amplifier 73, and the 0.1-second pulses to the fourth amplifier 74.

As in the case of the counter circuit of FIG. 1, the power jet of each of the four amplifiers 71, 72, 73 and 74 is initially directed into its left output tube OL. Then when the counter pulses are applied to the left control nozzle CL, they tend to deflect the power jet away from tube OL over into tube OR. However, as the power jet from the first amplifier 71 is discharged through the tube OL1, the fluid is directed through a line 82 into control nozzle CR2 of the second amplifier 72. Similarly, fluid from output tube OL2 of the second amplifier is directed through a line 83 to nozzle CR3 of the third amplifier 73, and fluid from the tube OL3 of the third amplifier is directed through a line 84 to nozzle CR4 of the fourth amplifier 74. Thus, each of the amplifiers 72, 73, 74 is "biased" to the left by the jets emerging from the control nozzles CR2, CR3 and CR4, and the first amplifier 71 is the only one that is not biased and, therefore, is "conditioned" for switching.

Because of the biasing of amplifiers 72, 73, and 74, these amplifiers are not switched by any pulses applied thereto prior to the switching of amplifier 71. When the first pulse is applied to control nozzle CL1 of amplifier 71, that amplifier is switched, and the bias is removed from the second amplifier 72. This conditions amplifier 72 for switching so that the next pulse applied to nozzle CL2 deflects the power jet in amplifier 72 from tube OL2 to tube OR2. This removes the bias from amplifier 73 so that it is conditioned for switching by the next pulse applied to control nozzle CL3. Finally, after switching of amplifier 73, the bias is removed from amplifier 74, which is switched by the next pulse applied to nozzle CL4.

It can be seen from the above description that the biasing lines 82, 83 and 84 and the right hand control nozzles CR2, CR3, and CR4 act as biasing or conditioning means which selectively control the switching of the bi-stable amplifiers by the applied fluid pulses from the various counters. Moreover, each of these biasing or conditioning means is responsive to the switching of the preceding amplifier so that the amplifiers are switched sequentially in timed relation to the pulses from the various counters.

As each of the first three amplifiers 71, 72 and 73 is switched from tube OL to tube OR, the fluid in tube OR is dumped to a suitable fluid sink. However, when the fourth amplifier 74 is switched, the fluid from tube OR4 is used as the output signal which is fed into an appropriate transducer. The particular time period represented by this signal depends on a number of factors, such as the frequency of the original fluid pulses applied to the counters and the setting of the various counter selector valves 50. Thus, if the original pulses were produced at a rate of 10 pulses per second and applied to a cascade of four counters each having ten switching elements, and with each of the four counter selector valves being set at the first port, the adder output would represent a period of 111.1 seconds. Of course, it will be apparent that this period could be varied by simply adjusting the setting of the selector valves, and would be accurate to values within a tenth of a second.

It will be understood that the timed fluid pulses applied through line 20 to the ring counter of FIG. 1 may be generated by any suitable source. One such source is a fluid-operated oscillator such as that illustrated in FIG. 4.

This oscillator comprises a bi-stable fluid amplifier 90 having a pair of feedback loops 91 and 92. Each feedback loop leads from one of the output tubes OL or OR back into the corresponding control nozzle CL or CR. Assuming the power jet initially locks on to output tube OL, a portion of the fluid leaks into feedback loop 91 and eventually issues as a control jet from control nozzle CL. This deflects the power jet over into output tube OR, where a portion of the fluid bleeds back through loop 92 and issues from control nozzle CR to deflect the jet back to output tube OR. This switching action continues as long as sufficient pressure is maintained in the power jet, with the period of frequency of the oscillator depending on the supply pressure and exhaust pressure, fluid temperature and flow resistance and capacitance of the feedback loops.

In order to provide the desired oscillator frequency, the feedback loops 91 and 92 are provided with capacity chambers 93 and 94, respectively, having corresponding baffles 93a and 94a therein. Also further modifications may be made to provide the required frequency stability. For example, in order to compensate for temperature fluctuations, it is contemplated that the feedback loops may be provided with resistance and/or capacitance means which expand and contract in accordance with respective increases and decreases in temperature. Similarly, to compensate for pressure variations, the source of pressurized fluid may consist of a chamber filled with a fluid in both liquid and vapor states whereby a constant supply pressure is maintained. It is further contemplated that temperature compensation may be provided by expandable chamber walls, if desired.

It will be seen that the invention provides an improved fluid-operated timer circuit in which the timed fluid pulses being counted or added are applied directly to each of the individual switching elements in the particular circuit involved, rather than being applied to only a single switching element and then passed sequentially through the remaining elements. Thus, each switching element is switched only once in each complete cycle, and the response time for any given pulse in a particular circuit is the response time of only a single switching element rather than the cumulative response time of a plurality of elements. Moreover, the circuits of this invention are positive starting and capable of automatic resetting.

What is claimed is:

1. A fluid-operated counter circuit for use in a fluid-operated timer, said counter comprising, in combination, means for transmitting pressurized fluid, a series of bi-stable fluid-operated amplifiers each of which has a body defining a jet chamber having a power nozzle at one end connected to said means for transmitting pressurized fluid to produce a power jet and having first and second output tubes at the other end, first and second primary control nozzles on opposite sides of said power nozzle, each of the amplifiers between the first and the last amplifiers of said series also having a secondary control nozzle on the same side as the second primary control nozzle, a fluid-operated oscillator connected directly to the first control nozzle of each amplifier for applying timed fluid pulses thereto, the second primary control nozzle of the first amplifier in said series being connected to the second output tube of the last amplifier and to the secondary control nozzles of the other amplifiers in said series, the second primary control nozzle of each of the other amplifiers being connected to the first output tube of the preceding amplifier in the series, and a selector valve connected to the second output tube of each of said amplifiers.

2. A fluid-operated timer circuit comprising, in com-

bination, means for transmitting pressurized fluid, a plurality of fluid-operated counters each generating timed fluid pulses at different predetermined frequencies, and a fluid-operated adder circuit comprising a series of fluid-operated switching elements each of which has a body defining a jet chamber having a power nozzle at one end connected to said means for transmitting pressurized fluid to produce a power jet and having first and second output tubes at the other end, first and second control nozzles on opposite sides of said power nozzle, the first control nozzle of each switching element being connected directly to one of said counters for receiving timed fluid pulses to switch said element from the first to the second state of operation, biasing means operatively associated with the second control nozzle of each switching element other than the first element for selectively controlling the switching of said elements by said timed fluid pulses from the counters, the biasing means for each switching element being responsive to the switching of the preceding element in the series so that said elements are switched sequentially, and reset means for restoring said switching elements to the first state of operation.

3. A fluid-operated counter circuit for use in a fluid-operated timer supplied with timed fluid pulses, said counter comprising, in combination, means for transmitting pressurized fluid, a series of fluid-operated switching elements each of which has a body defining a jet chamber having a power nozzle at one end connected to said means for transmitting pressurized fluid to produce a power jet and having first and second output tubes at the other end, first and second primary control nozzles on opposite sides of said power nozzle, each of the switching elements between the first and the last elements of said series also having a secondary control nozzle on the same side as the second primary control nozzle, means for transmitting the timed fluid pulses directly to the first control nozzle of each switching element, the first output tube of each of said switching elements, except the last element in the series, being coupled to the second primary control nozzle of the adjacent succeeding switching element so as to bias each switching element other than the first element toward its first output tube until the power jet of the immediately preceding switching element has been switched from the first output tube to the second output tube whereby said elements are switched sequentially in timed relation to said timed fluid pulses, the second output tube of the last switching element in said series being connected to the second primary control nozzle of the first switching element for resetting the

power jets in all said switching elements from the second output tube back into the first output tube in response to the switching of the last element.

4. A fluid-operated timer circuit comprising, in combination, means for transmitting pressurized fluid, a plurality of fluid-operated counters each generating timed fluid pulses at different predetermined frequencies, and a fluid-operated adder circuit comprising a series of fluid-operated switching elements each of which has a body defining a jet chamber having a power nozzle at one end connected to said means for transmitting pressurized fluid to produce a power jet and having first and second output tubes at the other end, first and second control nozzles on opposite sides of said power nozzle, the first control nozzle of each switching element being connected directly to one of said counters for receiving timed fluid pulses to switch said element from the first to the second state of operation, the first output tube of each of said switching elements, except the last element in the series, being coupled to the second primary control nozzle of the adjacent succeeding switching element so as to bias each switching element other than the first element toward its first output tube until the power jet of the immediately preceding switching element has been switched from the first output tube to the second output tube whereby said elements are switched sequentially in timed relation to said timed fluid pulses, and reset means for restoring said switching elements to the first state of operation.

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