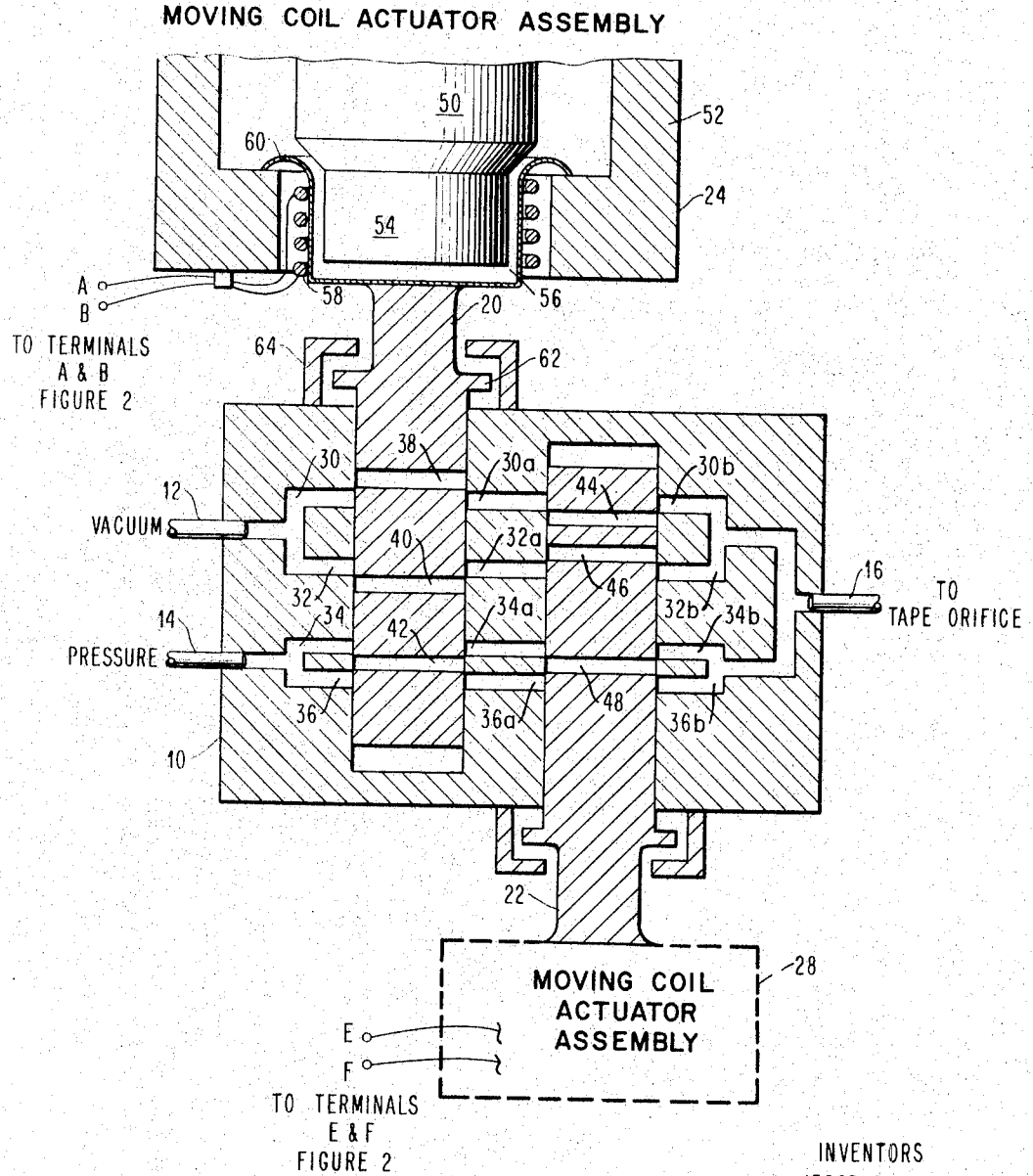
Aug. 15, 1967 T. J. HARRIS ETAL 3,335,755

HIGH-SPEED PNEUMATIC SWITCH

Filed Oct. 15, 1965 3 Sheets-Sheet 1

FIG. 1



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FIG. 2

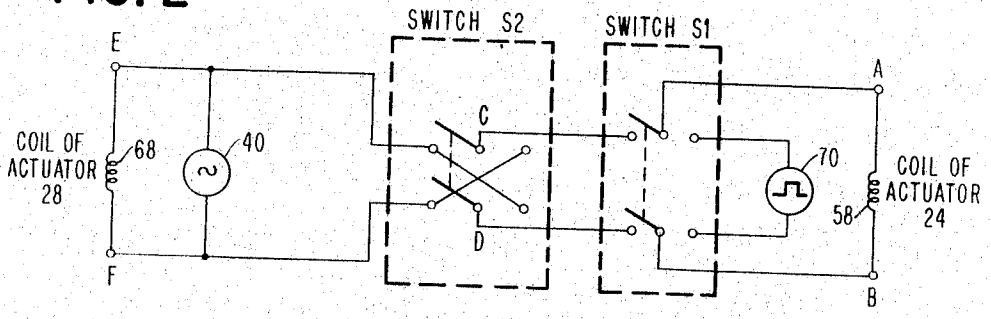

SWITCH S2
SWITCH S1
E
F
A
B
C
D
COIL OF ACTUATOR 28
68
40
70
58
COIL OF ACTUATOR 24

FIG. 4

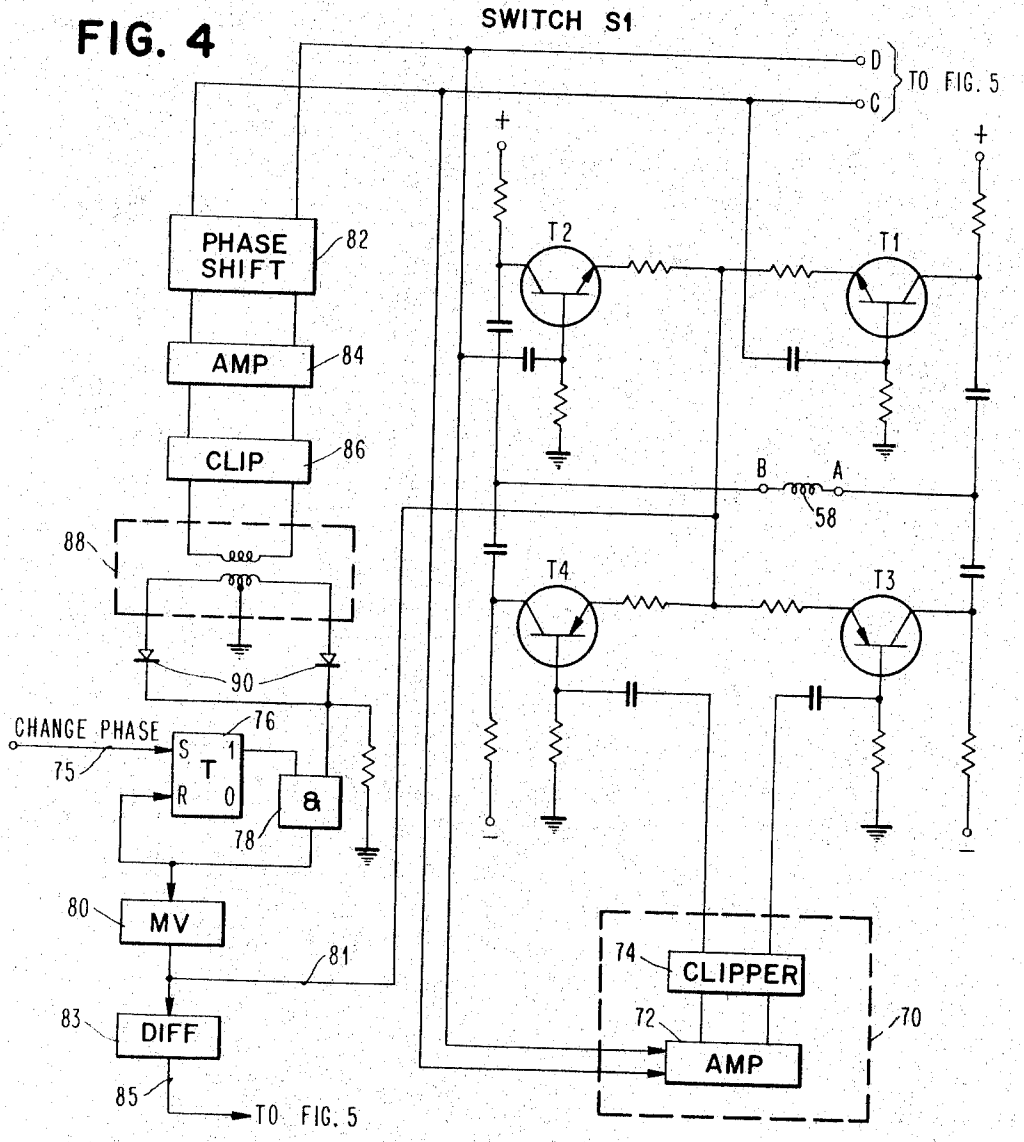

SWITCH S1
D
C
TO FIG. 5
PHASE SHIFT
82
AMP
84
CLIP
86
88
90
CHANGE PHASE
75
76
S
R
T
1
0
78
80
MV
81
83
DIFF
85
TO FIG. 5
T2
T1
T4
T3
B
A
58
74
CLIPPER
72
AMP
70

FIG. 3

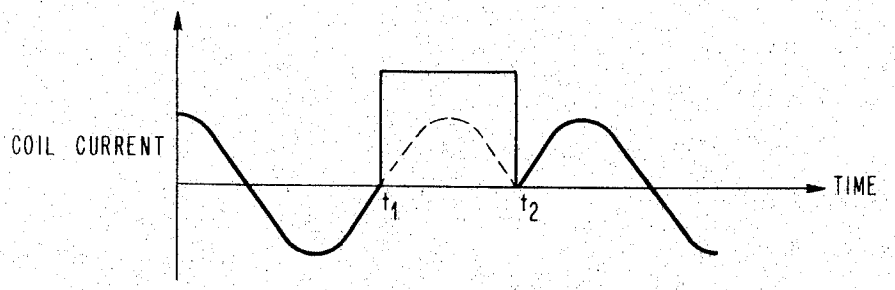
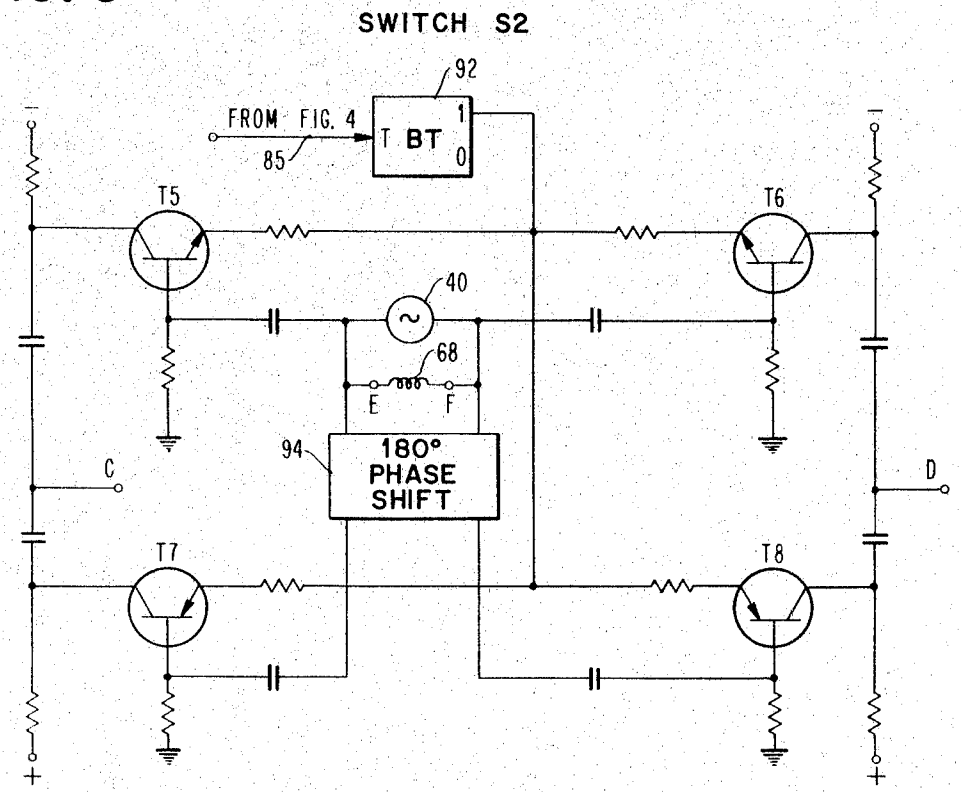

COIL CURRENT
TIME
t_1
t_2

FIG. 5


SWITCH S2
92
FROM FIG. 4
85
T BT
1
0
T5
T6
40
68
E
F
94
180° PHASE SHIFT
C
D
T7
T8

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HIGH-SPEED PNEUMATIC SWITCH

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This invention relates to hydraulic control systems and more particularly, to hydraulic valves employed in controlling flow of fluid through hydraulic systems.

Hydraulic tape transport mechanisms which use pressure and vacuum to control the movement of tape are well known in the art. Capstans are provided which rotate in opposite directions and over which the tape passes. Vacuum is applied through ports in one of the captans and pressure is applied through ports in the other capstan to drive the tape in contact with the first capstan and out of contact with the second capstan. In this manner, the tape is caused to move in the direction of rotation of the capstan which has vacuum applied to it. The tape motion is reversed by reversing the sense of vacuum and pressure. The speed for switching from one direction to the other is limited by the time required to change the conditions of vacuum and pressure under the tape at each capstan.

Existing mechanisms for applying vacuum or pressure to tape employ a diaphragm located within the capstan. When the diaphragm is seated in one position, pressure is applied to the tape through orifices in the capstan. When the diaphragm is seated in the opposite position, vacuum is applied to the tape. A push-pull electromagnetic motor attached to the diaphragm pushes or pulls the diaphragm to each seating position. The switching speed is limited by the time required to move the diaphragm and the motor armature from one position to the other. Since the diaphragm is moved from a standstill position, the switching time is relatively large because high inertia forces must be overcome.

It is therefore a paramount object of this invention to provide a high-speed hydraulic valve.

It is a further object of this invention to provide a high-speed hydraulic valve for controlling the flow through a plurality of pipelines.

It is also an object of this invention to provide a hydraulic valve which will rapidly switch from a vacuum condition to a pressure condition in a hydraulic tape system.

The above objects are accomplished in accordance with the invention by providing sliding valve members moving in harmonic motion past fixed orifices, either in phase or 180° out of phase with respect to each other. The valves have openings located such that when the valves are oscillating in phase, pressure is applied to the tape; and when the valves are operating out of phase, vacuum is applied to the tape. Pressure or vacuum is electronically switched by changing the phase of the oscillating members.

The invention has the advantage that since the members move in a predictable manner, wear on the sliding surfaces can be greatly reduced by thin air films between the moving parts. The members sliding in harmonic motion do not require high initial forces for rapid switching, do not have overshoot, and do not require valve seating.

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

In the drawings:

FIG. 1 is a cross-sectional view of a hydraulic valve in which the present invention is embodied;

FIG. 2 is a schematic diagram of an electrical circuit which may be used to control the switching of the valves shown in FIG. 1;

FIG. 3 is a timing diagram illustrating the waveforms produced by the circuit of FIG. 2; and

FIGS. 4 and 5 are more detailed diagrams of the switching circuit shown in FIG. 2.

The invention may be summarized with respect to FIG. 1. A hydraulic valve body **10** has inlet pipe orifices **12** and **14** for supplying pressure or vacuum respectively to an outlet pipe orifice **16** which communicates with the capstan of a hydraulic tape drive (unshown). Located within the hydraulic valve **10** are two oscillating members **20** and **22** which are driven by push-pull electromagnetic (moving coil) motors **24** and **28**. The motors **24** and **28** are controlled by the circuitry shown in FIG. 2.

The vacuum and pressure pipes feed into ducts **30**, **32**, **34**, and **36** which communicate with orifices **38**, **40** and **42** in the oscillating member **20**. The ducts **30**, **32**, **34**, and **36** continue through the hydraulic valve **10** to the tape orifice **16**. The sections are labeled **30***a*, **30***b*, **32***a*, **32***b*, etc.

The oscillating member **21** has orifices **38**, **40**, **42** cut therein. These orifices communicate with the ducts to allow fluid (vacuum or pressure) to pass through the duct **30** and the orifice **38**, and through the duct **36** and the orifice **42** when the member is in the lowermost extremity of its movement. When the member **21** is in the uppermost extremity of its movement, fluid passes through duct **32** and orifice **40**, and through duct **34** and orifice **42**.

The oscillating member **22** has orifices **44**, **46** and **48** cut therein. These orifices communicate with the ducts to allow fluid to pass through the duct **30***a* and the orifice **44** and through the duct **34***a* and the orifice **48** when the member is in the uppermost extremity of its movement. The orifices **46** and **48** allow fluid to pass through the ducts **32***a* and **36***a* when the member **22** is in the lowermost extremity of its movement. When the members oscillate in phase, pressure is applied to outlet **16**, and when the members oscillate 180° out of phase, vcauum is applied.

A detailed description of the hydraulic valve shown in FIG. 1 and the circuitry for controlling the operation thereof shown in FIGS. 2, 4, and 5, follows. The hydraulic valve assembly is comprised of a stationary portion **10** and moving members **20** and **22** which are moved by moving coil assemblies **24** and **28**. Moving coil assembly **24** is shown in detail and includes a permanent magnet **50**, a soft-iron return path **52**, a soft-iron magnetic cap **54**, a moving coil bobbin **56** (with a coil **58** wrapped around it) and a restoring spring **60**. The moving coil in the assembly **24** is attached to the output leads A and B. The maximum displacement of the element **20** is limited by a protrusion **62** which limits the motion between an element stop **64** and the valve housing **10**. A similar arrangement is provided for the moving element **22**.

The moving coils are controlled by the circuits shown in FIG. 2. Referring to FIG. 2, a sine wave signal from the generator **40** is applied to the coil **58** through switches S2 and S1, causing the currents in the coils to vary. The pulse generator **70** generates a square wave pulse which is in phase with the sine wave from the pulse generator **40**. When switch S1 is transferred opposite to the position shown, the square wave pulse is applied to the coil **58** at time T1 (see FIG. 3) for a duration of one-half the period of the sine wave. At time T2, the switch

S1 is returned to its normal position. At the same time, switch S2 is switched to the position opposite to that shown in the drawing to reverse the phase of the signal (from sine wave generator 40) applied to the coil 58.

A current waveshape of the type shown in FIG. 3 causes the element 20 to stop completely at time T1 for one-half a cycle completing a 180° phase shift at time T2. The switch S1 is operated when the velocity of the element 20 is zero. When this occurs, the displacement of the element 20 is maximum and all of the energy of the mechanical system is stored in the spring 60.

Switch S1 is shown in detail in FIG. 4 and switch S2 is shown in detail in FIG. 5. The purpose of S1 is to provide a 180° phase shift in the relative motion of the moving elements 20 and 22. Once this is accomplished, the coil currents and driving voltages are in phase with the oscillation of the moving parts.

Referring to FIG. 4, the square wave generator 70 includes an amplifier 72 and a clipping circuit 74. The input C, D to the amplifier 72 is provided from the sine wave generator 40, shown in FIG. 5. The output C, D of the sine wave generator also drives a phase shift circuit 82, the output of which is amplified by amplifier 84 and clipped by clipper circuit 86. The output from the clipper circuit 86 is a square wave which is differentiated by differentiator 88 and mixed by diodes 90 to provide a series of positive pulses at the zero crossings of the sine wave generator output signal. These pulses are provided to one leg of the AND circuit 78. A trigger 76 is provided, the output of which energizes the other leg of AND circuit 78. The output of the AND circuit 78 drives a single-shot multivibrator 80. The actual switching operation of switch S1 is accomplished by transistors T1, T2, T3, and T4 which are controlled by the output from multivibrator 80.

The switch S2 shown in FIG. 5 is also controlled by the multivibrator 80 and is comprised of transistors T5, T6, T7 and T8. Current is applied to coil 68 via terminals E and F attached to the output of pulse generator 40. Assuming that binary trigger 92 is turned off, the "1" output is negative, causing transistors T5 and T6 to conduct, thus connecting the output of sine wave generator 40 to terminals C and D.

Referring now to FIG. 4, the output of multivibrator 80 is normally negative so that the transistors T1 and T2 are conducting, thus applying the outputs C and D of switch S2 to the terminals A and B of coil 58.

A signal to change the relative phase of moving elements 20 and 22 is supplied to the trigger 76 via set input 75. The trigger 76 is turned on, thus energizing one leg of the AND circuit 78. The outputs C and D of switch S2 (FIG. 5) drive a phase shift circuit 82 which adjusts for delays in the circuitry. The sine wave signal is amplified by amplifier 84 and clipped by clipper 86 to thereby provide a square wave voltage in phase with the signal generator 40. The output of clipper 86 is differentiated by the circuit 88 shown within the dotted lines. The positive and negative differentiating spikes are mixed together by rectifying diodes 90 to provide positive spikes occurring at the zero axis crossings of the sine wave generator output. These spikes are gated via AND circuit 78 to energize the multivibrator 80 and reset the trigger 76. The output of the multivibrator 80 is a positive voltage which is maintained for one-half the cycle of the sine wave generator. That is from the time $t1$ to the time $t2$ shown in FIG. 3. The output 81 from the multivibrator 80 turns off transistors T1 and T2 and turns on transistors T3 and T4. This applies the output of the pulse generator 70 to the terminals A and B of coil 58. The output of pulse generator 70 is a high-amplitude step voltage occurring in phase with the sine wave input to the amplifier 72. Thus, the step voltage occurring at time $t1$ until time $t2$ in the waveform shown in FIG. 3 is generated.

The output of multivibrator 80 also drives a differentiator 83 which develops a positive and a negative voltage spike corresponding, respectively, to the leading and trailing edges of the multivibrator output. The output 85 of the differentiator drives a binary trigger 92 shown in FIG. 5. The positive output 85 sets the binary trigger to its opposite state, thus causing the output of the trigger to go positive. This causes transistors T5 and T6 to cease conducting and turns on transistors T7 and T8. The 180° phase-shifted output of the sine wave generator 40 is now applied to the terminals C, D of the switch S2.

When multivibrator 80 (FIG. 4) has timed out, its output 81 drops, causing transistors T1 and T2 to again conduct, turning off transistors T3 and T4. The square wave pulse generator 70 is now disconnected from the terminals A and B and the phase-shifted output pulse on ttrminals C, D is connected to the terminals A and B at time $t2$ in the cycle (FIG. 3).

In summary, the invention comprises a hydraulic valve 10 having moving elements 20 and 22 which move either in phase or 180° out of phase with respect to each other under control of electromagnetic moving coil actuators 24 and 28. When the elements 20 and 22 are operating in phase, that is, moving in the same direction with respect to each other, pressure is applied to the tape orifice 16 via ducts 34, 34*a*, 34*b*, and ducts 36, 36*a*, 36*b* alternately through cooperation with the orifices 42, 48.

Vacuum is supplied via duct 12 to the tape orifice 16 when the moving coil actuators are energized to cause the elements 20 and 22 to oscillate 180° out of phase with respect to each other. Thus, vacuum is supplied through the ducts 30, 30*a*, 30*b*, and the ducts 32, 32*a* and 32*b* through the action of the orifices 38 and 44 and the orifices 40 and 46, which alternately open and close the ducts.

The invention has been described with respect to a magnetic tape system; however, the valve may be used in other hydraulic systems such as, but not limited to, computer fluid logic and fluid pipelines. Further, the invention is not limited to moving coil control means, but may employ other electromotive powering or mechanical linkages.

Only two reciprocating valves have been illustrated; however, any number of oscillating valves may be utilized to control the flow through two or more pipes, by extending in an obvious manner the teachings of this invention. For example, if three pipes are to be controlled, three reciprocating members should be provided. Flow through the first pipe would require in-phase operation of all three members; through the second pipe, in-phase operation of the first two members and out-of-phase operation of the third; and flow through the third pipe would require in-phase operation of the second and third members, while the first member operates out of phase therewith. The location of the orifices in the members can be easily determined by one having ordinary skill in the art.

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

What is claimed is:

1. A system for controlling flow through a plurality of pipelines comprising:

inlet and outlet orifices for each pipeline; and

reciprocating elements in series between said orifices, said elements adapted to oscillate both in phase and out of phase with respect to each other past said orifices;

said elements and pipelines having openings therein located with respect to each other such that when said elements are oscillating in phase, at least one of said pipelines is opened in each extremity of operation of said elements and remains open during the oscillation except for a brief period intermediate the oscillation, while another of the pipelines remains closed during the entire oscillation, and when said

elements are oscillating out of phase, the first-mentioned pipeline remains closed during the entire oscillation while said other one of said pipelines is opened in each extremity of operation and remains open during the oscillation except for a brief period intermediate the oscillation, to thereby permit or impede the flow of the fluid through said pipeline, depending upon the relative phase of reciprocation of said elements.

2. The combination according to claim 1 including means for reciprocating said elements which means includes switching means for stopping the motion of one of said elements when the velocity of said element is substantially equal to zero and for starting said stopped element one-half cycle after said element has stopped to thereby cause said element to reverse its phase of oscillation, with respect to the other reciprocating elements.

3. The combination according to claim 2 wherein said reciprocating means further includes:

moving coil electromagnetic motors for driving each element and

said switching means includes: a sine wave signal source constantly applied to at least one of said moving coils;

a square wave signal source synchronised with said sine wave source;

selection means for selectively connecting said sine wave source and said square wave source to the moving coil of the element to be stopped;

phase reversal means for reversing the phase of said sine wave signal applied to the moving coil of the element to be stopped and

means operative upon energization of said switching means for causing said selection means to connect the square wave source to the moving coil of the element to be stopped for one-half of a cycle, for reversing the phase of said sine wave signal, and for causing said sine wave signal to be re-applied to said moving coil at the end of said one-half cycle.

4. A system for controlling the flow through a plurality of pipelines comprising:

first inlet and outlet pipes, each having first and second orifices;

second inlet and outlet pipes, each having first and second orifices;

first and second elements adapted to be moved sinusoidally having orifices therein located with respect to the first and second orifices of said pipes so that when the first element is in one extremity of movement, the first orifice of said first inlet pipe is closed and the second orifice is opened and the first orifice of said second inlet pipe is opened and the second orifice closed and when said first element is in the opposite extremity, the first orifice of said first inlet pipe is opened and the second orifice of said first inlet pipe is closed and the first orifices of said second inlet pipe is closed and the second orifice of said second inlet pipe is opened;

said second element having orifices located such that when the second element is in one extremity of movement, the first orifice at said first outlet pipe is opened and the second orifice is closed and the first orifice at the outlet of said second pipe is opened and the second orifice is closed; and when said second element is in the opposite extremity of operation, the first orifice at the outlet of said first pipe is closed and the second orifice is opened and the first orifice at the outlet of said second pipe is closed and the second orifice is opened;

whereby when said oscillating elements are oscillating substantially in phase with respect to each other, the orifices at the inlet and outlet of said second pipe are opened in each extremity of operation of said elements, and when said elements are oscillating substantially 180° out of phase, the orifices at the inlet and outlet of said first pipe are opened in each extremity of operation of said elements.

5. A system for controlling flow through a plurality of pipelines comprising:

inlet and outlet orifices for each pipeline; and

reciprocating elements in series between said orifices, said elements adapted to oscillate both in phase and out of phase with respect to each other past said orifices;

said elements and pipelines having openings therein located with respect to each other such that when all of said elements are oscillating in phase, one of said pipelines is opened in each extremity of operation of said elements and remains open during the oscillation except for a brief period intermediate the oscillation, while another of the pipelines remains closed during the entire oscillation, and when at least one of said elements is oscillating out of phase with respect to the remaining elements, the first-mentioned pipeline remains closed during the entire oscillation while said other one of said pipelines is opened in each extremity of operation and remains open during the oscillation except for a brief period intermediate the oscillation, to thereby permit or impede the flow of the fluid through selected ones of said pipelines depending upon the relative phase of reciprocation of said elements.

6. The combination according to claim 5 including means for reciprocating said elements which means includes switching means for stopping the motion of one of said elements when the velocity of said element is substantially equal to zero and for starting said stopped element one-half cycle after said element has stopped to thereby cause said element to reverse its phase of oscillation, with respect to the other reciprocating elements.

7. The combination according to claim 6 wherein said reciprocating means further includes:

moving coil electromagnetic motors for driving each element and

said switching means includes: a sine wave signal source constantly applied to at least one of said moving coils;

a square wave signal source synchronised with said sine wave source;

selection means for selectively connecting said sine wave source and said square wave source to the moving coil of the element to be stopped;

phase reversal means for reversing the phase of said sine wave signal applied to the moving coil of the element to be stopped and

means operative upon energization of said switching means for causing said selection means to connect the square wave source to the moving coil of the element to be stopped for one-half of a cycle, for reversing the phase of said sine wave signal, and for causing said sine wave signal to be re-applied to said moving coil at the end of said one-half cycle.

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