United States Patent [19]

Hall et al.

[11] **3,841,559**

[45] **Oct. 15, 1974**

[54] **APPARATUS FOR FORMING HIGH PRESSURE PULSED JETS OF LIQUID**

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[73] Assignee: **Exotech, Incorporated,** Gaithersburg, Md.

[22] Filed: **Oct. 18, 1973**

[21] Appl. No.: **407,496**

[52] **U.S. Cl.** **239/101,** 175/422, 299/17

[51] **Int. Cl.** **B05b 3/14**

[58] **Field of Search** 239/101, 102; 299/16, 17, 299/95; 175/422

[56] **References Cited**

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Attorney, Agent, or Firm—Malcolm L. Sutherland, Esq.; James N. Dresser, Esq.

[57] **ABSTRACT**

Apparatus for forming pulsed jets of liquid. A movable cylinder cooperates with a nozzle block to define a compressible charge chamber into which water, or other liquid flows. A latch retains the cylinder. When it is desired to generate a pulse, the latch is released, allowing the cylinder to move and expand the charge chamber, thereby drawing from the nozzle any liquid remaining from the preceding pulsed jet of liquid. A piston is then actuated to impact on the cylinder, compressing the chamber and expelling the charge through the nozzle as a pulsed liquid jet. The cylinder is moved so that the charge chamber is compressed and the latch again retains the device in this condition. A floating check valve permits escape of air from the chamber during filling with water.

4 Claims, 5 Drawing Figures

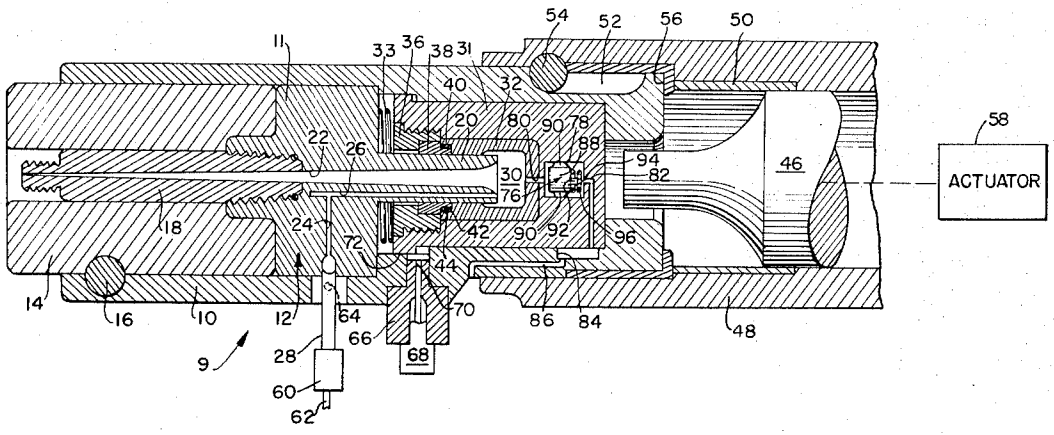

FIG. 1.

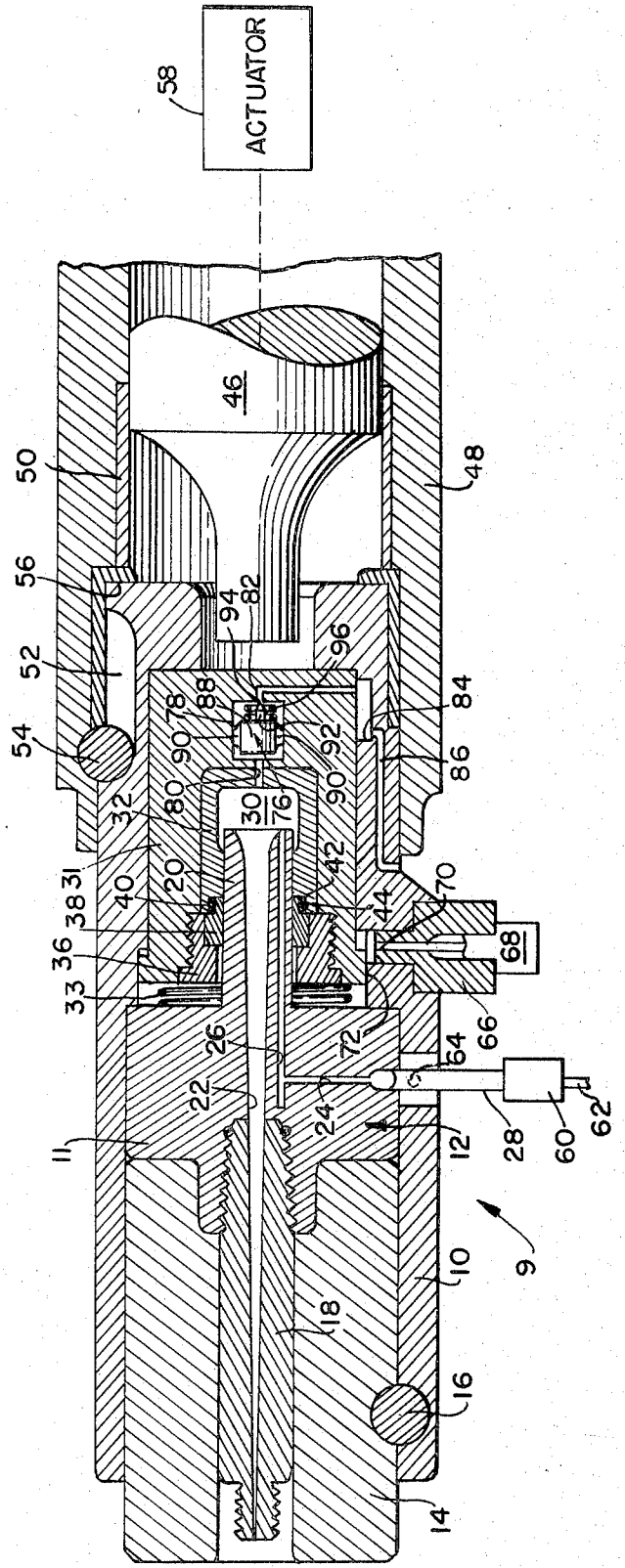
ACTUATOR
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FIG. 2A.

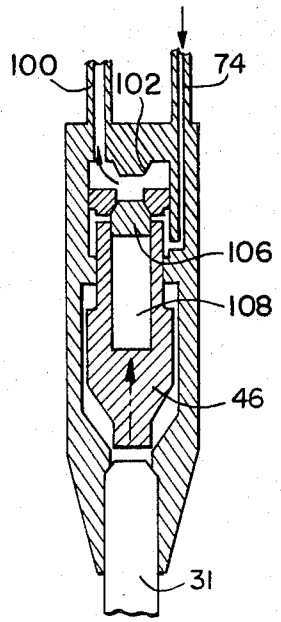


FIG. 2B.

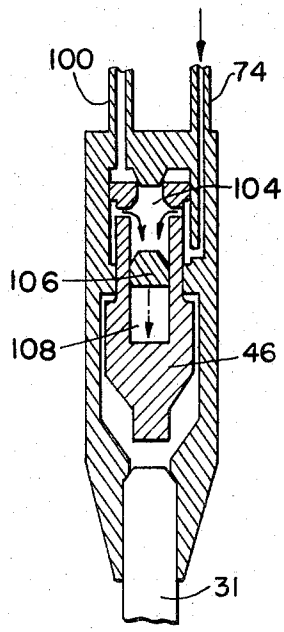


FIG. 2C.

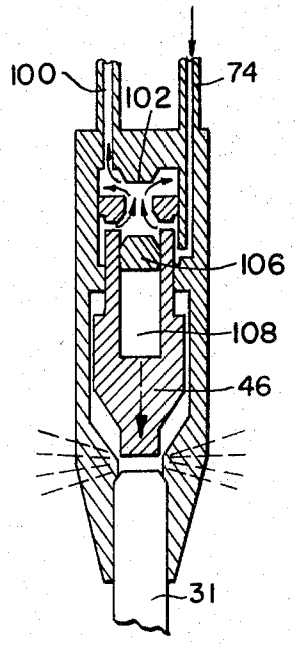
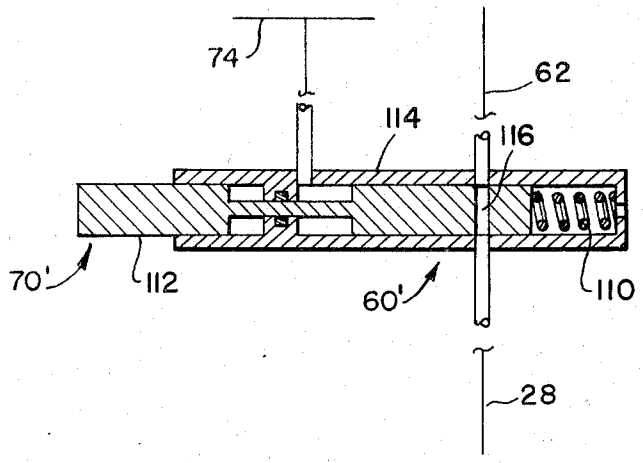


FIG. 3.



APPARATUS FOR FORMING HIGH PRESSURE PULSED JETS OF LIQUID

The present invention pertains to an apparatus for forming high pressure pulsed jets of liquid. More particularly, the present invention pertains to a liquid, pulsed jet forming apparatus including means for assuring that little, if any, liquid from a previous pulse is remaining in the discharge nozzle at the time a pulsed jet of liquid is expelled through the nozzle, since such remaining liquid might detrimentally affect the pulse generated.

Pulsed jets of liquid are utilized for many purposes, such as fracturing rock, cutting steel or concrete, etc. In typical apparatus for generating such pulsed jets of liquid, liquid enters a reservoir adjacent a pressure cylinder to form a liquid charge. A piston is actuated to contact the pressure cylinder, thereby compressing the reservoir and expelling the liquid charge through a narrow liquid outlet or nozzle at high velocity and pressure. It has been found that following ejection of a jet pulse of liquid, liquid is likely to remain within the nozzle, and this remaining liquid has an adverse effect on the characteristics, such as pressure and velocity, of the subsequent liquid jet pulse.

The present invention is an apparatus for generating pulsed jets of liquid, including means for assuring that at the time a pulsed liquid jet is generated, little, if any, liquid from a preceding jet remains in the nozzle. In the apparatus, in accordance with the present invention, a piston is actuated to move a pressure cylinder, applying pressure to a liquid charge in a chamber formed by the pressure cylinder, causing the charge to be expelled through a nozzle at high velocity and high stagnation pressure; for example, a pressure in excess of 100,000 pounds per square inch. Stagantion pressures of 300,000 to 500,000 pounds per square inch and above can be obtained employing the apparatus of the present invention. Thus, by a high pressure liquid jet pulse is meant a brief pulse of liquid with a stagnation pressure in excess of 100,000 pounds per square inch. Looking at the apparatus before generating a pulsed liquid jet, the pressure cylinder is latched to retain the charge chamber in a compressed condition and liquid is continuously applied to the charge chamber. When a jet is to be generated, the latch is released and the pressure cylinder moves to enlarge the charge chamber. Along with this movement, the liquid inlet is closed. This enlargement of the chamber reduces the pressure in the chamber and liquid remaining in the nozzle from the preceding pulse is pushed, or drawn, from the nozzle into the chamber. A floating check valve is provided to permit escape of air from the charge chamber as the liquid enters. After the enlargement of the chamber has emptied the nozzle, the piston is actuated to very rapidly move the pressure cylinder and compress the charge chamber, thereby expelling the charge out of the nozzle as a pulsed jet. The cylinder is then again latched until the next pulse is to be initiated.

The present invention is described in further detail with reference to the drawings, in which:

FIG. 1 is a view, partially fragmentary sectional and partially in block form, depicting a preferred embodiment of apparatus in accordance with the present invention;

FIGS. 2A, 2B and 2C are schematic views showing the three basic operative positions of an actuator suitable for use with the device of FIG. 1 and;

FIG. 3 is a view of a latch mechanism suitable for use with the device of FIG. 1.

As illustrated in FIG. 1, pulsed liquid jet forming device 9 includes an elongated cylindrical outer housing 10 having nozzle block 12 positioned within it. The central portion 11 of nozzle block 12 fits snugly within elongated cylindrical housing 10 and is maintained therein by retainer cylinder 14. Retainer key 16 prevents movement of retainer cylinder 14. Extending forwardly from nozzle block 12 and within retainer cylinder 14 is elongated forward member 18 which is of a diameter considerably smaller than that of central portion 11. Elongated forward member 18, for example, can be threadedly connected to nozzle block 12. Nozzle block 12 includes a rearwardly extending portion 20 which is likewise of a diameter considerably smaller than that of central portion 11 of nozzle block 12 and which preferably is coaxial with elongated forward member 18. Preferably, also, central portion 111 and retainer cylinder 14 are coaxial with elongated foward member 18 and rearwardly extending portion 20. An axial, tapered bore 22 passes through rearwardly extending portion 20, nozzle block 12, and elongated forward member 18. Although the figure depicts tapered bore 22 as having a uniform taper, this is not essential. Tapered bore 22 could have an arcuate or other taper so long as the cross-sectional area of bore 22 reduces over its length, from a maximum corss-sectional area within rearwardly extending portion 20 to a cross-sectional cross-sectional area within elongated forward member 18. If desired, the forward end of forward member 18 can be threaded to receive an extension, likewise having an axial bore therethrough. Since axial bore 22 is tapered, a liquid charge traveling through bore 22 from rearwardly extending portion 20 towards elongated forward member 18 has its velocity and pressure increased as it moves. Tapered bore 22 thus serves as an acceleration path for liquid jet pulses traveling through it.

Radial bore 24 passes from the exterior of central portion 11 and intersects interior longitudinal bore 26, which extends from this intersection through rearwardly extending portion 20. Radial bore 24 is adapted to mate with liquid inlet passageway 28.

Pressure cylinder 31 encircles the rear part of rearwardly extending portion 20 and is maintained and spaced from central portion 11 by spring 33. Cylinder insert 32 fits snugly within pressure cylinder 31 to define compressible chamber 30 behind rearwardly extending portion 20. Pressure cylinder 31 is concentrically positioned within elongated cylindrical housing 10 and is longitudinally movable therewithin. Retainer nut 36 is threadably attached to pressure cylinder 31 to surround rearwardly extending portion 20. Retainer nut 36 holds seal firmly within pressure cylinder 31. Seal 38 provides a substantially fluid-tight seal around rearwardly extending portion 20. Seal 38 is preferably a rigid, non-resilient material such as metal, and has a rearwardly protruding lip 40 which engages rearwardly extending portion 20. Rearwardly protruding lip 40 has surrounding it in a concentrical manner, resilient member 42 and a chamfer ring 44 so that rearwardly protruding lip 40 does not engage cylinder insert 32 at its circumference. When pressure is exerted upon resilient member 42 by liquid in the interface between cylinder insert 32 and lip 40, resilient member 42 exerts a force on seal 38 and, particularly, upon rearwardly protrud-

ing lip 40, to seal against rear portion 20. Chamfer ring 44 prevents extrusion of resilient member 42 into the interface between seal 38 and cylinder insert 32.

Piston 46 is positioned behind pressure cylinder 31 and is surrounded by jacket 48 within which it fits snugly, but slidingly. Preferably, a replaceable wear bushing 50 is provided on the interior wall of jacket 48. Elongated cylindrical housing 10 has on its outer surface adjacent jacket 48 an elongated recess 52. Retainer 54 is located within recess 52 to maintain housing 10 and jacket 48 together, while permitting longitudinal movement therebetween from the position illustrated in the figure, which is the firing position of the apparatus with housing 10 withdrawn into jacket 48 until the forward end of recess 52 contacts retainer 54 so that the rear face of housing 10 abuts shoulder 56 of jacket 48, to a non-firing position in which housing 10 is extended from jacket 48 with the rearward end of recess 52 contacting retainer 54. In this non-firing position with retainer 54 at the rearward end of recess 52, pressure cylinder 31 is sufficiently distant from piston 46 to prevent contact therebetween and thus to prevent accidental discharge of the apparatus.

Liquid inlet passageway 28 for chamber 30 has its inlet coupled to liquid control valve 60, the inlet of which is attached to liquid supply pipe 62. Preferably, liquid inlet passageway 28 includes a check valve 64 permitting flow of liquid from liquid control valve 60 to chamber 30, but preventing flow in the opposite direction, thereby isolating liquid control valve 60 from the high pressure created upon generation of a pulsed liquid jet.

Floating check valve 76 is provided to allow venting of air from compressible chamber 30. Valve chamber 78 is formed in pressure cylinder 31. Bore 80 provides fluid communication through pressure cylinder 31 and cylinder insert 32 from valve chamber 78 to compressible chamber 30. Bore 82 provides fluid communication through pressure cylinder 31 from valve chamber 78 to axial slot 84 in housing 10. Bore 86 provides fluid communication from axial slot 84 through housing 10 to the exterior of pulsed jet forming device 9.

Valve body 88 has a diameter slightly less than that of valve chamber 78 and includes a plurality of fins 90 extending outwardly from valve body 88 to contact the wall of valve chamber 78. Extension 92 extends from valve body 88 and terminates in a tapered end 94. The junction of bore 82 and valve housing 78 is tapered to substantially match the tapered portion of end 94. Spring 96 surrounds forward extension 92 and urges valve body 88 away from bore 82.

Mounting member 66 mounts solenoid 68 to housing 10. Solenoid 68 controls the position of latching member 70 adjacent pressure cylinder 31. With latching member 70 retracted and piston 46 inoperative as illustrated in FIG.1, spring 33 pushes pressure cylinder 31 away from nozzle block 12 so that compressible chamber 30 assumes an enlarged condition. Shoulder 72 of pressure cylinder 31 retains latching member 70 in this retracted position even when solenoid 68 is inoperative. Upon movement of pressure cylinder 31 toward nozzle block 12 as a result of actuation of piston 46, shoulder 72 clears latching member 70, and the latching member moves to its extended position, cooperating with shoulder 72 to latch pressure cylinder 31 in that position with chamber 30 compressed. Although operation of latching member 70 by a solenoid is shown, obviously other controls may be used such as compressed air or hydraulic fluid.

Piston 46 can be actuated by any suitable means, depicted diagrammatically as actuator 58. Such means might involve release of high pressure fluid, detonation of an explosive charge, release of a cocked spring, etc., to cause piston 46 to impact against pressure cylinder 31, moving the pressure cylinder and compressing chamber 30 to expel liquid from within chamber 30 through tapered bore 22 as a pulsed liquid jet. One such means is shown in FIGS. 2A, B and C. After each impact, hydraulic fluid in line 74 lifts piston 46, expelling the fluid above it through line 100, until the upper opening in piston 46 is sealed at face 102. The system is then compressed by fluid continuing to enter through line 74. This fluid now enters the charging chamber 104, pushing piston 106 down and compressing gas, e.g, nitrogen in chamber 108. The forces at the seal face and in chambers 104 and 108 are balanced such that the seal is broken at a desired point which triggers release of the stored energy. Piston 106 thereupon moves up and piston 46 moves down to strike pressure cylinder 31.

Operation of pulsed liquid jet forming device 9 is under the control of the actuator. Assuming that a pulsed liquid jet has just been generated, pressure cylinder 31 is latched adjacent nozzle block 12 by latching member 70, liquid control valve 60 is open, permitting passage of liquid to chamber 30, and piston 46 is retracted. In a firing position, the forward end of cylinder 14 preferably contacts the workpiece at which the pulsed liquid jet is directed to retain pulsed liquid jet forming device 9 in its firing position with housing 10 withdrawn into jacket 48. To generate a second pulsed liquid jet, solenoid 68 is actuated to retract latching member 70 and as latching member 70 releases cylinder 31, spring 33 moves cylinder 31 away from nozzle block 12, enlarging compressible chamber 30. Essentially at the same time, valve 60 is closed. As a consequence of this enlargement, liquid in tapered bore 22 is drawn into compressible chamber 30, thus leaving bore 22 substantially dry. Actuator 58 then causes piston 46 to impact against pressure cylinder 31. As a result, pressure cylinder 31 is impelled toward nozzle block 12, compressing chamber 30 and forcing the liquid therein out tapered bore 22 as a pulsed liquid jet.

Prior to the initial movement of pressure cylinder 31, valve body 88 is floating in chamber 78 and air which may be trapped in chamber 30 can escape through passages 80 and 82. The strength of spring 96 is such that it cannot overcome the liquid pressure in chamber 30 during filling thereof. Escape of liquid indicates that all of the air in chamber 30 has been exhausted. When, however, the actuator energizes piston 46 to strike cylinder 32, the sudden increase in the pressure in chamber 30 overcomes the bias of spring 96 so that tapered end 94 enters the tapered inlet of bore 82, closing passage 82 and sealing chamber 30.

When shoulder 72 of pressure cylinder 38 clears latching member 70, the latching member returns to its extended position to latch against shoulder 72. After the movement of cylinder 38 is over, spring 33 returns it to a position where it latches at shoulder 72, retaining pressure cylinder 31 adjacent nozzle block 12 with chamber 30 compressed. Preferably, solenoid 68 and latching member 70 include means normally urging

latching member **70** to this extended position so that solenoid **68** need be energized only to retract latching member **70** to permit pressure cylinder **31** to move away from nozzle block **12**, with shoulder **72** retaining latching member **70** in this retracted position after such movement of pressure cylinder **31**. Solenoid **68** can be any suitable device for causing the desired movement of latching member **70**. For example, latching member **72** can be spring biases to its extended positon so that solenoid **68** need be activated only momentarily to retract latching member **70**, with shoulder **72** retaining latching member **70** in this retracted position. Solenoid **68** can be an electrically operated solenoid or a pneumatically or hydraulically operated equivalent device. One such device is shown in FIG. **3**, in which the latching member **70'** and water inlet valve **60'** are combined. In this device, the pressure fluid in line **74** is balanced against a bias means, such as spring **110** (or compressed air), so that just prior to breaking of the seal at face **102**, the piston **112** moves in its casing **114** to withdraw the forward end, which is latching member **70'**, and to close valve **60'** formed by bore **116** therethrough. With an electric solenoid and electrically operated valve, the same pressure fluid can be used to triggger the latching member and close the valve.

Using water as the liquid charge material, pulsed jets have been created using the above described device having a stagnation pressure of at least 100,000 p.s.i. The jets have demonstrated their ability to break rock and to drill holes in metal.

Although the present invention has been described with reference to a preferred embodiment, numerous modifications and rearrangements could be made, and still the result would be within the scope of the invention.

What is claimed is:

1. Apparatus for forming pulsed jets of liquid comprising:

a nozzle block having a fluid discharge passageway therethrough;

a pressure cylinder cooperating with said nozzle block to define a compressible chamber in fluid communication with said nozzle block discharge passageway, said pressure cylinder being capable of assuming a middle, latched position relative to said nozzle block, a second, expanded position in which said compressible chamber is in an enlarged condition and a third, compressed position relative to said nozzle block in which said compressible chamber is in a compressed condition;

one of said nozzle block and said pressure cylinder having a fluid inlet passageway therethrough communicating with said compressible chamber;

bias means for urging said pressure cylinder to assume the second, expanded position;

latch means capable of assuming a latching condition in which said latch means cooperates with said pressure cylinder to retain said pressure cylinder in the middle, latched position and of assuming a non-latching condition in which said pressure cylinder is free to assume the second, expanded position under the urging of said bias means;

valve means connected to said fluid inlet pasageway and adapted for connection to a liquid source, said valve means capable of assuming a fill conditon in which liquid is permitted to flow from the liquid source through said valve means and said fluid inlet passageway to said compressible chamber and of assuming a closed position in which liquid is prevented from flowing through said valve means;

impelling means for acting on said pressure cylinder to compress said compressible chamber;

control means for controlling operation of said latch means, said valve means and said impelling means to cause in sequence:

a. said latch means to assume the latching condition preventing said bias means from moving said pressure cylinder to the second, expanded position,

said valve means to assume the fill condition, permitting liquid from the liquid source to pass through said valve means and said fluid inlet passageway to said compressible chamber;

b. said latch means to assume the non-latching condition, permitting said bias means to move said pressure cylinder to the second, expanded position,

said valve means to assume the closed condition, preventing liquid flow through said valve means;

c. actuation of said impelling means to move said pressure cylinder to the third compressed position while compressing said compressible chamber and expelling liquid from said compressible chamber out said fluid discharge passageway as a pulsed liquid jet and to cause said latch means to be released from non-latching position, thereby permitting said latch means to assume the latching condition and retain said pressure cylinder in the middle, latched position.

2. Apparatus as claimed in claim **1** in which one of said nozzle block and said pressure cylinder has a vent passageway therethrough interconnecting said compressible chamber with the exterior of said apparatus and in which said apparatus further comprises valve means in said vent passageway having a first valve position in which fluid flow is permitted through said vent passageway, so that fluid from said compressible chamber is permitted to pass said valve means to be vented from said compressible chamber, and second position assumed upon compression of said compressible chamber, said second position preventing fluid flow through said vent passageway.

3. Apparatus for forming pulsed jets of liquid comprising:

a nozzle block having a fluid discharge passageway therethrough;

a pressure cylinder cooperating with said nozzle block to define a compressible chamber in fluid communication with said nozzle block discharge passageway, said pressure cylinder being capable of assuming a middle, latched position relative to said nozzle block, a second, expanded position in which said compressible chamber is in an enlarged condition and a third, compressed position relative to said nozzle block in which said compressible chamber is in a compressed condition;

one of said nozzle block and said pressure cylinder having a fluid inlet passageway therethrough communicating with said compressible chamber;

bias means for urging said pressure cylinder to assume the second, expanded position;

latch means capable of assuming a latching condition in which said latch means cooperates with said pressure cylinder to retain said pressure cylinder in the middle latched position and of assuming a non-latching condition in which said pressure cylinder

is free to assume the second, expanded position under the urging of said bias means;

valve means connected to said fluid inlet passageway and adapted for connection to a liquid source, said valve means capable of assuming a fill condition in which liquid is permitted to flow from the liquid source through said valve means and said fluid inlet passageway to said compressible chamber and of assuming a closed position in which liquid is prevented from flowing through said valve means:

impelling means for acting on said pressure cylinder to compress said compressible chamber.

4. Apparatus as claimed in claim **3** in which one of said nozzle block and said pressure cylinder has a vent passageway therethrough interconnecting said compressible chamber with the exterior of said apparatus and in which said apparatus further comprises valve means in said vent passageway having a first valve position in which fluid flow is permitted through said vent passageway, so that fluid from said compressible chamber is permitted to pass said valve means to be vented from said compressible chamber, and second position assumed upon compression of said compressible chamber, said second position preventing fluid flow through said vent passageway.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,841,559 Dated October 15, 1974

Inventor(s) James Michael Hall; Louis L. Clipp

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 35, "Stagantion" should read --Stagnation--;

Column 2, line 19, "portion 111" should read --portion 11--;

Column 2, line 28, "corss-sectional" should read --cross-sectional--;

Column 2, line 29, after "a", insert --minimum--;

Column 2, line 30, after "sectional", delete --cross-sectional--;

Column 2, line 55, after "seal", insert --38--;

Column 5, line 9, "biases" should read --biased--;

Column 5, line 9, "positon" should read --position--;

Column 5, line 25, "triggger" should read --trigger--;

Column 5, line 63, "pasageway" should read --passageway--;

Column 5, line 65, "conditon" should read --condition--;

Column 7, line 10, after "means" delete colon (:) and insert semi-colon (;).

Signed and sealed this 14th day of January 1975.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

FORM PO-1050 (10-69)

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