United States Patent

[15] 3,647,137
[45] Mar. 7, 1972

Naydan

[54] **HYDRAULIC CHAMBER INCORPORATING A JET NOZZLE**

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[22] Filed: **Oct. 20, 1970**

[21] Appl. No.: **82,320**

[52] **U.S. Cl.** **239/102,** 60/203, 60/221, 239/601

[51] **Int. Cl.** **B05b 7/30**

[58] **Field of Search** 239/3, 4, 15, 102, 601, 101; 60/203, 221, 317; 72/56

[56] **References Cited**

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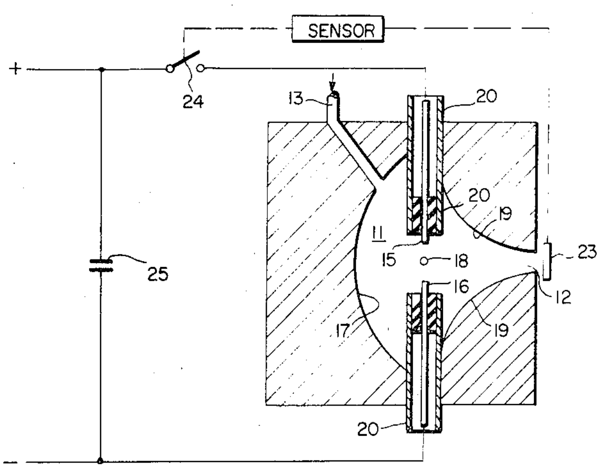
[57] **ABSTRACT**

A hydraulic chamber incorporating a nozzle capable of delivering a very high instantaneous pulsed dynamic jet in apparatus producing a shock wave in a relatively incompressible liquid is obtained when the effective locus of the shock wave is such that the pressure wave generated thereby is transmitted to build up rapidly and uniformly in a direction along the centerline of the nozzle. A suitable configuration for such chamber is a parabolic cissoid in which the locus of the shock wave is effectively at the focal point of the parabolic portion of such chamber thereby converting the resultant spherical waves into additive plane waves in the direction of the centerline of the nozzle opening. The shock wave employed in the apparatus can be produced by mechanical or electrical energy, or a combination thereof.

5 Claims, 4 Drawing Figures



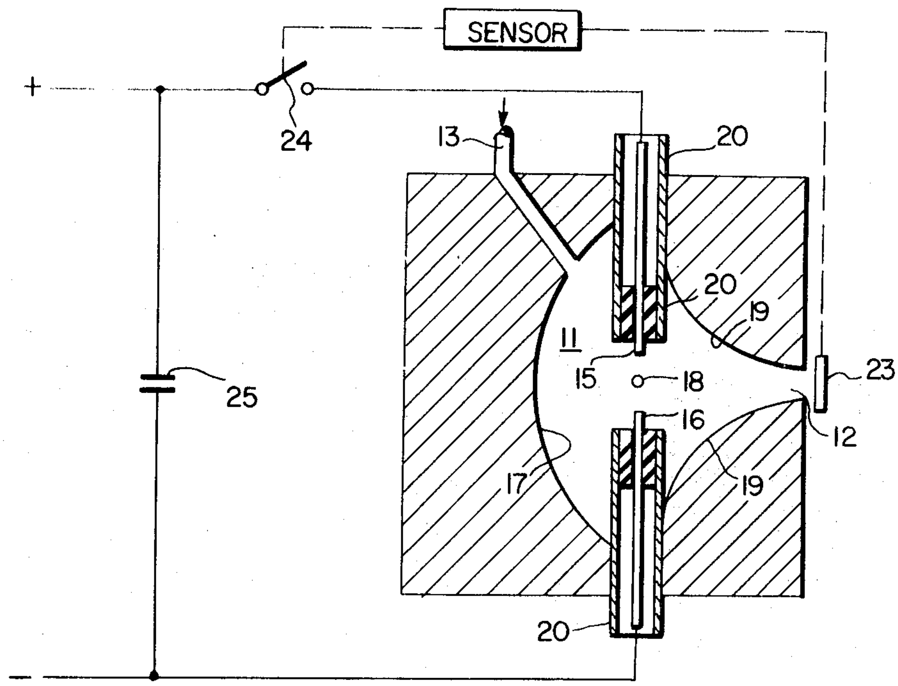


FIG. 1

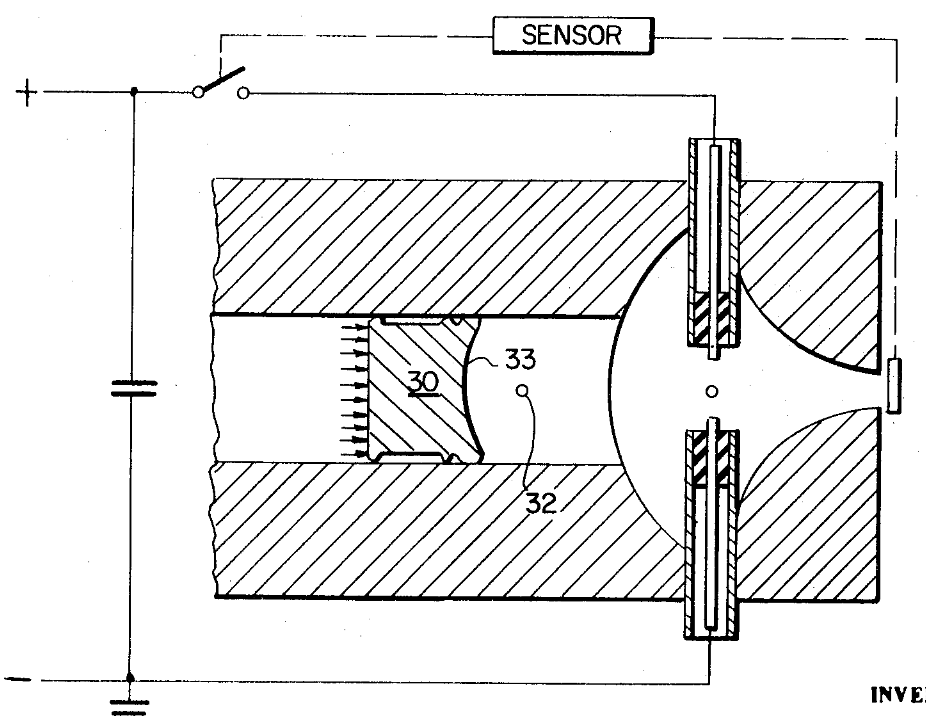


FIG. 2

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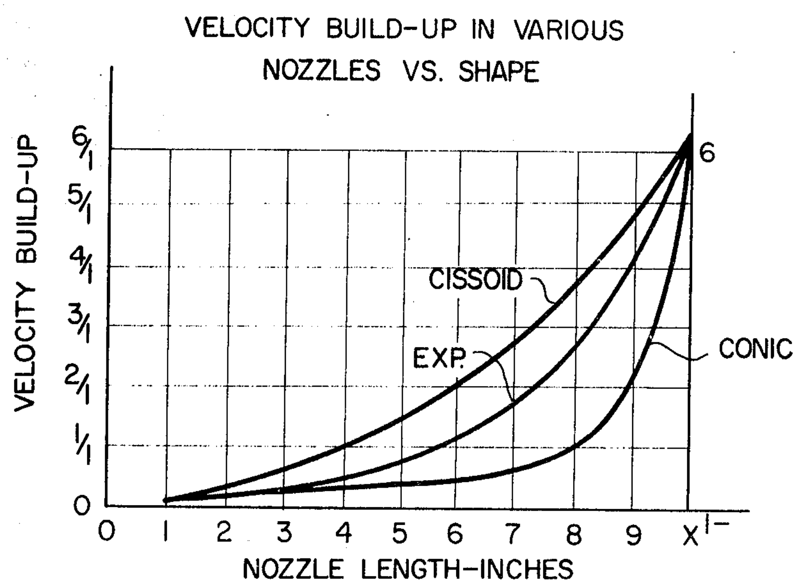

FIG. 3

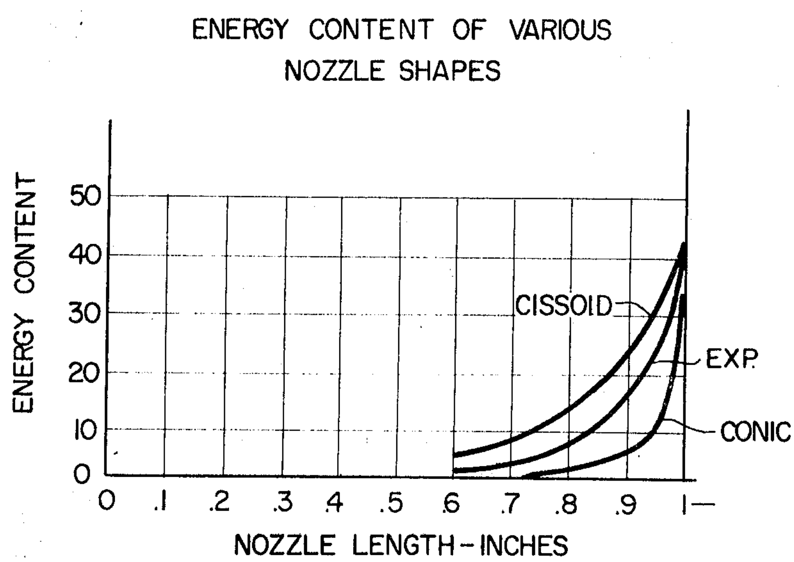

FIG. 4

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HYDRAULIC CHAMBER INCORPORATING A JET NOZZLE

BACKGROUND OF THE INVENTION

1. Scope of the Invention

This invention relates to a shaped hydraulic chamber incorporating a nozzle and capable of delivering a very high instantaneous pulsed dynamic liquid jet in apparatus employing the discharge of electrical energy within liquid contained in such a chamber to create a shock wave which powers the jet.

2. The Prior Art

It is well known that a liquid jet having a sufficiently high velocity can be used to fracture, cut, form or disintegrate various materials. The creation of such jets has been proposed by such diverse methods as the use of centrifugal force and the force transferred to confined liquid by a freely accelerating body. Attempts have also been made to employ the principle of acceleration of the foremost portion of liquid travelling within a contracting cavity.

My copending application Ser. No. 83,218 filed Oct. 20, 1970, now U.S. Pat. No. 3,592,866 and entitled "Process and Apparatus for the Production of Hydroelectric Pulsed Liquid Jets," the disclosure of which is incorporated herein by reference is directed to the production of high-energy liquid jets by the discharge of electrical energy through a relatively incompressible liquid in an essentially closed chamber having a shaped outlet nozzle. This application discloses that the discharge of electrical energy from a suitable source such as a capacitor bank into a closed container of a suitable liquid such as water by means of proper coupling electrodes will generate a high-temperature channel between the electrodes. Since the delivery of the electrical energy to the spark gap between the electrodes is at a faster rate than the ability of the liquid to absorb the heat generated thereby, a rapidly expanding gaseous bubble is formed in the channel between the electrodes. The rapid expansion of the gaseous bubble produces a shock wave in the relatively incompressible fluid. This shock wave meets mechanical resistance at all directions except through the nozzle opening. Thus the shock wave acts to force a jet of liquid through the nozzle opening.

The prior art has disclosed both conical and exponential configurations for jet nozzles for delivering high-velocity liquid jets. Because of such factors as turbulence, back pressure and the like, such configurations have been inefficient and have produced relatively slow and nonuniform pressure buildup. The exponential configuration has shown improved characteristics over the conical configuration.

SUMMARY OF THE INVENTION

In accordance with the present invention, it has been discovered that the shape of the hydraulic reaction chamber including the shape of the jet forming nozzle has a marked effect on the force of the resultant jet.

It is an object of the present invention to provide an improved hydraulic chamber and jet nozzle for the production of high-pressure liquid jets.

It is a further object of the present invention to provide an improved hydraulic chamber and jet nozzle which will more effectively utilize the shock wave produced within such chamber to drive a jet of liquid through the jet nozzle.

According to the present invention these objects are achieved by shaping the internal cavity of the hydraulic chamber so that the pressure wave formed therein is a plane wave and shaping the jet nozzle portion of the hydraulic chamber so that the pressure therein resulting from the plane pressure waves builds up uniformly and gradually to its final peak value at the outlet end of the jet nozzle.

In my copending application Ser. No. 83,218, entitled "-Process and Apparatus for the Production of Hydroelectric Pulsed Liquid Jets" there is described in detail the circuitry and apparatus required to produce high-energy pulsed liquid jets by the discharge of electrical energy into a liquid contained in a suitable hydraulic chamber. Reference is made to this application for complete details of the several embodiments and the disclosure thereof is incorporated herein by such reference. Generally this application discloses that the discharge of stored electrical energy from a suitable source into a relatively incompressible liquid such as water contained in a hydraulic chamber having a single outlet nozzle by means of proper coupling electrodes will result in the production of a rapidly expanding gaseous bubble in the channel between the electrodes. Since expansion of the bubble takes place during the relatively short time period of energy release a shock wave is produced in the liquid within the chamber. Since the hydraulic chamber is essentially a closed container except for the jet nozzle opening, this shock wave meeting mechanical resistance in all directions except through the nozzle opening will drive a slug or jet of liquid through the opening at a high velocity.

The shock wave thus produced by the rapidly expanding gaseous bubble radiates spherically within the hydraulic chamber from the point of formation between the electrodes. It has now been discovered in accordance with the present invention that this spherically radiating shock wave can be converted into a plane wave with its effective locus at the point of discharge and with the direction of propagation in the direction of the jet nozzle opening if that portion of the hydraulic chamber opposed to the jet nozzle opening has a parabolic configuration. If the configuration of such a chamber is so selected and the focus of the parabolic configuration is at the point of formation of the spherical shock wave between the electrodes, then that portion of the spherical shock wave radiating in the direction of the parabolic configuration will be converted into a plane wave with its direction of propagation in the direction of the jet nozzle opening.

It has further been discovered in accordance with the present invention that the shape of the jet nozzle has a marked effect on the buildup of pressure in the nozzle and on the momentum imparted to the liquid jet delivered by the nozzle. In order to maximize the momentum and hence the kinetic energy imparted to the liquid jet, it is necessary to build up the velocity in the converging jet nozzle both uniformly and rapidly. It has now been discovered that such uniform and rapid velocity buildup can be achieved in a converging jet nozzle having the shape of a cissoid of Diocles as a surface of revolution about the centerline of the nozzle in accordance with the cissoid equation:

$$l^2(2a-r)=r^3$$

Where: r is the internal radius of the nozzle along the length l

l is the length along the nozzle

$2a$ is the entrance radius of the nozzle

It may readily be seen that while each of these features contributes substantially to improved performance of a liquid jet apparatus, the combination of features results in a jet with an output far markedly exceeding heretofore known apparatus for comparable input of energy.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of one embodiment of an electrohydraulic jet apparatus according to the present invention;

FIG. 2 is a cross-sectional view of a second embodiment of an electrohydraulic jet apparatus according to the present invention;

FIG. 3 is a graph of the velocity buildup in a jet nozzle expressed as a function of nozzle length; and

FIG. 4 is a graph of the energy content of liquid in a jet nozzle expressed as a function of nozzle length.

DESCRIPTION OF PREFERRED EMBODIMENTS

The improved hydraulic chamber of the present invention can best be described with reference to the drawings. For purposes of illustration a single electrohydraulic jet apparatus is shown.

In the embodiment shown in FIG. 1 the electrohydraulic apparatus includes a hydraulic chamber 11 having a jet nozzle opening 12. Liquid is supplied to the chamber 11 under pressure from a source (not shown) through line 13 to a supply port 14 opening into the chamber 11 at any suitable location. Electrodes 15, 16 are positioned within the chamber 11. The hydraulic chamber 11 includes a parabolic portion 17. The electrodes 15, 16 are so arranged within the chamber 11 that the discharge channel 18 between the electrodes 15, 16 coincides with the focus of the parabolic portion 17 of the hydraulic chamber 11. The hydraulic chamber 11 has a second portion 19 which is the nozzle portion and terminates in the jet nozzle opening 12. The nozzle portion 19 has the configuration of a cissoid of Diocles.

The electrodes 15, 16 are insulated from the hydraulic chamber 11 by insulating means 20 and preferably are provided with sleeves 21, 22. The sleeves 21, 22 are insulated from the electrodes 15, 16 and the hydraulic chamber 11 by the insulating means 20. The jet nozzle opening 12 is selectively closed by means of a valve or shutter 23. In a further modification, the valve or shutter can be dispensed with and the chamber 11 filled with water on a continuing basis which develops an aiming or directive stream out the nozzle when not electrically energized and a pulsed stream when energized. A spring-loaded, unidirectional ball valve placed in line 13 permits water to enter chamber 11 in one direction but not in the reverse direction when electrodes 15, 16 are energized. The electrodes 15, 16 are connected through switch means 24 to a source of electrical energy. This is represented in a capacitance 25 charged by a high-voltage source (not shown) but can be any suitable source such as an induction coil, transformer or the like. The shutter 23 is connected through sensor means 26 to the switch means 24 to cause the shutter 23 to open the nozzle opening 12 in timed relationship to the discharge of electrical energy. When the switch means 24 is actuated, the electrical energy in the capacitance 25 is discharged across the discharge channel 18 between the electrodes 15, 16. The hydraulic chamber 11 is filled with liquid at the time of discharge. A gaseous bubble will be formed in the liquid in the discharge channel 12. The high temperature and pressure developed in the channel 18 by the discharge of electrical energy therein will cause the bubble to expand at a rapid rate creating a spherical shock wave radiating outward from the point of discharge. The point of discharge 18 is at the focus of the parabolic portion 17 of the hydraulic chamber 11 and on a line with the jet nozzle opening 12. The spherical shock wave radiating in the direction of the parabolic portion 17 of the chamber will be reflected back to the focus 18 of that portion of the chamber being thereby converted into a plane shock wave which has its direction of propagation in the direction of the jet nozzle opening 12. The effective locus of this shock wave is the point of discharge 18. This will reinforce the effect of the remainder of the shock wave. This reinforced shock wave drives the liquid in the nozzle portion 19 of the hydraulic chamber 11 in the direction of the jet nozzle opening 12. Since the configuration of the nozzle portion 19 of the hydraulic chamber 11 is that of a cissoid of Diocles, the pressure buildup within the nozzle portion 19 will be rapid and uniform. The liquid will exit from the nozzle opening 12 with a high momentum.

In the embodiment of FIG. 2, the operation is similar to that of the embodiment of FIG. 1. A freely accelerating piston 30 is employed to compress the liquid in the hydraulic chamber 11 prior to the discharge of the capacitance 25 between the electrodes 15, 16. The liquid is supplied to the piston cylinder 31 through suitable means such as a port 32. The piston 30 is driven at a high rate of speed through the cylinder 31 by external power means (not shown). The piston picks up the liquid supplied by the port 32 and accelerates this liquid during delivery to the hydraulic chamber 11. The liquid thus enters the hydraulic chamber 11 at a high rate of speed and with considerable force. It fills the reaction chamber and at the instant that the chamber 11 is filled, and piston 30 is at top dead center position, switch means 24 causes a discharge of the electrical energy in the discharge channel 18. The face 33 of the piston 30 is designed to conform to and form a continuation with the parabolic portion 17 of the hydraulic chamber 11.

FIGS. 3 and 4 show graphically the improved result obtained by the cissoid nozzle configuration 19 of the present invention. The cissoid of Diocles nozzle configuration 19 is compared with an exponential configuration 29 and a conical configuration 39. All other factors except configuration were the same. The nozzle length in each instance was 1 inch, the entrance diameter was 0.7 inch and the exit diameter was 0.08 inch.

FIG. 3 illustrates the superior uniform and rapid velocity buildup accomplished with the cissoid nozzle configuration. Velocity developed at 60 percent of nozzle length by the cissoid nozzle is 6 times that of the conical nozzle 39, and 1.8 times that of the exponential nozzle 99.

FIG. 4 illustrates the superior property of the cissoid nozzle configuration 19 of the present invention as compared with an exponential nozzle configuration 29 and a conical configuration 39. Again all factors except nozzle configuration were the same. Energy content of the liquid rises more rapidly with the cissoid nozzle configuration and is higher at any given point along the nozzle length for the cissoid configuration 19 over the exponential configuration 29 and the conical configuration 39. It can thus be seen that the cissoid configuration is much more efficient than the exponential or conical configuration in generating the requisite high-pressure liquid jets.

Although the present invention has been described in connection with the preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand. For example, the shock wave utilized to impart momentum to the water jet can be produced by any suitable mechanical, electrical, chemical or hydraulic means, or any combination thereof capable of producing such a shock wave in a relatively incompressible liquid confined in a hydraulic chamber with the configuration or configurations disclosed herein. Such modifications and variations are considered to be within the purview and scope of the invention and the appended claims.

I claim:

1. In a hydraulic chamber for obtaining high pulse dynamic liquid pressure jets from a shock wave generated in a substantially incompressible liquid contained therein for discharge through a nozzle forming a part thereof, the improvement wherein the effective configuration of said chamber at the instant of production of the shock wave is that of a parabolic cissoid.

2. In the hydraulic chamber of claim 1, wherein the port of the chamber forming the nozzle has the cissoid configuration.

3. A jet nozzle for obtaining high pulse dynamic liquid pressure jets from a shock wave generated in a substantially incompressible liquid adjacent the entrance of said nozzle, said nozzle having the configuration of a cissoid of Diocles.

4. A jet nozzle for the production of hydraulic liquid jets having an internal configuration corresponding to a surface of revolution about the centerline of said nozzle of a cissoid of Diocles.

5. A hydraulic chamber for the production of high-pressure liquid jets powered by a shock wave generated at a point therein by the discharge of electrical energy in an incompressible liquid confined in said chamber wherein the chamber has a first portion having a parabolic configuration and a second portion having a nozzle opening therein and a configuration conforming to a surface of revolution of a cissoid about the centerline of said opening, the point of generation of the shock wave being the focus of the parabolic configuration of said first portion and adjacent the intersection of said first and second portions and on the centerline of the nozzle opening of said second portion.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,647,137 Dated March 7, 1972

Inventor(s) Theodore T. Naydan

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 21, "83,218" should read -- 82,319 --; line 22, "now U.S. Patent No. 3,592,866" should be cancelled; line 70, "83,218" should read -- 83,219 --.

Signed and sealed this 24th day of October 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents