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 [73] Assignee **Continental Can Company, Inc.**
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[54] SONIC MULTISTAGE PUMP 5 Claims, 9 Drawing Figs.

[52] U.S. Cl. **417/379,**
 417 53, 417/246, 417/383

[51] Int. Cl. **F04b 9/10,**
 F04b 23/04, F04b 43/02

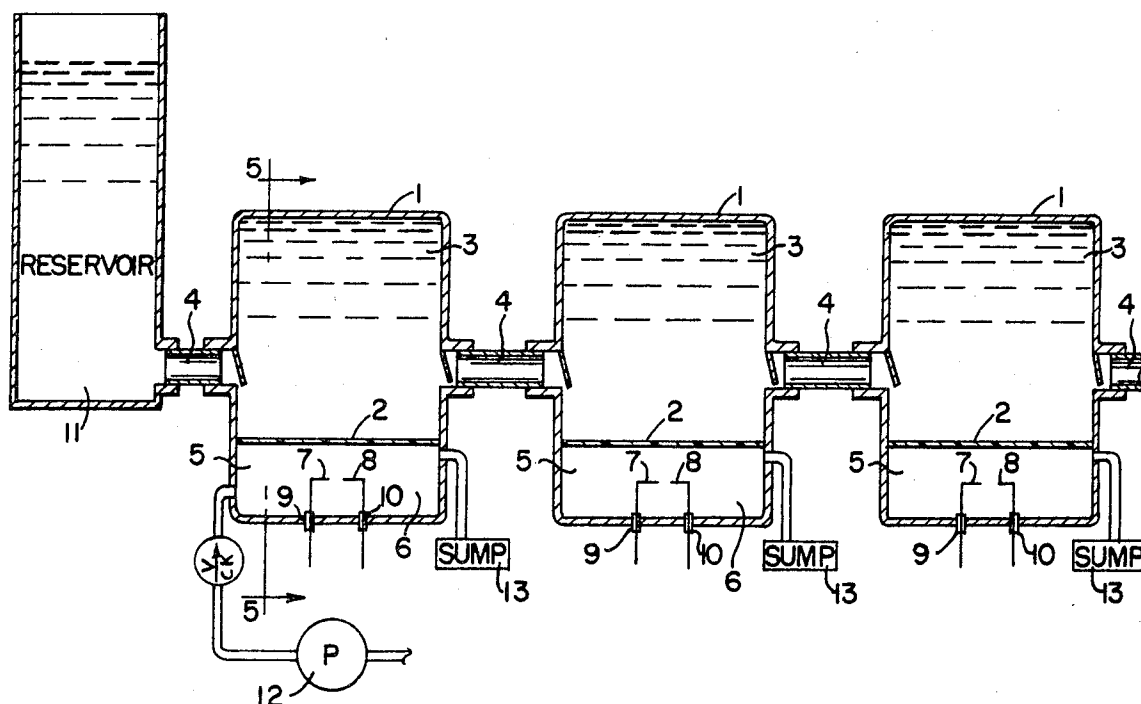
[50] Field of Search 103/1, 1 E,
 1 M, 255, 5, 165; 417/48, 246, 322, 379, 383

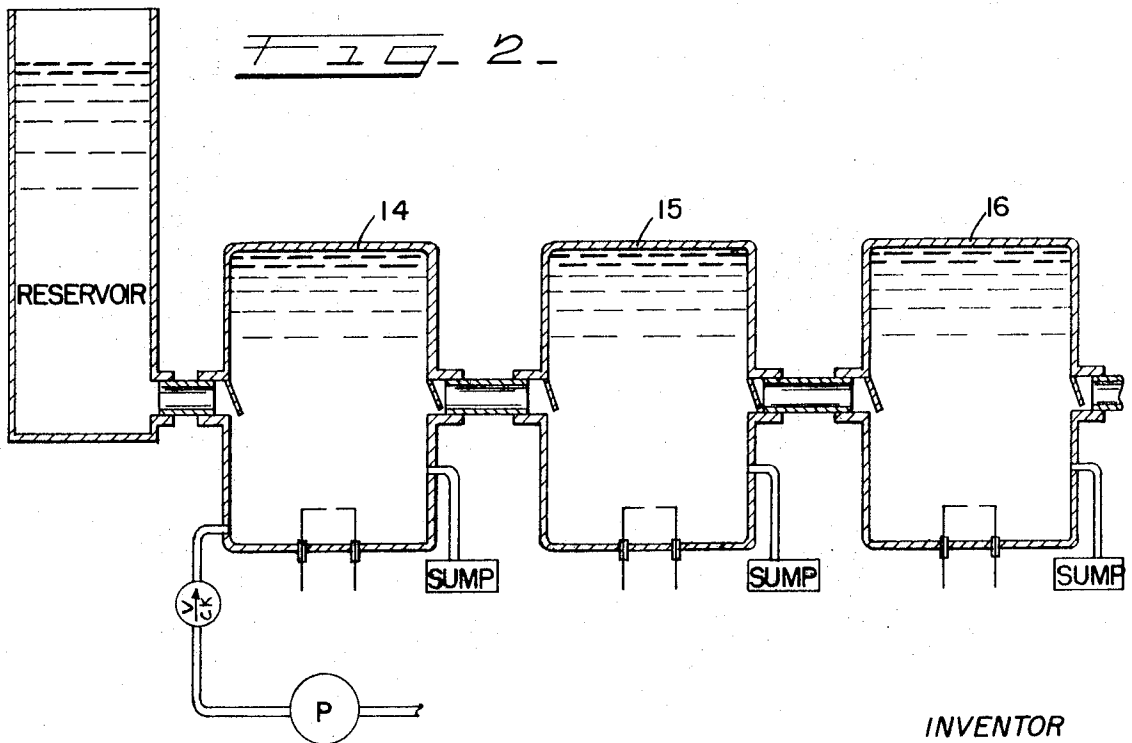
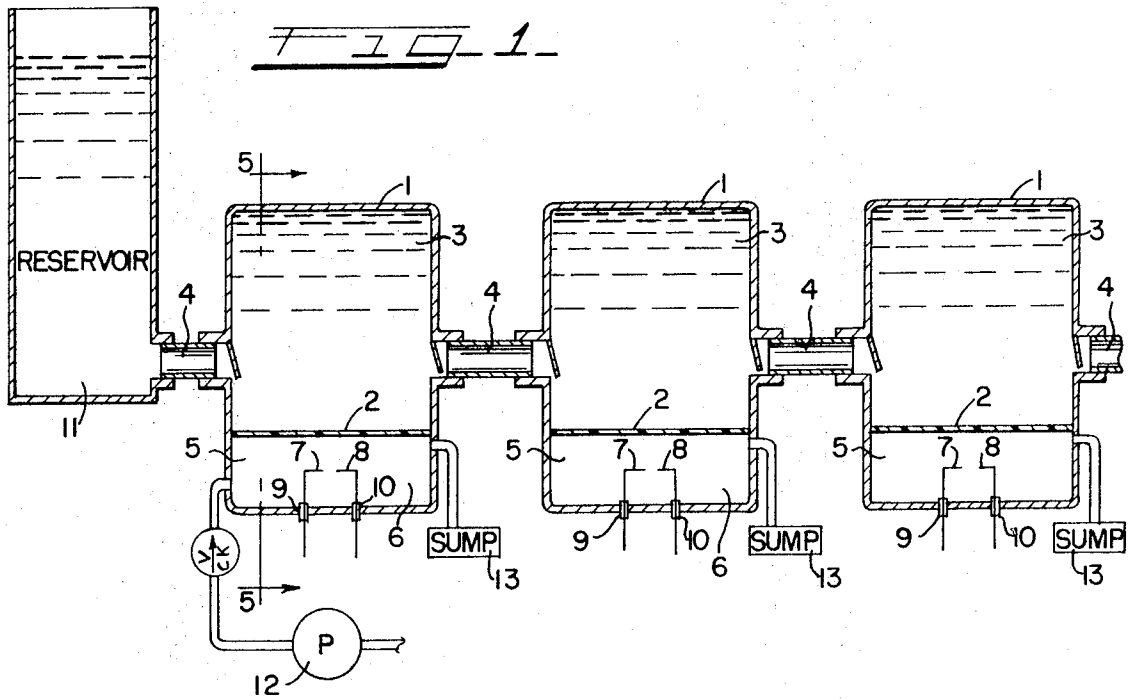
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ABSTRACT: An electrohydraulic multistage pump is composed of a series of stages, each stage being connected to the next stage so that when an electric pulse is applied in a stage, fluid is displaced into a succeeding stage and at this time, an electric spark passes across the arc gap to augment the pressure in the succeeding stage. The stages are arced at proper times so that the arc occurs when each stage is under pressure from the sonic wave actuated or caused by the preceding stage. A considerable pressure is developed at the output by the series of electrical pulses operating to raise the pressure in successive stages.





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FIG. 3.

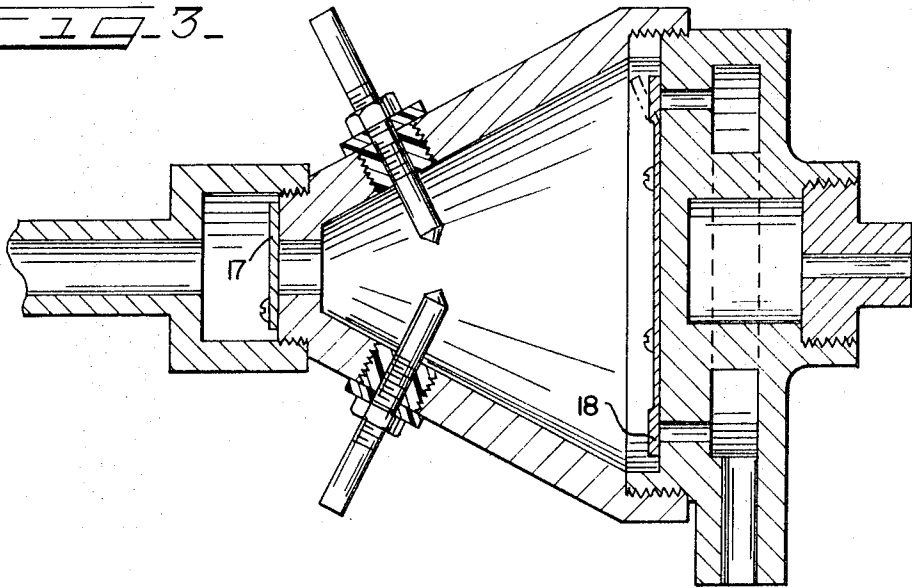


FIG. 4.

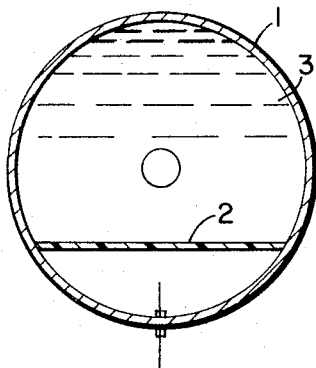
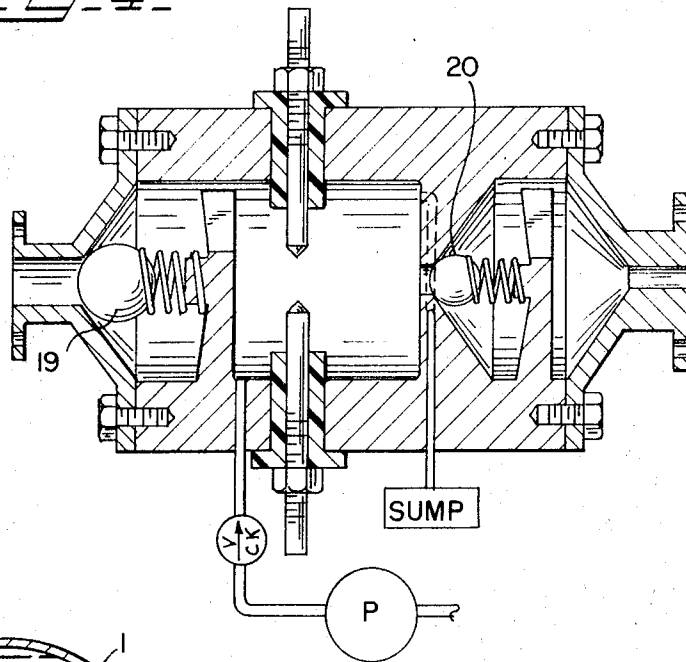


FIG. 5.

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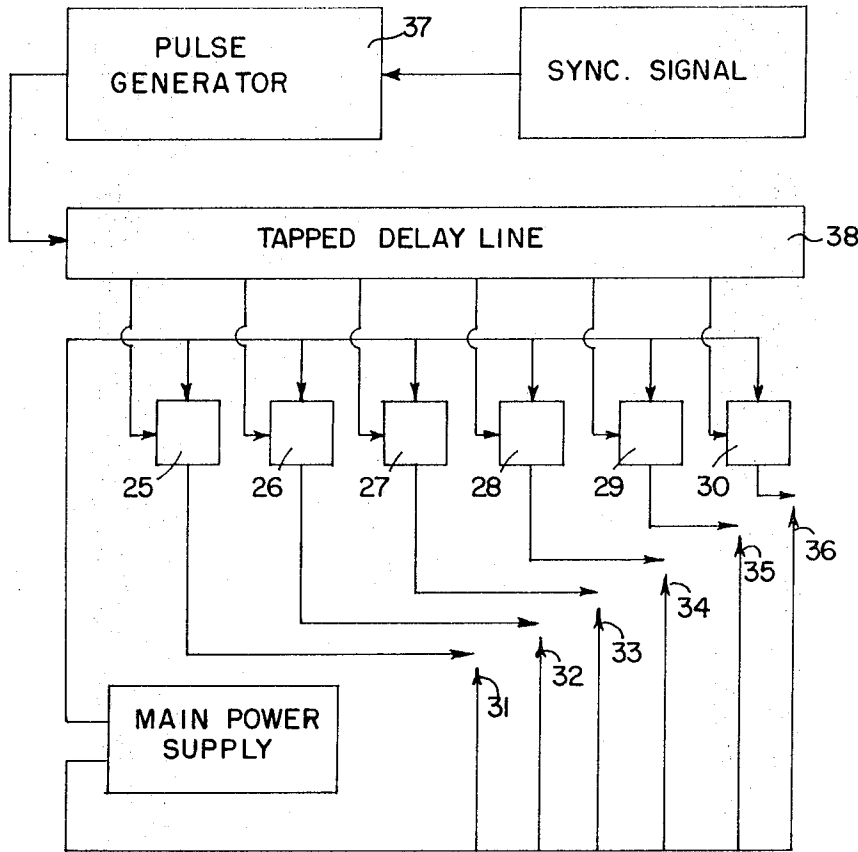


FIG. 7

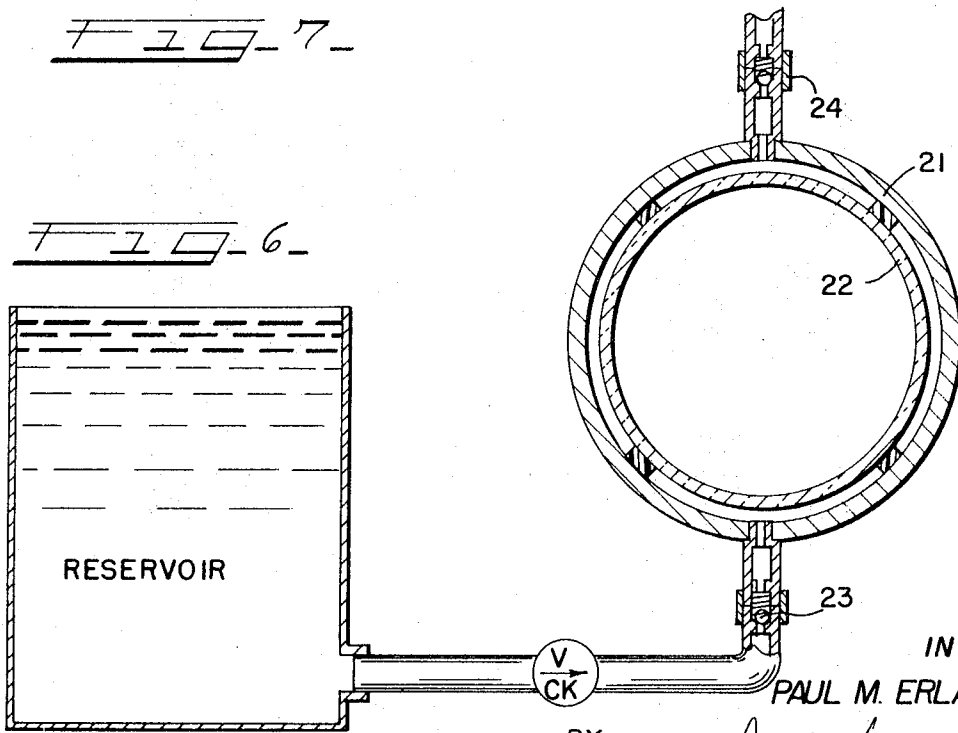


FIG. 6

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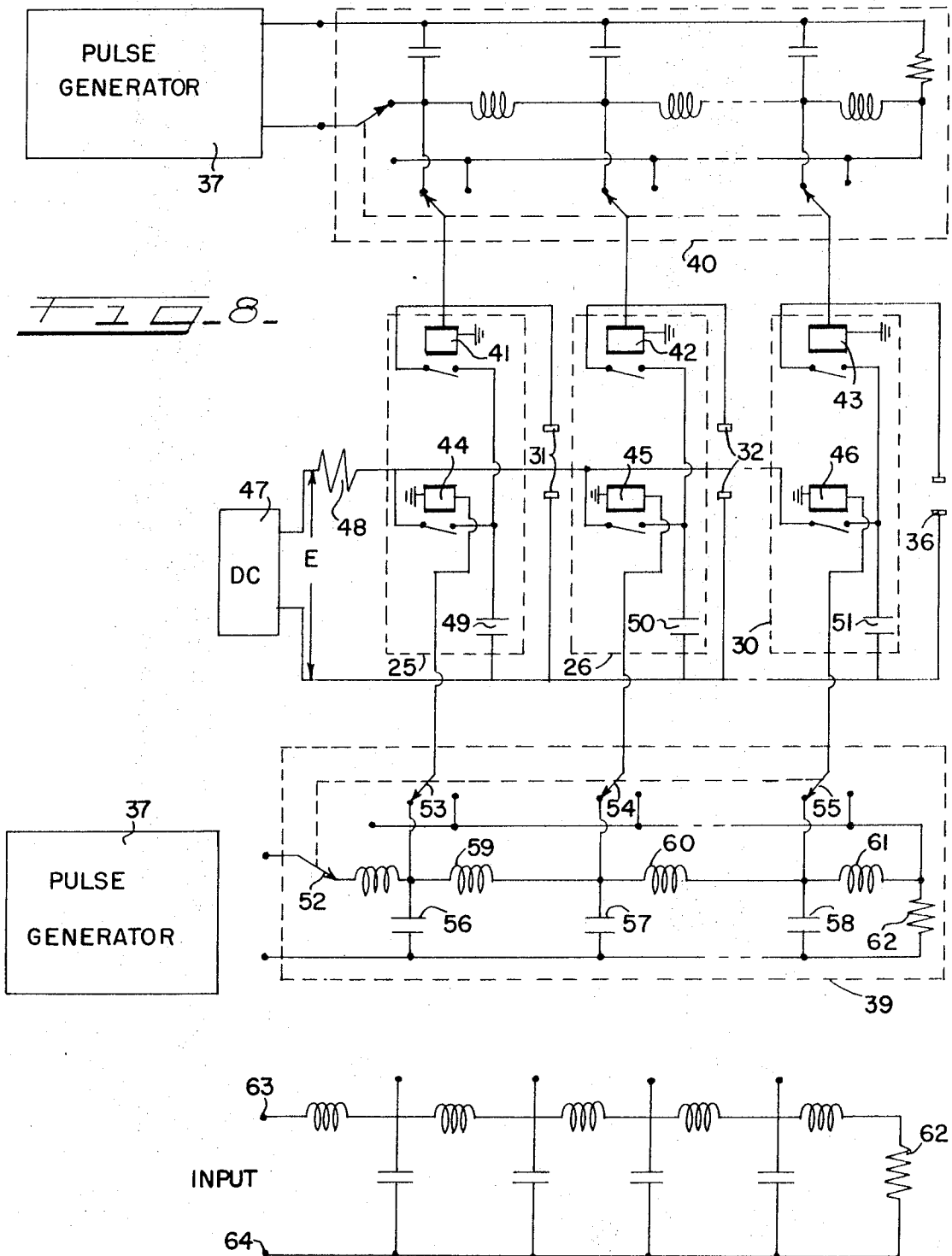


FIG. 9

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SONIC MULTISTAGE PUMP

My invention is drawn to an electrohydraulic pump for fluids and particularly to an electrohydraulic multistage pump or piezoelectric pump for furnishing a high-velocity fluid jet of extremely high pressure.

The development of electrohydraulic pumps has led to numerous schemes for utilizing the expansion of a liquid or gas when a pair of electrodes are supported by a housing and are placed within a pump chamber and a spark arcs across the electrodes to expand the fluid in the chamber. Check valves are placed at each end of the chamber to allow unidirectional flow of fluid through the chamber. Such a system is shown in the patent to R. C. Smith, U.S. Pat. No. 3,185,106 with a chamber with entrance ports and exit ports and suitable valves for entrance and exit of fluid to the chamber. A pair of electrodes are mounted in the chamber walls. Fairly high pressure is produced in this type of electrohydraulic pump. However, there is some debris from the electrodes which comes into the fluid and the pressure increase and rate of flow is not especially larger. Similarly, the patent to C. L. Stec, U.S. Pat. No. 3,150,582, shows an electric pump which utilizes the differential expansion of piezoelectric spheres to develop a fluid flow through a chamber. This application is subject to the same limitations discussed above in regard to the patent to R. C. Smith.

It is an object of my present invention to obtain a high-pressure jet pump capable of delivering a volume of fluid.

It is another object of my invention to show an apparatus having a multistage high-velocity jet pump.

It is still another object of my invention to show a machine having long life and low maintenance for obtaining high-pressure jets.

A further object of my invention is to provide large impulses of power from a power supply without the necessity of drawing large peak currents from a primary supply, such as a utility company powerline, a battery, or other means.

Another object of my invention is to provide sequential impulses of electrical energy form a primary supply to storage elements, during a large portion of each cycle, such that large impulses of power are available during the relatively shorter output portion of the cycle without necessitating the drawing of large peak currents from the primary supply.

Another object of this invention is to provide an accurately timed series of electrical energy impulses to multiple devices which function in a cooperative manner to produce an end result.

A further objective of this invention is to provide sequential pulses of electrical energy to one or more devices, the total energy being approximately equivalent to a single pulse of like amplitude whose duration equals the combined duration of the sequential pulses, but eliminating the disruptive effect of the single pulse upon the energy transfer mechanism.

It is a final object of my invention to define a machine having a high efficiency and high controllability of pressure and jet velocity.

In brief, my invention is an electrohydraulic multistage pump having a series of stages, each adapted to give its impulse in a predetermined sequence. Each stage is composed of an electrohydraulic pump, and each pump is fired by time-delay circuits at such a time as its developed pressure is added to the pressure wave from the preceeding stage. In this way, by firing each pump when the maximum pressure wave from the preceding stage has arrived in the pump chamber, the additional pressure causes the pressure inside this stage to step up and this pressure is transmitted into the succeeding stage where the same cycle takes place. By repeated application of this cycle, a high-pressure, high-velocity jet is obtained.

The foregoing and other objects and advantages will appear more fully hereinafter from consideration of the description which follows, taken together with the drawings. It is understood, however, that the drawings are for illustration purposes only, and do not define the limits of the invention.

FIG. 1 shows a schematic drawing of the multistage pump and an electrically controlled circuit for firing the arcs.

FIG. 2 shows a schematic view as in FIG. 1, but not using the diaphragm.

FIG. 3 shows an individual arc pump with reed valves.

FIG. 4 shows the individual arc pump with ball check valves.

FIG. 5 shows a cross-sectional view of a single cell taken along line 4-4 of FIG. 1.

FIG. 6 shows a cross-sectional view of a piezoelectric pump.

FIG. 7 shows a schematic diagram of an electric switching power supply for arcs in each cell.

FIG. 8 shows a detailed diagram of portions of the schematic diagram of FIG. 7.

FIG. 9 shows the L-C circuit of a delay line.

FIG. 1 shows three pump stages connected in series. Each of the series of stages generates a certain amount of velocity and pressure. Each pump consists of a chamber housing 1 which may be cylindrical, conical or any other desired shape. A flexible diaphragm 2 is stretched across the chamber to form two compartments. One compartment 3 of the chamber is filled with a fluid which is conducted into the compartment through a conduit 4 to a flap valve in the side of the chamber 1. The other compartment 5 formed by the flexible diaphragm 2 is filled by a liquid 6 having a fairly high dielectric constant with a sharp electrical breakdown point when the electrical potential across the liquid reaches a certain voltage. Mercury of transformer oil, for example, are materials of this sort. A conductive liquid can also be used. Two electrodes 7, 8 are mounted in insulators 9, 10 and extend through openings in the side of the wall and are spaced apart so that a spark may arc from one electrode to the other. When the spark arcs across the gap, the volume occupied by the mercury, for example, is tremendously expanded and the flexible diaphragm 2 moves upward to cause a decrease in the size of the chamber above the diaphragm. Fluid is forced out through a one-way valve on the right of the chamber.

The three chambers shown are lined in series and movement of the more or less incompressible fluid in one of the chambers causes movement in the next chamber. A sharp impact is imparted by the flexible diaphragm 2 to the pressure-transmitting liquid 11 in the other compartment of the chamber. Thus, when this sharp impact comes through the flexible diaphragm 2, a pressure wave is produced in the first chamber which is transmitted to the second chamber. At the time that the pressure wave arrives in the second chamber, the pressure in the second chamber is appreciably higher than before the arrival of the pressure wave, and at this same time, a second pressure is induced in the second chamber by the firing of the second set of electrodes in a similar manner to the operation in the first chamber. A more or less double pressure wave is now transmitted to the third chamber and simultaneously with the pressure wave arrival in the third chamber, its electrodes fire to heighten the pressure one more step. Therefore, as the pressure wave travels down the stages, it can be built up to considerable heights of pressure. Any number of stages may be used to develop pressure depending on the pressure to be obtained. Suitable power supplies are attached to each stage for supplying the high voltage and amperage necessary to cause an arc. Similarly, also because some gas and debris may accumulate after some arcings, and each arcing may consume some liquid, a small amount of the liquid is forced into the firing chamber 5 by a pump 12 and the debris and residual materials are taken out across the top of the lower compartment 5 to a sump 13 for possible purification and recirculation. Each power source is tripped by a single master control. A master control timer is set to fire synchronously for the speed of propagation of the sonic wave in whatever liquid is passing through the stages of the pump. This arrangement gives a sonic pump which delivers liquid at very high pressures and relatively small volumes of flow.

In order for a high-intensity pressure wave to be generated and transmitted down the series, fluid in the pressure-trans-

mitting chamber and connecting conduits must have a relatively high modulus of elasticity. Mounting a diaphragm between the explosion chamber and the transmitting chamber avoids contamination of the pressure liquid by debris which may be left over from the explosion of the pressure-transmitting liquid.

A piezoelectric pump such as that shown in the patent to C. L. Stec, U.S. Pat. No. 3,150,592, previously referred to, can be used at each stage to provide a pressure increase or volume-changing element of the pump. An example of a piezoelectric pump suitable for use in my present apparatus is shown in FIG. 6 of my drawings. A piezoelectric pump can be used as a pumping stage in the same manner as the pumping stages shown in FIG. 1.

FIG. 2 shows a series of pumping stages 14—16 using no flexible diaphragm. In the situation where particular purity of the flowing pressure liquid is not necessary, the flexible diaphragm may be eliminated. In this case, waste material is taken but by the flowing liquid. Operation of this device is in all essentials the same as described above in reference to the embodiment of FIG. 1.

A variety of valves have response times rapid enough for use with my invention. Such a valve is a reed valve 17, 18 shown in FIG. 3. A ball check valve 19, 20 arrangement is shown in FIG. 4.

To aid in the visualization of a possible embodiment of my invention, FIG. 5 shows the cross section taken along line 5—5 of FIG. 1. In this embodiment, the flexible membrane 2 is shown of a thickness sufficient merely to act as a barrier between the two liquids involved.

FIG. 6 shows a piezoelectric stage which may be used in place of each stage shown in FIG. 1. A hollow metal sphere 21 has a hollow piezoelectric sphere 22 inside of it. Ball check valves 23, 24 are mounted at the entrance and exit of the cavity. If a piezoelectric stage is used, it is not necessary to use banks of capacitors to store the electric current since the amount of current needed to activate a piezoelectric pump is relatively small. The timing device is set to the essential timing necessary to add the piezoelectric pressure to the pressure of the pressure wave as it travels through each of the compartments.

Various advantages accrue to this apparatus. For example, high efficiency, very high pressure, quiet operation, relative compaction, and low cost.

It is anticipated that this invention may be used in the preparation of the edges of can body blanks. To clean the edges of can body blanks, a small volume of liquid flowing under high pressure is required.

The power supply and control circuitry for the above apparatus is shown in the accompanying figures.

The schematic electrical circuit shown in FIG. 7 is designated to apply high electrical potential and amperage across the arcs in each of the pressure compartments. The switching arrangements of the switching units are such that the circuits apply electric potential sufficient to break down the gap between the electrodes and create heightened pressure to augment the pressure wave as it passes from compartment to compartment, thus stepping up the pressure. It is readily apparent from FIGS. 7 and 8 that any number of switching units 25—30 having storage capacitors and electrode pairs 31—36 may be used corresponding to the number of stages in the pump. The pulse generator 37 which is shown is applied to the tapped delay line 38. This delay line 38 includes both the tapped charge delay line 39 and the tapped discharge delay line 40 shown in FIG. 8. The frequency of the pulse cycle determines the number of pressure waves which are to proceed down the fluid pressure buildup apparatus. One side of the main power supply is connected to one electrode of each of the electrode pairs 31—36. In FIG. 1, only three of these pairs are shown as electrodes 7 and 8.

The application of electrical potential is accomplished by means of the main power supply which charges capacitors in the switching units 25—30. Individual switches 41—46 (FIG.

8) are provided in each of the switching units for switching the storage capacitor to charge and switching the storage capacitor to discharge through the individual arcs located in each of the chambers. The delay line 38 and through the delay line the switches are operated by a synchronous signal conducted through a pulse generator to give rise to a signal strong enough to operate tapped delay line 38.

A more detailed showing of the power supply is given in FIG. 8 except three of the switching units and related equipment shown in FIG. 7 are deleted in FIG. 8. A main power supply or primary source of direct current 47 delivers a terminal voltage E_1 across its terminals. Connected across these terminals is a charging resistor 48 having a resistance of R ohms and considerable wattage capacity. Switch 44 is mounted in series with the energy storage capacitor 49 and charging resistor 48 across the main power supply 47. Similarly, switch 45 is mounted in series with the charging resistor and a second energy storage capacitor 50 and so on down the line to the last switch 46 mounted in series with the energy storage capacitor 51. The each individual circuit, the switch, storage capacitor and primary power supply are connected in electrical series. Thus, several energy storage capacitors are mounted in parallel with their respective switches across the primary DC supply. In this way, the energy storage capacitors are being charged at varying initial times, the drain on the primary electrical supply is almost constant, and the voltage E_1 is not substantially reduced.

In the operation of this circuit, the charging and discharging is taking place in a more or less continuous fashion as the pressure wave proceeds down through the various stages of the electrohydraulic pump. When switch 44 is closed by an impulse from the charge delay line 39, the voltage on the capacitor 49 is initially zero and at any time after switch 44 is closed, this voltage is given by the equation:

$$E = E_0 \left(1 - e^{-\frac{t}{RC}} \right)$$

wherein E equals the instantaneous voltage, E_0 equals the voltage across the primary supply, t equals the time the voltage E_0 has been applied across the capacitor, R equals the resistance, and C equals the capacitance in the circuit.

In a similar fashion, the capacitors 49, 50 and 51 charge when their respective switches 44, 45 and 46 are closed by the charge delay line 39.

Switches 41—43 together with switches 44—46 are typically heavy switches capable of conducting the necessary current and may be an ignatron hydrogen thiratron or solid state device of the Silicone Controlled Rectifier type. In any case, the switches are switched to the "on" or conducting position for application of the suitable potential and are turned "off" by removal of the potential. When the capacitors 49, 50 and 53 are being simultaneously charged, ganged switches 51, 54, 55 are switched to the upper alternate position shown in FIG. 8 to cause switches 44, 45, 46 to close when a synchronization signal is applied from the pulse generator to the charge delay line. However, in the operation of my device, it is intended that sequential operation of the switches 44, 45, 56, is to be accomplished thereby causing the charging circuit of the capacitors 49, 50, 51 to operate in a staggered or sequential fashion through the use of a suitable delay line composed of a series of equal valve capacitors 56, 57, 59, and equal valve inductors 59, 60, 61 shown in FIG. 8 when the switches 52—55 are in position shown in FIG. 8.

The capacitors and inductances in the charge delay line and the discharge delay line are of equal value to give equal timed delays. Either the discharge delay line or the charge delay line may have an inductor of one-half the value of the sector inductance to delay the pulse in one line so that the switches cause each capacitor to charge and discharge in a phased relationship.

A schematic of the control part of the charge delay line is shown in FIG. 9. This line is shown having equal effective inductances in each section and equal effective capacitors in

each section. It is terminated by a resistance 62 having a resistance equal to the characteristic impedance of the line. In the case where equal intervals of time are desired between switchings, then a pulse of proper length is applied at the input terminals 63, 64 from a matched voltage source and is propagated along the line with a constant velocity until it reaches the terminating resistor 62 where the power is absorbed. If the line is tapped at a number of places as shown in FIG. 9, the pulse voltage will appear at successive times at each tap along the length of the line. Such a voltage is used to actuate switches 44, 45, 46 at each charging element. The overall result is that energy is delivered to a number of different physical locations according to a predetermined and repeatable timed sequence while using the charge delay line to control a multiplicity of individual switches.

The total delay time for single line section is approximately:

$$\sqrt{T_s = L_s C_s}$$

wherein L_s is the inductance in the sector, and C_s is the capacitance in the sector.

The sequential discharge of capacitors 49, 50, 51 (FIG. 8) may be accomplished by operating switches 41, 42, 43 through a sequential discharge delay line which operates on exactly the same principle as explained in regard to the charge delay line. The discharge delay line and charge delay line are, however, out of phase so that suitable electrical energy may be stored in capacitors 49, 50, 51. Whatever lead time is necessary between the charge delay line and discharge delay line, the discharge delay line must fire or send an impulse to its respective switches at spaced intervals so that the pressure wave passing from compartment to compartment is augmented in each compartment to give a resultant high-pressure volume flow of liquid through the electrohydraulic sonic pump.

The foregoing are descriptions of illustrative embodiments of the invention, and it is applicant's intention in the appended claims to cover all forms which fall within the scope of the invention.

What I claim is:

1. An electrohydraulic high-pressure, low-flow pumping apparatus comprising:
 - a series of chambers of approximately equal size and shape having fluid means therein;
 - elastomeric diaphragm means mounted across each chamber to form a first and a second compartment;
 - pressure-transmitting liquid filling said first compartment;
 - means providing a conduit from said first compartment to at least one other first compartment;
 - one-way valve means in each said conduit means for allowing said fluid pressure to pass through said series of compartments in one direction;
 - means including spaced electrodes in each second compartment for raising the fluid pressure in said second compartment;
 - electrode surrounding liquid filling said second compartment;
 - first conduit means connecting each said electrode compartment to a pump for pumping said electrode surrounding liquid to said compartment;
 - second conduit means connecting said first compartment to a liquid reservoir whereby said first compartment is kept filled with pressure-transmitting liquid;
 - electrical means for intermittently applying electric potential across said spaced electrodes and synchronizing the operation of said pressure-raising means in each chamber with that of each other chamber so that an ultimate pressure wave is generated in the end chamber of said series and is reinforced by said pressure-raising means in each chamber as the wave travels through said series of chambers.

2. An electrohydraulic high-pressure, low-flow pumping apparatus as set forth in claim 1 in which said one-way valve means comprises:

a flap valve.

3. An electrohydraulic pumping apparatus comprising:

a series of chambers of approximately equal size and shape having a fluid therein;

means providing a conduit from each said chamber to at least one other chamber;

one-way valve means in each said conduit means for allowing said fluid pressure to pass through said series of chambers in one direction;

paired means including a first and second electrode spaced from each other in each chamber for raising the fluid pressure in said chamber;

a plurality of means for applying voltage across each pair of electrodes in sequence, each said means of said plurality comprising:

a storage capacitor having first and second terminals;

a means for charging said storage capacitor on a periodic basis to a predetermined potential;

first connecting means for electrically connecting said first terminal of said capacitor to said first electrode;

a first switch having a first and second terminal and a control element for opening and closing said switch;

second connecting means for electrically connecting said first terminal of said switch to said second terminal of said capacitor;

third connecting means for electrically connecting said second terminal of said switch to said second electrode; and

a first L-C delay discharging circuit means for operating each said switch control element to open and shut each said switch of each of said plurality of voltage-applying means in a timed relationship.

4. An electrohydraulic pumping apparatus as set forth in claim 3 in which said means for electrically charging said storage battery comprises:

a source of direct current having a first and a second external terminal;

a second switch having a first and second terminal and a control element for opening and closing said switch;

fourth connecting means for electrically connecting the first terminal of said switch to the second terminal of said capacitor;

fifth connecting means for electrically connecting the second terminal of said switch to the first terminal of said direct current source;

sixth connecting means for electrically connecting the first terminal of said capacitor to said second terminal of said direct current source; and

a second L-C delay discharge circuit means for operating said switch control element to open and shut said switch in timed synchronism with said first L-C delay discharging circuit means whereby said capacitor charges and discharges at different times.

5. An electrohydraulic pumping apparatus as set forth in claim 3 in which said first L-C delay discharging circuit means comprises:

a means for operating each said switch control element to shut said switch of each of said plurality of voltage applying means in a sequence whereby the fluid pressure in successive chambers is raised just at the time that the pressure wave from the preceding chamber has arrived and the magnitude of the pressure wave is increased by successive increments being added in successive chambers.