

[54] **METHOD OF FORMING WORKPIECES
BY MEANS OF UNDERWATER IMPACT
PRESSURE**

[72] Inventors: **Jochen Haeusler**, Nürnberg-Laufamholz; **Gunther März**; **Helmut Seifert**, both of Nürnberg, all of Germany

[73] Assignee: **Siemens Aktiengesellschaft**, Berlin, Germany

[22] Filed: **March 5, 1970**

[21] Appl. No.: **16,736**

[30] **Foreign Application Priority Data**

March 6, 1969 GermanyP 19 11 424.0

[52] U.S. Cl.72/56

[51] Int. Cl.B21d 26/10

[58] Field of Search72/56; 29/421 E; 340/125 D

[56] **References Cited**

UNITED STATES PATENTS

3,203,212	8/1965	Simicich	72/56
3,232,086	2/1966	Inoue	72/56
3,228,221	1/1966	Zernow et al.	72/56
3,208,254	9/1965	Inoue	72/56

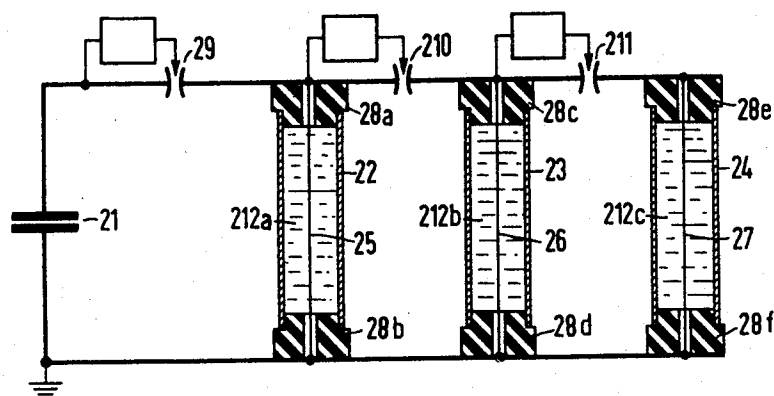
Primary Examiner—Richard J. Herbst

Attorney—Curt M. Avery, Arthur E. Wilfond, Herbert L. Lerner and Daniel J. Tick

[57] **ABSTRACT**

A method of hydro-pressure forming workpieces has the step of sequentially applying a charged capacitor battery across a plurality of ignition wires clamped between pairs of underwater electrodes defining corresponding spark gaps so that each successive ignition occurs at a time when the current in the immediately preceding ignition wire ceases to flow.

3 Claims, 5 Drawing Figures



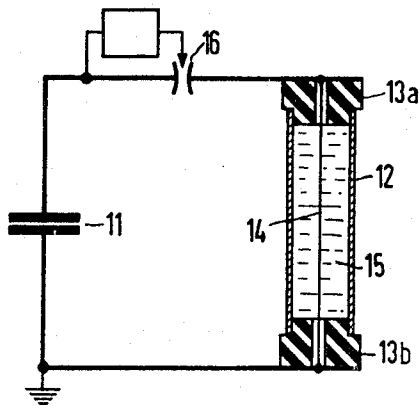


Fig. 1a
PRIOR ART

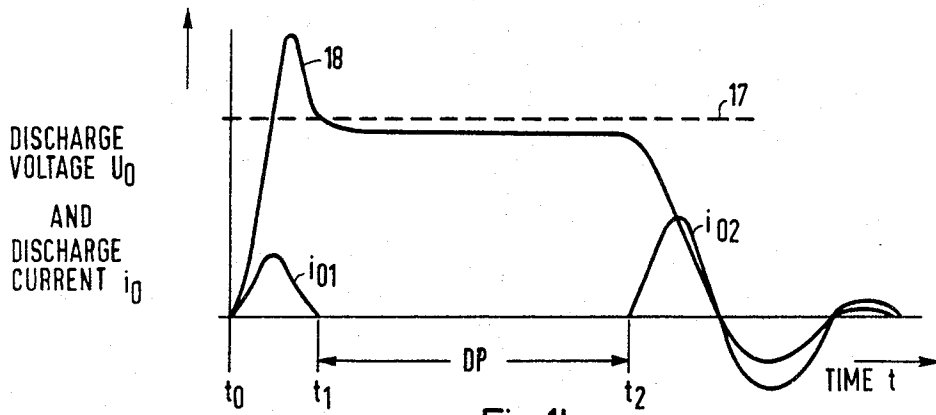


Fig. 1b
PRIOR ART

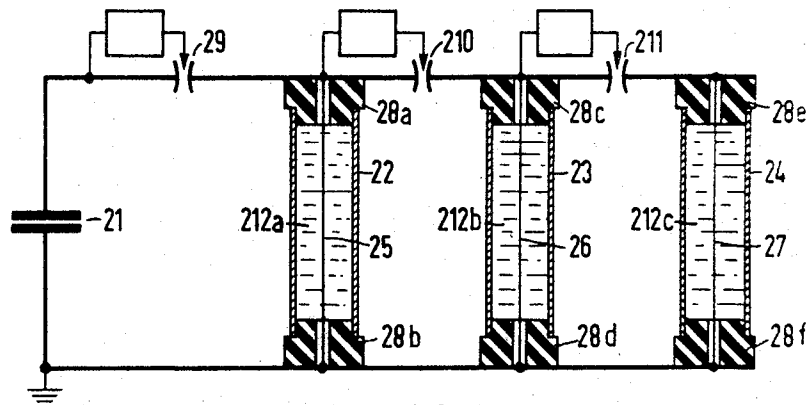
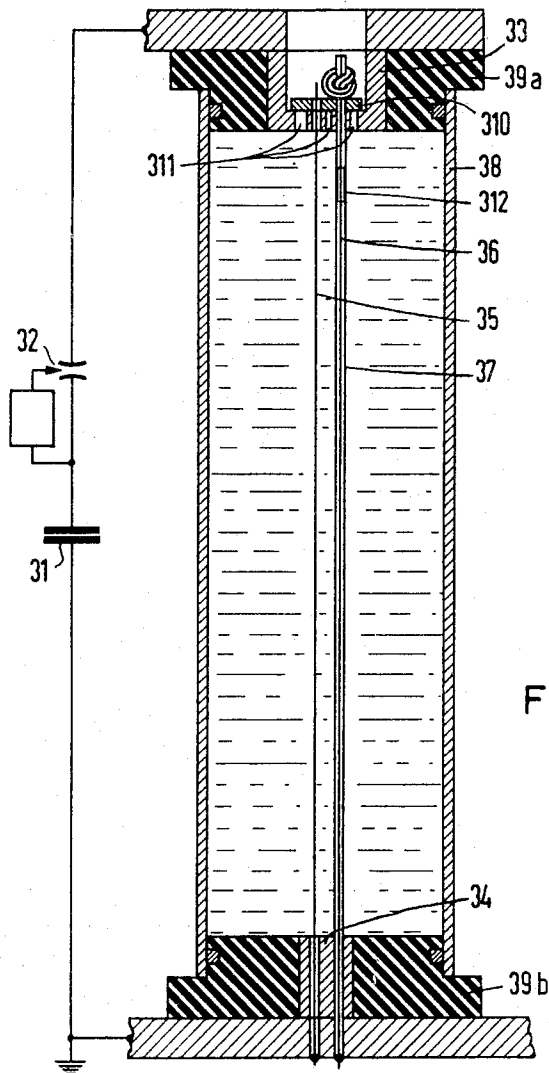
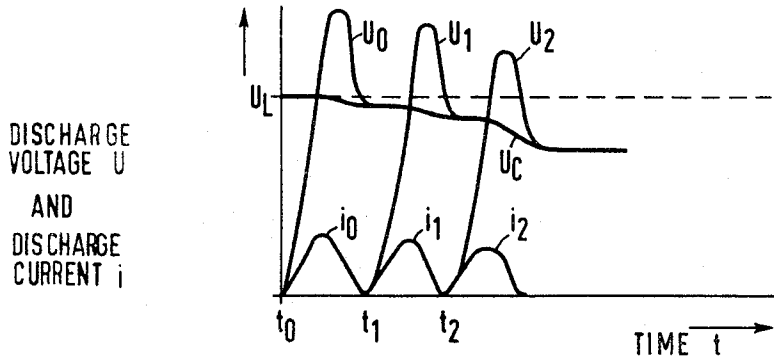


Fig. 2a



METHOD OF FORMING WORKPIECES BY MEANS OF UNDERWATER IMPACT PRESSURE

DESCRIPTION OF THE INVENTION

The invention relates to a method of forming workpieces by means of underwater impact pressure which occurs during an explosion-like evaporation of an ignition wire clamped between electrodes defining an underwater spark gap. The explosion-like evaporation is produced by an underwater spark discharge of a capacitor battery. The method increases the degree of effectiveness by avoiding the so-called dark interval.

During the high speed forming of metal by means of underwater spark discharges, a capacitor battery is discharged via a spark gap which is located in a liquid such as water. The sparkover between the spark gap electrodes causes the formation of a vapor column maintained under high pressure. The expanding vapor column drives the pressure wave, in form of impact waves, through the liquid. The impact waves strike and form the workpiece. In this connection, reference may be made to the German publication: "Werkstatt und Betrieb," Vol. 96, 1963, pages 297-305.

No ignition wire is required between the electrodes when the electric field intensity that occurs in the spark gap is high enough for an electrical breakdown, the electric field intensity occurring when the capacitor battery charged to working voltage is switched on. However, it is customary to use such an ignition wire even in such cases, since the homogeneity and the reproducibility of the discharge channel are thereby improved.

During the forming of workpieces by means of underwater impact pressure in the manner indicated above, the wires, which evaporate explosion-like in response to a capacitor discharge, must frequently be selected to have a length sufficient to produce impact pressures thereby rendering the occurrence of a dark interval or dead time unavoidable. During the dark interval, there is an interruption of the discharge of the capacitor and thus an interruption of the conversion of the stored energy, as happens, for example, during the forming operation performed on a workpiece.

The occurrence of the dark interval is explained as follows. As a result of the onset of the capacitor discharge, the ignition wire becomes so quickly heated, molten and evaporated, that a metal vapor column forms under extremely high pressure. The column occurs because the medium surrounding the wire, for example water, impedes the free expansion of wire material because of its mass inertia. The high pressure does not permit impact ionization in the metal vapor, wherein a metallic conductor is no longer feasible, because the atomic spacing is too great. This renders the wire material, that at first bridges the electrode gap, non-conductive within a few microseconds, thereby interrupting the discharge. Depending upon the parameters of the discharge circuit and up to the discharge interruption, at times only a small percentage of the stored energy is converted in the discharge channel. Only a certain amount of the energy is available for forming the workpieces, for example, as forming energy.

In considering the degree of effectiveness, the above-described condition was not given great importance because during a finite dark interval and following a

reignition in the metallic vapor, which has in the meantime expanded to a lower pressure, a complete discharge of the remaining stored energy in the spark channel with a renewed formation of shock waves could be observed. In this connection, reference may be made to: "Über die Elementarvorgänge bei der elektrischen Explosion dünner Metalldrähte" from the Conference relating to Combustion, Shock waves and Detonation, St. Louis Laboratory 1951, LRSL-14 m/51. The oscillating discharge which occurs following the reignition should display a much stronger light and shock wave formation. See: "Zeitschrift für Physik," Vol. 149, 1957, p. 397/411.

By contrast, the use of underwater pressure impact produced by wire explosion led to the discovery, in forming technology, that the impact pressure which occurs with the first discharge pulse, performs the main share of the forming work. This can be easily understood in connection with discharges where a reignition does not occur, for example, because the dark interval has a longer duration than the conductive state of the high-voltage switch. The high-voltage switch serves to connect the capacitor battery to the discharge channel. During such discharges, more than 90 percent of the stored energy may remain in the capacitor battery, so that the processing may be carried out only with minimal effectiveness. The discharge channel, which is apparently very low ohmic or of very low resistance following the reignition, absorbs only a small amount of the remaining energy still stored following the dark interval, while the principal portion of the residual energy is dissipated in the unavoidable connecting lead resistance following reignition.

Since the high-voltage capacitor batteries which are customarily used in the art have maximum load voltages of 30 to 40 kilovolts, discharges with dark intervals occur even at wire lengths of several hundred mm. In such instances, one must be satisfied from the start with a smaller degree of effectiveness, for the above-disclosed reasons.

Accordingly, it is an object of our invention to provide a method of forming workpieces, with underwater impact pressure, which affords a greater degree of effectiveness than heretofore obtained. More particularly, it is an object of our invention to provide a method of hydro-pressure forming workpieces with a greater degree of effectiveness even where a long ignition wire is required.

It is still another object of our invention to provide a method of hydro-pressure forming workpieces wherein the dark interval associated with capacitor body discharge in the known methods is avoided.

According to a feature of the invention, the capacitor battery is discharged in time-sequential discharge steps via a plurality of ignition wires and in such a manner that upon the occurrence of a dark interval, the ignition wire of the discharge channel which is connected first to the capacitor battery, is connected in parallel with another discharge channel.

This feature makes it possible that, following the renewed ignition, the respective wire explosions occur faster than the low pressure arc discharge which performs a lesser amount of forming work.

It has already been pointed out in "Elektrische Explosion spiraler Drähte im Vakuum," Kvarzhava J.F.,

et al, JETP 35, 1958, p. 911/916, that the geometry of the occurring shock waves can be varied during wire explosions by the arrangement and the contour of the wires. Hence, with regard to the production of various forms of pressure fronts, a number of suggestions are found in the literature to combine wires in a parallel or serial connection in various arrangements. See for example: "High Velocity Metalworking — A Survey," Noland, M.C. et al NASA Sp-5062, Washington D.C. 1967.

The suggestion has also been made in connection with plating by underwater pressure impacts, to ignite discharge channels each having its own energy storage, in a desired time sequence. See for example, Austrian Patent application A 4,186/65. In the processing problem all these features are directed to a geometrical adjustment of the pressure impacts. Even when an appropriate adjustment produces an improvement in the degree of effectiveness, the latter still remains within the aforescribed limits set by the dark interval.

By contrast, the invention offers a fundamentally new improvement in the effectiveness due to geometrical adjustment, in addition to the already known improvements in the degree of efficiency, whereby the improvement according to the invention lies in avoiding the dark interval by means of discharge channels ignited in sequence.

The invention will be disclosed in greater detail with reference to the accompanying drawings, wherein:

FIG. 1a illustrates the known arrangement and basic circuit diagram for the expansion of a tube by means of underwater wire explosion;

FIG. 1b shows the discharge curve which occurs during the discharge according to FIG. 1a;

FIG. 2a illustrates a basic circuit arrangement for carrying out the method of our invention wherein three tubes are arranged for expansion by means of underwater wire explosion;

FIG. 2b shows the discharge curve which occurs during the discharge sequence according to the invention; and

FIG. 3 is a schematic diagram for an arrangement for the expansion of a tube according to the method of the invention;

FIG. 1a shows how, with an underwater wire explosion, an elongated tube is expanded in a conventional manner by discharging a capacitor battery. Reference numeral 11 denotes the capacitor battery, 12 the tube to be processed, 13a and 13b the insulating parts, 14 the ignition wire, 15 the water and 16 a three electrode spark gap, as a high-voltage switch. The tube or pipe 12 is sealed in a known manner by insulating portions 13, through which the ignition wire 14 leads into the interior of the tube. The tube 12 is filled with water 15.

FIG. 1b illustrates the discharge curve which occurs during the switch-on of the spark gap 16. The abscissa represents the time t and the ordinate represents the discharge voltage U_0 and the discharge current i_0 . The broken line 17 shows the load voltage U_L of the capacitor battery 11. The curve 18 indicates the voltage curve during the discharge of the capacitor battery 11. From FIG. 1b, it is evident that the degree of efficiency obtained during the forming process is limited by the fact that during the first current pulse i_{01} , only a slight discharge occurs in the time interval t_0-t_1 and that the

second current pulse i_{02} performs no forming work following the reignition in the ignition wire 14 subsequent to the dark interval DP.

FIG. 2a shows a basic circuit arrangement illustrating how three tubes can be expanded with a stepwise discharge sequence according to the method of our invention. The stepwise discharge utilizes the energy stored in a capacitor battery in such a manner that each pipe or tube is provided with a separate discharge channel and with its own high-voltage switch.

Reference numeral 21 depicts the capacitor battery; 22, 23 and 24 are the tubes to be expanded, for example steel tubes; 25, 26 and 27 are ignition wires; 28a, 28b and 28c, 28d and 28e, 28f indicate the insulating parts and 29, 210 and 211 denote three electrode spark gaps which perform as high-voltage switches. The tubes 22, 23 and 24 are sealed in a known manner by insulating parts 28a to 28f through which the corresponding wires 25, 26 and 27 lead into the interior of each tube and each tube is filled with a medium 212a, 212b and 212c, such as water.

FIG. 2b illustrates the discharge curve U_c , which occurs during the performance of the method of FIG. 2a. The abscissa represents the time t and the ordinate represents the discharge voltage U and the discharge current i . U_L depicts the load voltage of the capacitor battery 21. U_0 , U_1 and U_2 are the voltage curves occurring with the respective closings of the high voltage switches.

At a time t_0 , the three electrode spark gap 29 is ignited and the discharge process is thereby initiated via the ignition wire 25. As a result of the commencing capacitor discharge, the wire 25 is heated up so fast, melted and vaporized that a vapor column develops under extremely high pressure. The high pressure does not permit any impact ionization in the metal vapor. As a result, the wire material which first bridges the electrode gap becomes non-conductive within a few microseconds and the discharge is interrupted. Following the decay of the current pulse i_0 to a time t_1 , during which the dark interval commences in the wire 25, the three electrode spark gap 210 is ignited whereby the discharge via wire 26 occurs. If the dark interval sets in here, too, following the decay of the current pulse i_1 at a time t_2 , the next three electrode spark gap 211 is ignited and the discharge current pulse i_2 is continued via the ignition wire 27. This may be continued during the distribution of the discharge to a plurality of workpiece processes for so long as the impact pressures, the energy of which decreases, suffice for a given forming operation.

For hydro-pressure forming technology it is even more important to obtain the improvement of the effectiveness according to the method of the invention, even when only one workpiece is formed.

The embodiment of FIG. 3 illustrates that the improvement in effectiveness obtained with the method of the invention by means of a sequential supply of discharge channels that optimally convert the energy discharged by a capacitor, is not necessarily dependent on providing several faster high-voltage switches, such as spark gaps or ignitrons. Rather, the mechanical action of the pressure waves which were already produced by the preceding discharge, may be utilized as a mechanically operating switch, or the thermal ef-

fect of the first discharge can release new discharge channels which convert the energy to a maximum, by means of planned insulation damage. FIG. 3 illustrates such an arrangement for expanding a tube.

In FIG. 3, the reference numeral 31 denotes the capacitor battery; 32 the three electrode spark gap; 33 the high-voltage electrode; 34 the ground electrode; 35 and 36 the ignition wires; 37 an insulation tube; 38 the tube to be processed; 39a and 39b the insulation parts; 310 the transport disc and 311 the pressure channels.

In the immediate vicinity of the axis of tube 38 sealed by the insulating parts 39a and 39b, the ignition wires 35 and 36 are guided in the insulating portions 39a and 39b through the bored electrodes 33, 34. The ignition wire 35 has contact with the high-voltage electrode 33 and with the ground electrode 34, so that following the ignition of the spark gap 32 at the time t_0 , the discharge of the capacitor battery 31 is initiated. The ignition wire 36 is connected only to the ground electrode 34 and is, moreover, covered by the insulating tube 37, which has less thermal and mechanical stability but more resistance to high voltages. For this purpose, the tube 37 may comprise foils of low pressure polyethyls of about 0.3 mm wall thickness, the foils being particularly well suited therefor. If, following the impingement of the impact pressure issuing from the ignition wire 35 and produced by the expanding metal vapor, the insulating tube 37 becomes mechanically or thermally destroyed, especially in the high voltage electrode 33, after the start of the dark interval in the ignition wire 35, the discharge may be continued over the ignition wire 36.

The high-voltage electrode 33 is so constructed that in addition to the aforescribed damage to the insulation, the impact pressure issuing from the ignition wire 35 can establish contact between the high-voltage electrode 33 and the ignition wire 36 in still another manner. To this end, the insulating tube 37 is constructed in two parts with both parts overlapping at 312. The shorter portion, which is the upper part in FIG. 3, of the tube 37 is affixed to a transport disc 310, which disc is in the high voltage electrode 33. As a result of the pressure channels 311 provided in the high-voltage electrode 33, a portion of the pressure front issuing from the ignition wire 35 impinges upon the transport disc 310 and greatly accelerates said disc. The accelerated transport disc 310 carries along the end of the insulating tube 37 attached thereto and

closes the connection between the high-voltage electrode 33 and the ignition wire 36.

The switching-on of new discharge channels through planned insulation damage can also be realized by an ignition means, having conductive and insulating layers disposed in an alternating sequence in a concentric arrangement, so that the respective discharges weaken, by means of a conducting layer, the insulation layer disposed adjacent thereto to such an extent that the voltage which remains during the dark interval punctures the insulation layer and continues the discharge via the next-succeeding conductive layer.

To those skilled in the art it will be obvious upon a study of this disclosure, that the invention permits of various modifications and hence may be given embodiments other than illustrated and described herein, without departing from the essential features of the invention and within the scope of the claims annexed hereto.

We claim:

1. In a method of forming workpieces by undersurface pressure waves generated by an explosion-like vaporization of an ignition wire initiated by an undersurface spark discharge of a capacitor battery, the ignition wire being tensioned between the electrodes of an undersurface spark gap, which method includes the step of continuously discharging a charged capacitor battery by sequentially applying the charged capacitor battery across a plurality of ignition wires, so that each successive ignition occurs at a time when the current in the next preceding ignition wire material ceases to flow, whereby a continuous conversion of the energy stored in the capacitor battery occurs.

2. In the method of claim 1, wherein the capacitor battery is connected to a plurality of ignition wires through a corresponding plurality of high-voltage switches, and wherein said method includes the step of sequentially closing said switches so that each successive ignition occurs at a time when the current in the immediately preceding ignition wire ceases to flow.

3. In the method of claim 1 wherein the capacitor battery is connected across a plurality of ignition wires through a single high-voltage switch, and wherein the method includes the step of closing the switch to sequentially apply the battery to each of said ignition wires, so that each successive ignition occurs at a time when the current in the immediately preceding ignition wire material substantially ceases to flow.

* * * * *

50

55

60

65