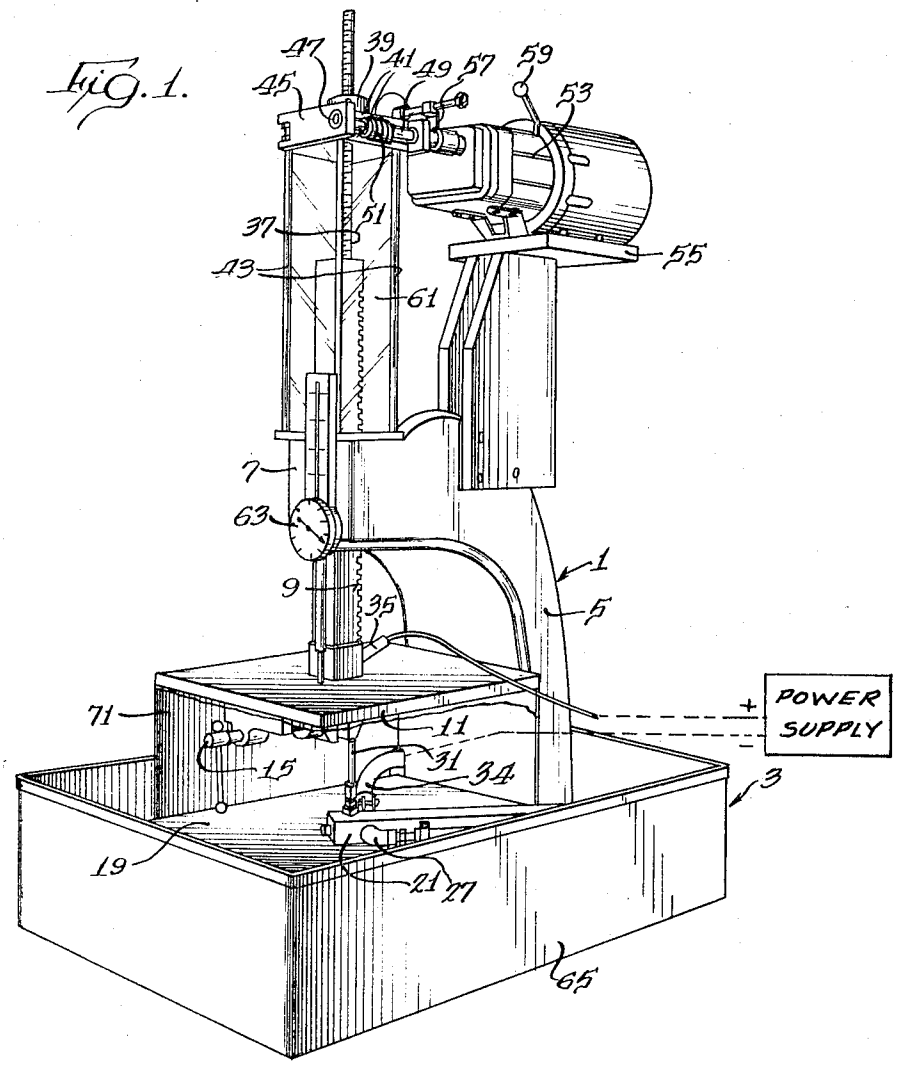
April 22, 1969 L. A. WILLIAMS 3,440,161

ELECTROLYTIC SHAPING APPARATUS

Original Filed Nov. 10, 1958 Sheet 1 of 2

Fig. 1.



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Fig. 2.

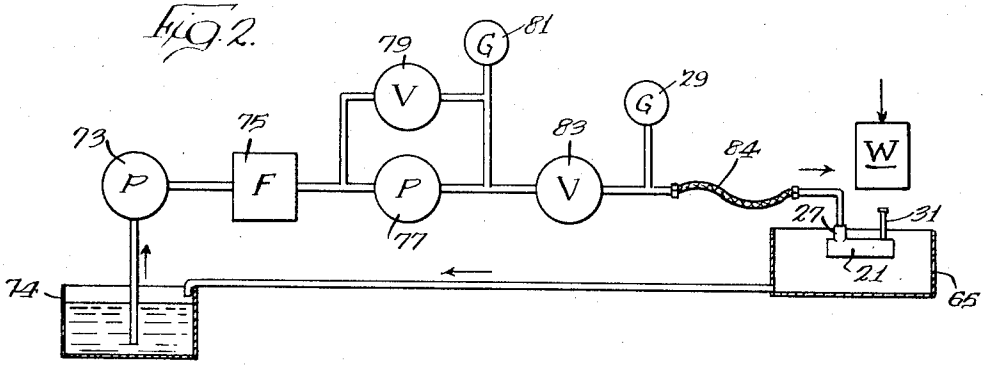


Fig. 3.

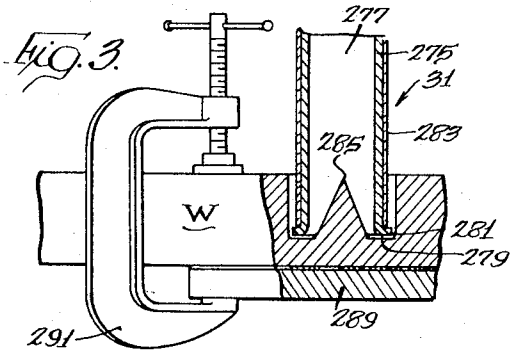
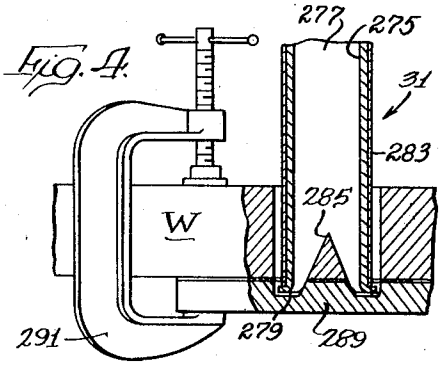


Fig. 4.



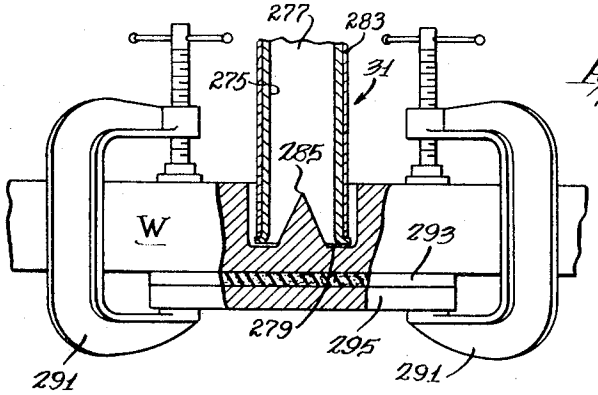


Fig. 5.

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United States Patent Office 3,440,161
Patented Apr. 22, 1969

3,440,161

ELECTROLYTIC SHAPING APPARATUS

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Application Dec. 8, 1961, Ser. No. 158,042, which is a division of application Ser. No. 772,960, Nov. 10, 1958, now Patent No. 3,058,895, dated Oct. 16, 1962. Divided and this application July 25, 1966, Ser. No. 567,555
Int. Cl. B23p 1/04
U.S. Cl. 204—224 6 Claims

This application is a division of my application Ser. No. 158,042, filed Dec. 8, 1961, now U.S. Patent 3,276,-987, entitled, "Electrolytic Shaping Apparatus," which in turn is a division of my application Ser. No. 772,960, filed Nov. 10, 1958, entitled, "Electrolytic Shaping," now issued into Patent No. 3,058,895, dated Oct. 16, 1962.

It has long been known that metal and metalloid materials may be removed by electrolytic attack in a configuration where the metal or metalloid workpiece is the anode in an electrolytic cell. This principle has been used industrially to some degree for the removal of defective plating and the like, and is sometimes referred to as "stripping." It has also been used to some extent for electrolytic polishing in which application, however, the principal purpose is to produce a smooth finish with a minimum removal of the work material. Here the purpose is to remove substantial amounts of metal rapidly and with accuracy.

In the present instance, the term "metalloid" is used somewhat specially in referring to those electrically conductive materials which act like metals when connected as an anode in an electrolytic cell, and are capable of being electrochemically eroded. The term as used here and in the claims includes metals and such similarly acting materials as tungsten carbide, for instance, and distinguished from such conductive nonmetalloids as carbon.

George F. Keeleric has proposed in his patent, No. 2,826,540, issued Mar. 11, 1958, for "Method and Apparatus for Electrolytic Cutting, Shaping and Grinding" the use of electrolysis in conjunction with a metal bonded, abrasive bearing, moving electrode, and the method and apparatus of this Keeleric patent have found extensive industrial use.

The present invention departs from the teachings of Keeleric in utilizing relatively fixed or slow moving electrodes without abrasive, and is intended for work of a quite different character, as will appear in the detailed description of the invention which follows.

In general, in the present invention an electrode, quite frequently a hollow electrode, is advanced into the work material by mechanical means while electrolyte is pumped through the work gap between the electrode and the work, and at times the hollow portion of the electrode, under substantial pressure. In some circumstances the side walls of the electrode are protected by an insulating material so as to minimize removal of work material except where desired. Various forms of electrodes are used for different kinds of work, and likewise different techniques of advancing the electrode toward and into the work material are used, depending upon the nature of the operation to be performed. An important aspect of the invention lies in providing electrodes in which a flow of electrolyte between the electrode and the work is maintained at high velocity and across a short path between the point of entry and the area of exit regardless of the overall size of the electrode. An electric current is supplied so that current passes from the electrode, which is negative, through the electrolyte to the workpiece, which is positive. For purposes of shaping the electrodes, direct current may be passed in the opposite

sense to make the electrode positive. In some instances, alternating current may be used.

Among the objects of the invention are the following:

To provide novel apparatus for rapid removal of work material by electrolytic means; and

To provide novel apparatus for obtaining sharp and clean edges to a through hole in a workpiece.

Other objects and advantages will become apparent from the following description taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a perspective view of one form of electrolytic shaping apparatus embodying the present invention;

FIG. 2 is a diagrammatic representation of an electrolyte supply system which forms a portion of the apparatus of FIG. 1;

FIGS. 3 and 4 are side elevations, partly in section, showing one arrangement for electrolytically piercing a hole completely through a workpiece; and

FIG. 5 is a view similar to FIGS. 3 and 4, but shows another arrangement for piercing a hole through the workpiece from one side to the other.

Referring to FIG. 1, the apparatus of this invention includes a frame member **1** which in this instance is the frame member of a conventional and well known arbor press sold under the trade name of Famco. It includes a base section **3**, a column **5**, and a head **7** which is adapted in the conventional manner to accommodate a ram **9** for vertical reciprocating motion. The detail of the ram mounting is not important to this invention, but it is desirable to provide adjustable gibs or the equivalent in the head so that the ram may move vertically with a smooth action and without lateral play which might introduce undesired side motion. To the bottom end of the ram **9** there is mounted a workplate **11** made of an electricaly insulating material which is resistant to the corrosive effect of the electrolyte, and through which a plurality of bolt holes is provided to permit adjustable mounting of a work holding vise **15**.

On the base portion **3** there is mounted a metal bottom plate, and on top of this a waterproof chemical resistant plastic mounting plate **19**. This is provided with a number of threaded bolt holes to permit mounting of an electrode holder **21**, which is made of suitable metal and is provided with one or more mounting slots so that it can be adjusted as to its position by selection of the suitable bolt holes in mounting plate **19**.

At the working end, the electrode support member **21** is hollow and is adapted to receive an electrolyte feed tube fitting **27** connected to a line leading to a source of electrolyte under pressure.

Extending from the upper surface there is mounted an electrode **31** having a conductive working face, shown here as fastened by brazing to a pipe nipple threaded into the electrode support member **21**. Within the hollow support member **21** the electrode is connected by a suitable passage to the feed tube fitting **27**. The electrode preferably is of the hollow or tubular type as described hereinafter.

An electric cable **34** is connected to the electrode block or support member **21** and supplies current from the power source. Another electric cable **35** is fastened to workplate **11** to furnish the other (normally positive) connection from the power source.

To move the workplate **11** up and down, a lead screw **37** is secured to and extends upwardly from the upper end of the ram **9**. A lead nut **39** is threaded upon the lead screw and is mounted between two horizontal plates **41** which are supported by four column bars **43**. The lead nut peripherally is formed as a worm gear so that it may be rotated to move the lead screw **37** up and down. A journal plate **45** is mounted to the plates **41** and carries

a bearing bushing **47** which supports the outboard end of a drive shaft **49** which carries worm **51** meshed with the peripheral worm gear of lead nut **39**.

The worm drive shaft **49** is, in turn, rotated by a variable speed electric motor drive **53** mounted upon a platform **55** attached to the column **5**. This drive mechanism has a speed adjusting handle **57** and a reversing handle **59**, the latter having a neutral midposition as well as updrive and downdrive positions.

The sizes and proportions of the drive parts are arranged to permit adjustment in the vertical speed of movement of the workplate **11** from zero to one inch per minute. The motion must be smooth, not jerky, and, accordingly, reasonable accuracy and freedom from excessive friction are an advantage in the moving drive parts. The lead screw **37** may be protected against splatter and corrosion by a plastic enclosure **61** wrapped around the column bars **43**.

A conventional dial indicator **63** is shown as mounted to the head **7** of column **5** and has its working tip extended downwardly against the upper surface of workplate **11** so as to indicate relative movement as between these elements.

The entire assembly is mounted in a pan **65** which has an outlet spud adapted to drain electrolyte back into a supply sump or reservoir **74**. The workplate **11** is fitted with plastic curtains **71** which can be tucked down below the level of the pan top to prevent excessive splatter and to enclose the work area for the workpiece and the electrode **31**.

The plumbing system (FIG. 2) comprises a low pressure pump **73** which feeds a suitable conductive electrolyte from the reservoir **74** through a filter **75** into high pressure pump **77**, the outlet of which leads to a bypass valve **79** which may be either manually set or of the spring-loaded constant-pressure type. On the inlet side of the bypass valve **79** a pressure gauge **81** is mounted. Also from the inlet side, a pipe lead is taken through a needle valve **83** to an electrolyte feed tube **84** leading to the electrode fitting **27**. A second gauge **29** is connected to the feed tube **84** so as to indicate the pressure at the electrode.

In operation, a workpiece is positioned in the vise **15** above the electrode **31**, and the workplate **11** is then driven down until the workpiece is almost touching electrode **31** as gauged by a piece of paper or shim of known thickness, say .003 inch. The dial indicator **63** is then adjusted to zero minus the known thickness, .003 inch in this example. The curtains **71** are lowered or otherwise closed, the electrolyte pumps **73** and **77** are started, and the valves **79** and **83** are adjusted so that gauge **81** reads about 120 p.s.i., and gauge **29** about 90 p.s.i. This is done while the reversing handle **59** is in neutral position. Then, simultaneously, the reversing handle is moved to down drive position, and the electric power supply is turned on.

As the electrode approaches the workpiece, there will be a rise in pressure at the gauge **29**. If the capacity of pumps **73** and **77** is several times the free flow discharge rate through the electrode, the pressure upstream of the needle valve **83** and of bypass valve **79** as read at gauge **81** will change scarcely at all with changes in proximity of the electrode **31** to the work, for most of the flow is passing through bypass valve **79**, and it is the adjustment of this which is principally determinative of the pressure at gauge **81**. In short, the pumps and pumping system up to needle valve **83** constitute a substantially constant pressure source. The same result may be obtained in many other ways. A constant pressure type pump may be used; e.g., a centrifugal pump operating near cutoff. Or a pressure regulator may be used. Or a spring-loaded relief valve adapted to maintain constant pressure may be used.

Needle valve **83**, however, is set so as to constitute a sufficient restriction to flow so that when the electrode is discharging into the open, the pressure, as read at gauge **29**, will be noticeably lower than when its outlet is restricted by being in close proximity to the work.

Thus, if gauge **81** normally reads 120 p.s.i., then when the electrode **31** touches the workpiece so as to shut off the flow, or nearly so, the pressure downstream of needle valve **83** as read at gauge **29** will rise to almost the same value, 120 p.s.i. If, however, the electrode **31** is spaced away by several thousandths of an inch, the pressure at gauge **29** will drop, say to 90 p.s.i.

This change in liquid pressure may be used in adjusting the rate of feed of the work toward the electrode. The initial feed rate may be set at a low level (for an unknown working condition or work material), and then increased by adjustment of the handle **57**. Gauge **29** is observed to watch for a pressure rise which approaches that of gauge **81**. It takes a little time for the pressure reading to stabilize during actual removal operations, for inasmuch as material is being removed by anodic dissolution, it is necessary for the moving electrode to catch up with the receding work material and to establish an equilibrium spacing distance, for as the electrode comes closer to the work, the removal rate tends to increase. By the exercise of reasonable care, it is possible to make a precise adjustment such that the electrode pressure gauge **29** reads only a few pounds per square inch lower than gauge **81**, indicating that the electrode is moving forward at such a rate as to leave only a small gap between the electrode and the work.

In effect, this hydraulic system constitutes a flow meter, and the same result may be obtained by using a more formal flow meter to sense the flow rate through the gap between the electrode and work. Such flow meter may be of any suitable sort, as for instance of the orifice type (which, in effect, uses the principle of the system just described), or of some other type, for example, that in which a moving bob is supported by upward flow in a conical glass vessel (e.g., the Fischer & Porter type).

It is not easy to measure this gap with accuracy, as apparently it is not always uniform at every point, but as measured in a practical way, by turning off the current and advancing the electrode until it seems to bottom, the distance may be as small as .001 inch or less, to as much as .010 inch, with satisfactory results, although it is preferred to work with the shortest spacing distance which can be managed without causing occasional contact and arcing between the electrode and the work, and I have found that about .002 inch to .005 inch is usually a safe distance while still permitting rapid removal of work material.

In general, low voltages and close spacing, of the order of .001 inch to .005 inch, give high removal rates and low electric power costs and a higher degree of accuracy, but less striation is produced upon the side wall of the work cavity when greater spacing, of the order of .010 inch, is used. The greater spacing results in a lower work removal rate unless the voltage is raised, however, since removal rate is a function of current. As a practical matter in most applications, I prefer to use about 4 to 15 volts and from 100 to 3000 amperes per square inch of active electrode area.

It should be noted that work material is removed by electrolytic action, not by spark or arc erosion as with the so-called electrodischarge method. This is important for several reasons, among them the fact that damaging thermal metallurgical effects on the work material are avoided and that there is virtually no erosion of the electrode.

As taught in Patent No. 3,058,895, suitable controls are provided to regulate the rate of feed of the electrode **31** and the workpiece relatively toward each other.

FIGS. 3 to 5 illustrate a form of electrode for making simple cavities and through holes. The electrode generally designated by reference number **31** may be made of a copper body **275**, although stainless steel or titanium are better for most purposes since they have less tendency to acquire plating deposits. It has a central passage **277** and at the working tip **279** is a flange or laterally extending lip **281**. In practice, this lip may pro-

ject beyond the body **275** by about .010 inch to .030 inch or more. In the axial direction, the thickness of the lip may be from .010 inch to .030 inch or more, but I prefer to make it about .020 inch to .030 inch. The lip may taper in thickness so as to have a much thicker section near the body and quite a narrow section at its extremity. The purpose in keeping the lip thin is to minimize the area exposed in such a way as to minimize side action; that is, the removal of material from the sides of the cavity as the electrode penetrates the work.

Some amount of side action seems unavoidable, but the use of a narrow edged lip holds this to a minimum value, and moreover, helps to keep the amount of side action fairly uniform so that the side walls of the cavity can be kept straight and so that cavities of the same size can be produced repetitively. I find that side action can easily be held to about .005 inch (.010 inch on the diameter) and reproducibility can be held to within a few thousandths of the given dimension.

The body **275** of the electrode is coated with a ceramic or vitreous enamel layer **283** which is better for this purpose than any organic coating I have found. For this purpose I have used ceramic oxide frits of the kind commonly used for decorative enameled jewelry, or the kind used for protection of electrical resistors of the heavy duty type. The frit is mixed with water and agar to make a creamy suspension, which is applied to the electrode body with a spray gun. Then the electrode is placed in an oven or kiln and fired to 1500° F. to 1800° F. or whatever is required to fuse the particular frit being used. The enamel layer **283** which is thus formed should be free of discontinuities, and it may be necessary to apply one or more additional layers to insure this. The coating should be reasonably uniform in thickness and should not extend sidewardly beyond the projection of lip **281**, for if it has humps which extend too far, they will bump the side wall of the cavity as the electrode advances and deflect the electrode sideways, which may produce a crooked hole or cause the lip **281** to strike the side wall of the cavity, causing a short circuit and arcing, with consequent possibility of damage both to the electrode and to the work.

The purpose of the enamel coating is to utilize its insulating properties to minimize electrolytic side action between the electrode body and the side walls of the cavity. In some instances, however, where the lip **281** extends a substantial distance, this insulation is not required, and very little side action is observed without it. The explanation for this is believed to be as follows: When the electrode tip is in close proximity to the frontal working face of the work, the gap for the escape of electrolyte is only a few thousands of an inch. Thus the electrolyte exiting under the tip under substantial pressure has high velocity as it enters the much larger space behind the tip. With a small amount of electrolyte at high velocity, many discontinuities are created so that electrolytic conduction to the side walls is impaired sufficiently to prevent substantial removal of material, and in addition, it is possible to operate at a high enough voltage and current density so that electrolyte in the narrow work gap is heated above its normal input temperature, between 120° F. and 160° F., and also, some gas is involved.

Within the confines of the work gap, however, the liquid is held under a relatively high pressure of several atmospheres so that its boiling temperature is considerably elevated. I have commonly used electrolyte pressure of the order of 100 p.s.i. gauge. When the liquid passes beyond the lip **281** into the relatively open space behind it, there is, in the first place, not a very high mass flow because of the restriction of the narrow work gap, but the liquid has high velocity because of the pressure and can be observed to foam as it exits. It is conjectured, therefore, that the electrolyte in the space between the body **275** and the wall of the cavity as it exits at high velocity from the work gap becomes almost instantly full of discontinuities due to gas bubbles either from boiling or electrolytic decomposition in the work gap, or both, so that conductivity from the body **275** to the side wall is quite poor.

Whether or not this is the explanation, the fact is that in cavities up to an inch in depth, there does not seem to be much side action when a lip of substantial protrusion is used. Notwithstanding this, it is preferred to use an insulating coating, as the finish on the side walls of the work seems to be better in most cases when this is done.

Vitreous enamel is the best coating I have found, but other insulating materials may be used. I have found Teflon quite satisfactory where it can be easily applied. However, the organic lacquers and paints which have been tested have not been very satisfactory because they seem to be chemically or physically attacked near the working tip. The vitreous enamel seems to be quite impervious to such deterioration.

Copper is a good substance for forming the electrode because it is a good electrical conductor, but good success has been had with cold rolled steel. Brass may be used, but it is difficult to get a good vitrified enamel coating on brass, and accordingly it is not preferred. All of these materials are, in general, somewhat less satisfactory than stainless steel or titanium in that they are susceptible to the formation of plating deposits which, under some conditions, may make the outline of the electrode less clean, and in some instances such deposits may change the current flow characteristics of the system.

Whenever an electrode of the type above described breaks through the remote side of a workpiece, there may be difficulty if the remote side is not precisely parallel to the plane of the electrode tip. In fact, this is true of any electrode used for piercing a through hole. The difficulty is threefold.

First, if the breakthrough occurs at one place before another, which is more likely than otherwise, the electrolyte will tend to flow out through the opening thus created, and when the first opening is large enough, all of the electrolyte will exit through it and none will be present between the unpierced portion of the work and its opposing portion of the electrode tip. Accordingly, if the electrode is advanced further toward the work, it will make mechanical contact and cause short circuiting.

Second, if the feed mechanism is of the type controlled by hydrostatic pressure in the electrolyte supply line or by electric current in the electrolytic work circuit, the initial breakthrough will cause a drop in electrolyte pressure at the electrode and in electric current, and the result will be that the feed rate will be increased by the false signal, and this too will cause short circuiting.

Third, in hole piercing operations, it is common to use a simple, thin wall, hollow electrode and to allow a projection **285** of the work material to remain within the electrode, as shown in FIGS. 3, 4, and 5, for instance, and where the hole is not large, it is common not to insulate the interior wall of the electrode; although where the electrode is large, this is done to reduce current consumption. It is also done where it is desired by a trepanning operation to form an accurate untapered shape on the work within the electrode, this portion thereby becoming the finished workpiece, or an integral portion thereof.

If no preventive measures are taken, this projection **285** may cock to one side when the electrode breaks through the remote side of the workpiece. This occurs where the breakthrough occurs almost simultaneously around the perimeter of the electrode tip but still leaves one thin and small point of attachment weak enough to bend and allow the projection within the electrode to swing over and make contact with the inner wall of the electrode, thus causing a short circuit and causing a burn off through the small, thin, remaining area of attachment.

To overcome these difficulties, a dummy workpiece **289** is fastened on the remote surface of the workpiece W by gluing with a water soluble glue. Waterglass (sodium sili-

cate solution) is inexpensive and has been found suitable for the purpose. As a precaution, the dummy workpiece is mechanically clamped as by the C-clamp **291** shown in the drawings. As the electrode **31** advances from the position shown in FIG. 3 through the workpiece proper, as shown in FIG. 4, it exposes and the electrolyte dissolves the glue beneath the edge of the electrode so that the electrode penetrates into the dummy workpiece, as shown, but the projection **285** within the electrode remains glued to the dummy workpiece **289**. Penetration of the electrode into the dummy workpiece should be carried far enough to assure straight side walls of the cavity in the work, but should not be prolonged unduly as the glue holding the projection **285** to the dummy workpiece will gradually dissolve and release the projection, which then rattles around within the electrode, causing intermittent short circuiting. While this does not harm the work, it does roughen and erode the wall of the electrode, and should be avoided.

A variant arrangement somewhat easier to apply is shown in FIG. 5. A plastic sponge **293** is held by support member **295** against the remote side of the workpiece W. The support member may be held by C-clamps **291**, as shown, or in any other suitable manner. The sponge should be thick enough and resilient enough to permit the working tip of electrode **31** to be pressed down into it as it passes through the workpiece. Yet it must be firm enough to offer resistance to the passage of liquid through it. Thus, if upon breakthrough, an opening occurs at one point before another, there is no free exit of electrolyte, and the remainder of the electrode tip continues to be supplied with electrolyte so that all of the necessary material is removed electrolytically, thus providing a clean and sharp opening. The one negative aspect of this variant is that if the electrode penetrates too far or for too long a time beyond the workpiece, there may be some unwanted electrolytic action between the electrode tip and the face of the remote side of the workpiece. This may be minimized by going only as far as needed for a clean breakthrough, but it is avoided almost entirely by the arrangement and procedure of FIGS. 3 and 4.

Any other sufficiently resilient material, such as soft rubber for instance, may be used in place of the sponge **293**, so long as it provides a seal and permits slight electrode penetration.

From the foregoing it will be appreciated that the objectives which were claimed for this invention at the outset of the description are fully attained by the apparatus shown and described.

Also from the above description of my invention, it will be appreciated that many changes may be made in the apparatus without departing from the scope or spirit of the invention, and that the scope of the invention is to be determined from the scope of the accompanying claims.

I claim:

1. In an electrolytic apparatus for piercing a hole through an electrically conductive and electrochemically erodible workpiece by means of an electrode having at least one electrolyte passage therethrough and a conductive working face, means for moving said electrode toward and away from the workpiece to define a narrow work gap between the workpiece and said electrode working face, means connected for pumping an electrolyte to and through the work gap at a greatly superatmospheric pressure, circuit means connected for passing an electrolyzing current between said electrode working face and the workpiece, and a member secured against the opposite side of said workpiece where said electrode emerges, said member accommodating at least a slight passage of the electrode working face when completely through the workpiece.

2. Apparatus as claimed in claim **1**, wherein said member includes an electrically conductive and electrochemically erodible dummy workpiece.

3. Apparatus as claimed in claim **2**, including means temporarily securing said dummy workpiece to the surface of the workpiece opposite said electrode.

4. Apparatus as claimed in claim **3**, wherein said securing means includes an adhesive soluble in the electrolyte pumped through the work gap.

5. Apparatus as claimed in claim **3**, wherein said securing means includes clamping means.

6. Apparatus as claimed in claim **1**, wherein said member is yieldable to permit the restrained escape of electrolyte after at least a portion of said electrode has passed through said workpiece.

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U.S. Cl. X.R.

204—143, 225

Dedication

3,440,161.—*Lynn A. Williams*, Winnetka, Ill. ELECTROLYTIC SHAPING APPARATUS. Patent dated Apr. 22, 1969. Dedication filed Dec. 23, 1971, by the assignee, *Anocut Engineering Company*.

Hereby dedicates to the Public the portion of the term of the patent subsequent to Dec. 24, 1971.

[*Official Gazette April 25, 1972.*]