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ELECTRODE FOR ELECTROLYTIC SHAPING

Original Filed Nov. 10, 1958

2 Sheets-Sheet 1

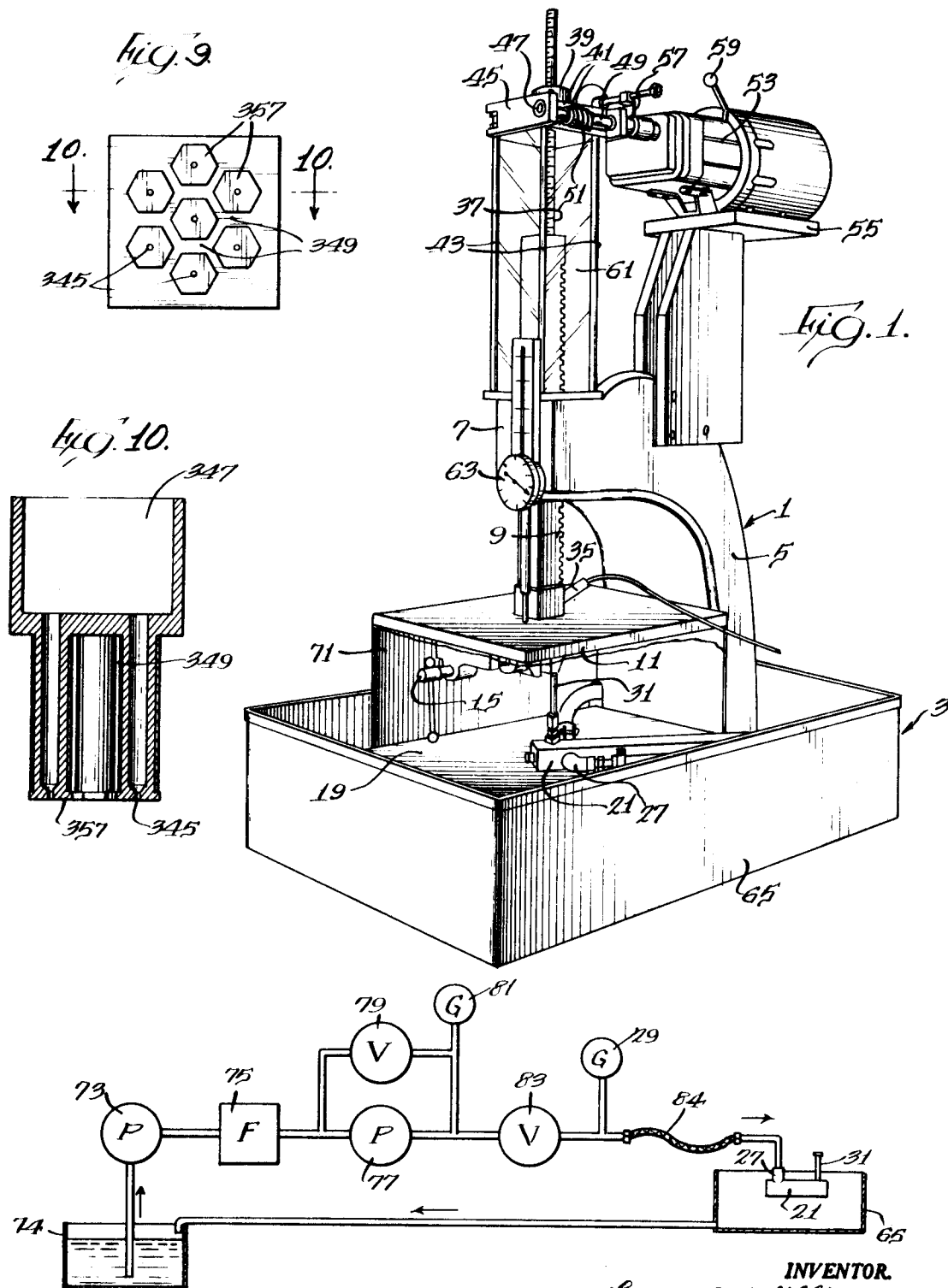


FIG. 2.

By

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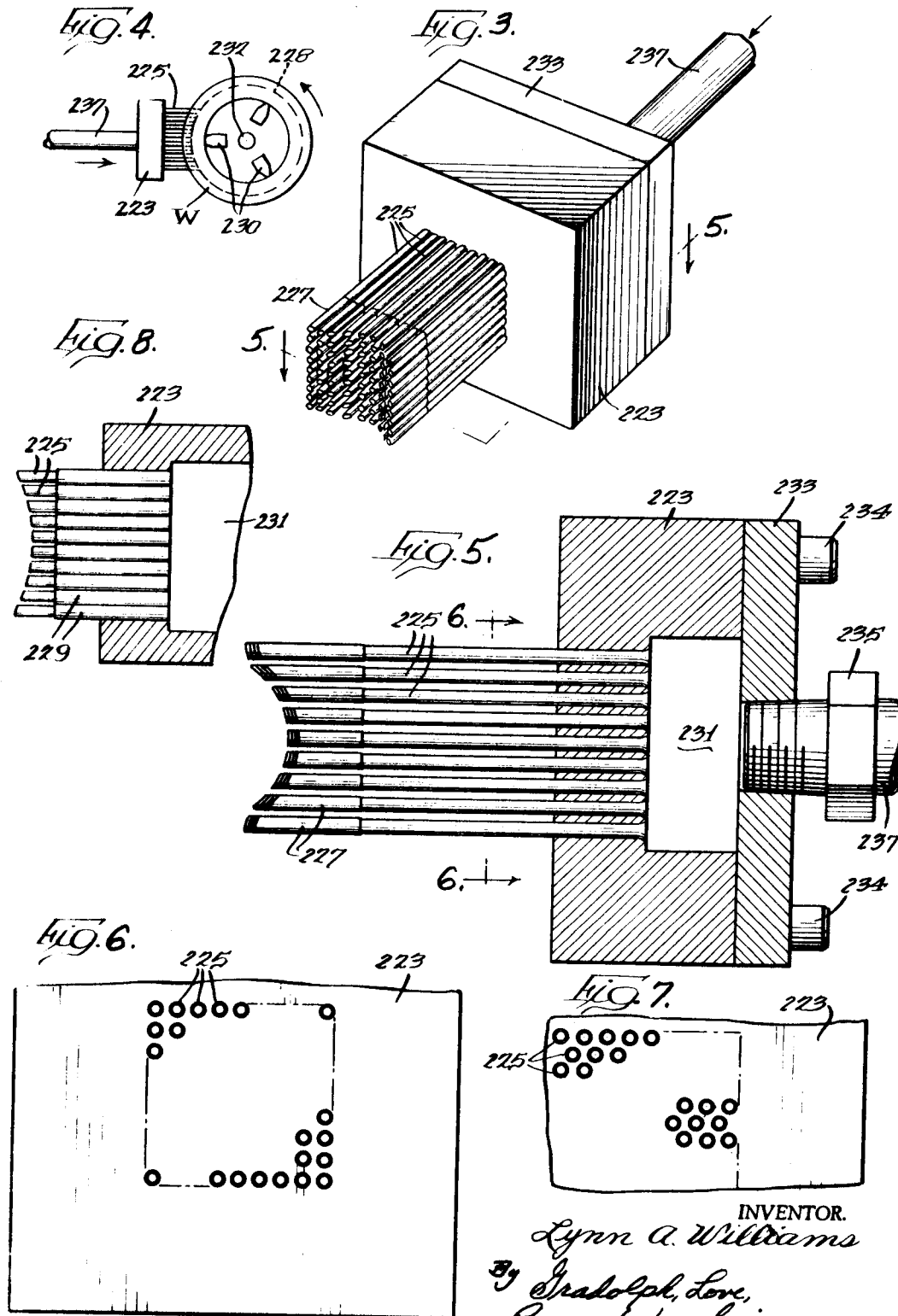
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1

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**ELECTRODE FOR ELECTROLYTIC SHAPING**  
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Application Feb. 14, 1966, Ser. No. 552,652, which is a  
continuation of application Ser. No. 165,569, Jan. 11,  
1962, which in turn is a division of application Ser.  
No. 772,960, Nov. 10, 1958. Divided and this applica-  
tion Nov. 18, 1968, Ser. No. 776,355

Int. Cl. B01k 3/04

U.S. Cl. 204—284

6 Claims

## ABSTRACT OF THE DISCLOSURE

This invention relates to an electrode for use in electro-  
lytic shaping apparatus which electrode is formed of a  
plurality of closely spaced metallic tubular members  
adapted to be connected into an electrolyzing circuit. Each  
of the members has a working and electrically conductive  
face at one end thereof adapted to be brought into close  
spacing relationship with an electrically conductive and  
electrically erodible workpiece to be shaped. Each mem-  
ber has an opening opposite the working face through  
which an electrolyzing fluid is pumped and have metallic  
areas contiguous to the face exposed laterally to provide  
controlled lateral electrolytic erosion of the workpiece. An  
insulating sheath encases each tubular member in intimate  
contact therewith from the laterally exposed area to a  
distance substantially away from the working face.

## CROSS-REFERENCES TO RELATED PATENTS

This application is a division of my application Ser.  
No. 552,652, filed Feb. 14, 1966, now Pat. No. 3,421,997  
of Jan. 14, 1969, which application is a continuation of  
my application Ser. No. 165,569, filed Jan. 11, 1962, now  
abandoned, which application is a division of my applica-  
tion Ser. No. 772,960, filed Nov. 10, 1958, entitled "Elec-  
trolytic Shaping," now issued into Pat. No. 3,058,895,  
dated Oct. 16, 1962.

## BACKGROUND OF THE INVENTION

### Field of the invention

This invention relates to electrodes for use in electro-  
chemically shaping metal and metalloid materials.

### Description of the prior art

It has long been known that metal and metalloid mate-  
rials may be removed by electrolytic attack in a configura-  
tion where the metal or metalloid workpiece is the anode  
in an electrolytic cell. This principle has been used in-  
dustrially 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 elec-  
trolytic polishing, in which application, however, the prin-  
cipal purpose is to produce a smooth finish with a mini-  
mum removal of the work material. Here the purpose is  
to remove substantial amounts of metal rapidly and with  
accuracy.

## SUMMARY OF THE INVENTION

In the present instance, the term "metalloid" is used  
somewhat specially in referring to those electrically con-  
ductive materials which act like metals when connected  
as an anode in an electrolytic cell and are capable of be-  
ing electrochemically eroded. The term as used here and  
in the claims includes metals and such similarly acting

materials as tungsten carbide, for instance, and dis-  
tinguishes from such conductive non-metalloids as carbon.

George F. Keeleric has proposed in his Pat. No.  
2,826,540, issued Mar. 11, 1958, for "Method and Appa-  
ratus 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 elec-  
trodes without abrasive, and is intended for work of a  
quite different character, as will appear in the detailed de-  
scription 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 differ-  
ent kinds of work, and likewise different techniques ad-  
vancing 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 be-  
tween 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 over-all 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 posi-  
tive. In some instances, alternating current may be used.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of one form of apparatus  
utilizing the electrode of the present invention;

FIG. 2 is a diagrammatic representation of an electro-  
lyte supply system which forms a portion of the appa-  
ratus of FIG. 1;

FIG. 3 is a perspective view of one form of electrode  
for forming comparatively large cavities of irregular shape  
in the bottom surface thereof;

FIG. 4 shows an adaptation of the electrode of FIG. 3  
for operation upon a rotating workpiece;

FIG. 5 is a longitudinal sectional view through the  
electrode of FIG. 3, taken substantially along the line  
5—5 of FIG. 3, looking in the direction of the arrows;

FIG. 6 is a transverse sectional view through a por-  
tion of the electrode of FIG. 5 taken along the line 6—6  
of FIG. 5, looking in the direction of the arrows;

FIG. 7 is a view similar to FIG. 6 showing an alterna-  
tive arrangement of the electrode elements which may be  
used in place of the arrangement of FIG. 6;

FIG. 8 is a longitudinal sectional view through an elec-  
trode generally similar to that of FIG. 5 illustrating an  
alternative method of constructing the electrode;

FIG. 9 is an end view of an electrode particularly  
adapted for producing a plurality of cavities simultane-  
ously so as to have walls of a generally honeycomb con-  
formation between the cavities; and

FIG. 10 is a longitudinal sectional view taken along  
the line 10—10 of FIG. 9, looking in the direction of  
the arrows.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, the apparatus 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 through which a plurality of bolt holes is provided to permit adjustable mounting of a workholding 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, 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.

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

To move the work plate 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 mid-position as well as updrive and downdrive positions.

The sizes and proportions of the drive parts are arranged to permit adjustment of the vertical speed of movement of the work plate 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 in 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 work plate 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.

The plumbing system (FIG. 2) comprises a low pressure pump 73 which feeds 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 work plate 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 plumbing 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 the 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 10 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. The fact that the electrode is not eroded is of great importance where the cavity is to be accurately shaped, for accurate shaping is rendered very difficult when the electrode is being eaten away at a rate rapid enough to alter its dimensions during the operation.

Thus, it is important to avoid too fast a feed rate which may cause arcing between the electrode and the work.

Another method of gauging the feed rate is by reference to an ammeter in the electrolytic power supply circuit. Once the penetration of the electrode into the work has been well established, the rate of feed is gradually increased until an arc is observed. Usually this will be of short duration. The reading of the ammeter is observed and read just prior to the first arc, and the speed is then adjusted downwardly until the ammeter shows a reading of little below the critical point where the first arc occurred.

A transducer sensitive to either the electrolyte liquid flow rate or the electrolytic electric current may be used as the signal generating element in an automatic feed control system.

Referring to FIGS. 3 to 8, there are shown perspective and sectional views of an electrode with minor variations for sinking cavities having irregularly shaped bottom and/or side wall surfaces.

Into a metallic header 323 are drilled a multiplicity of holes arranged in a regular pattern, as shown in the fragmentary header layout drawings of FIGS. 6 or 7. Then metal tubes 325 are fitted into the header holes, and their inner ends are expanded slightly by a tapered tool or brazed or otherwise secured to seat, seal, and lock the tubes in the header. The tubes may be straight or, optionally, they may be enlarged at their working ends as shown at 327. The enlargement may be accomplished by electroplating—for example, with copper or nickel—to a depth of, say, .005 inch to .010 inch or more. The purpose is to permit close spacing of tubes 325 at their working ends without making it too difficult to fabricate

header 323 by requiring exceedingly thin walls between the holes for the tubes. The tube bundle may be made by copper plating stainless steel tubes; then nesting them together and soldering them into the header 323 at one end, and thereafter dipping the working end in nitric acid to eat away the copper and leave the stainless steel so that there is space between the tubes at the working end for exit of electrolyte.

For rough work the tubes may be about  $\frac{1}{16}$  inch in diameter and should have centre bores about .030 inch for the passage of electrolyte. The spacing between tubes should not exceed  $\frac{1}{64}$  inch, and this close spacing may be brought about either by close spacing of the header holes or by enlarging the working ends of the tubes and using somewhat more generous spacing of the header holes. To minimize pattern in the work I prefer needles of about .025 inch outside diameter with .010 inch bore and about .010 inch spacing.

A chamber 331 is formed in the header 323 for introducing electrolyte into the tubes, and a cover plate 333 is fastened by bolts 334 to the header. In the cover plate is a centrally located opening threaded to receive a pipe fitting 335 at the end of a rigid supply tube 337, which also serves for mounting the electrode in a feed device, for example, like that of FIG. 1. An electric cable (not shown) brings the negative electrical connection to the header and is conveniently fastened under one of the bolts 334 holding the cover plate 333 to the header 323.

In FIGS. 3, 5, and 8 there is shown a compound contour at the working end of the tubes 325. This may be shaped by a variety of mechanical means, if so desired. For example, the individual tubes 325 may be precut to the appropriate lengths before being inserted and fastened in header 323.

I prefer, however, to use a process which I believe to be unique to impart the desired shape into the electrode. A master form is made with a shape which is a negative of the shape desired in the electrode. This may be made of metal or it may be of plastic or plaster with a conductive metal coating. The master form is mounted in the place where the work is ordinarily mounted, and the polarity of the power source is reversed so that the electrode is an anode.

At this point it should be understood that the tubes 325 may terminate roughly on a plane normal to the tube axes. Their ends do not define any special form.

Now, with electrolyte being pumped through the supply tube 337 and through the tubes 325 the electrode assembly is advanced slowly toward the master form. As any tubes approach the master form, they are anodically reduced, shortening their length to conform to the shape of the master form. When all of the tubes are far enough advanced to be in active electrolytic relationship with the master form—that is, when all have been shortened somewhat by electrolytic attack—the speed of advance of the electrode is increased as much as possible without causing contact with the master form. Then, simultaneously the electrolytic current is turned off, and the advance is stopped. By the fast feed for final forming, each tube is brought within .001 inch of the confronting surface of the master form so that any deviation between the form of the master and the form defined by the tube ends is less than .001 inch.

The master is then replaced by a workpiece—for example, a hardened die block—the polarity of the electrical supply is restored to normal so that the work is the anode, and now the form established by the master can be reproduced in the work.

To do this, the same procedure is followed as in shaping the electrode. The advance of the electrode is held at moderate speed until all tubes are electrolytically removing work material. Then the speed is increased to the maximum attainable without contact with the work. This maximum is determined by the nature of the work ma-

terial, the electrolyte, its temperature, its pressure, the voltage, the available current supply, etc. As a practical matter, one learns quite quickly what speeds are suitable under practical operating conditions. For this work where high accuracy is desired, it is good to use electrolyte of lower conductivity made, for example, by diluting a high removal solution with water. By reducing the conductivity, the differential in removal rate between the parts of the electrode in close proximity to the work and those more remote is accentuated so that better conformation between electrode and work is obtained.

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.

It has been found practical to make the tubes 325 of 18-8 stainless steel because this material can be reduced very rapidly for shaping the electrode. Also, the removal is even and the surface is smooth.

When the cavity has been formed by this means, the cavity surface will show the pattern of the tubes 325, but only a relatively small amount of material needs to be removed to smooth the surface to acceptable standards if the tubes are small and the tube spacing is close.

It should be observed that the spaces between the tubes provide channels for the exhaust of electrolyte.

If desired, the outside tubes, after the electrode has been shaped, may be coated with ceramic so that the side walls of the cavity will not be unduly attacked and removed electrolytically. For many cavities of this general kind, this is not important, but for some it is.

The purpose of the ceramic or enamel coating is to utilize its insulating properties to minimize electrolytic side action between the electrode body and the side walls of the cavity.

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.

It should also be noted that for fine detail, or where there are steep contours, finer tubes may be used and should be used, and I have successfully used tubes of .020 inch in diameter with .010 inch spacing, and probably even smaller tubes could be used, if necessary, by providing adequate electrolyte pumping pressure and good filtration to prevent clogging of tubes of fine bore.

FIG. 4 shows an electrode similar to that of FIG. 3 as used for forming grooves 328 in the surface of a rotating workpiece. Here the work, a ring W, is held by chuck jaws 330 and rotated upon a spindle 332. The electrode is supported by the electrolyte supply pipe 337 in a tool rest and advanced into the work as the work rotates. Electrolyte at a pressure of 25 to 200 pounds per square inch is pumped through the electrode. It thus cuts a smooth slot in the workpiece periphery.

In general, the electrode illustrated in FIGS. 3 to 8 is suitable for the rapid removal of work material, particularly where the side walls and bottom surface of the cavity produced in the work may be somewhat rough without this being objectionable. Because of the rotation of the work in FIG. 4, the groove formed will, of course, be smooth.

FIGS. 9 and 10 show electrodes in which the end faces indicated at 357 are hexagonal. Each of these end faces

is connected to the interior 347 of the electrode by passages 349 which lead to small holes 345 at the working end of the electrode. If desired, and as shown in FIGS. 9 and 10, the hexagonal end faces 357 may be spaced from each other sufficiently so that as the electrode is advanced into the work, a honeycomb formation of ridges remain as an integral portion of the main body of the work. This arrangement is of great utility where it is desired to remove weight, as in aircraft elements and equipment, without appreciably reducing the overall strength of the particular part. If the working tips are brought close enough together (about .010 inch to .015 inch), the honeycomb fin will be eliminated and this arrangement is useful when removing material over a large area since the round stems above the hexagonal faces provide considerable flow capacity for conducting electrolyte away, particularly from the central portion of the electrode. Ordinarily, with large electrodes it is difficult to provide enough exit area at the centre to insure even electrolyte flow throughout the electrode.

From the above description of my invention which has been illustrated in several embodiments and variations, the features and applications of the inventive idea to practical problems have been discussed. From this it will be apparent that certain generalizations may be made.

The amount of metal removed from a workpiece by electrolytic action is a direct function of the current in the electrolyzing circuit. The voltage necessary to pass any particular current with any particular set of circumstances will depend upon the spacing between the electrode and the workpiece. It will also depend upon the electrode size or effective area, but for a particular job the electrode size usually will not be a variable.

The cost of operation will vary rather directly with the wattage—that is, the amperage in the circuit times the voltage necessary to produce the current. From these considerations it follows that from the practical standpoint it is essential that the electrode to workpiece spacing be held to a practical minimum so that minimum voltages may be used, thereby enabling the operation to be conducted at minimum cost. As an example, by following the teachings of the present invention, precisely held small spacings may be used and most electrolyzing operations may be conducted at approximately ten volts or, in some cases, even less with work gaps from half a thousandth to a few thousandths of an inch. The current densities which appear to be most satisfactory as a practical matter are between 100 and 3000 amperes per square inch of effective electrode area. The wattage, therefore, is between one and thirty kw. per square inch. For large areas the voltage may be reduced to four volts while still obtaining reasonable current density.

All prior systems with which I am familiar, which attempt to remove metal by electrolytic action, require far greater total electric energy than this to remove an equivalent amount of metal. Prior workers in this field have found it necessary to use voltages of the order of 100 to 110 volts or more with the result that the energy requirements—or in other words, the cost of removing the metal—are of the order of ten or more times that required when using the invention discussed above. Furthermore, if low voltages are attempted with wide work gaps, the rate of material removal is low and thus more machines are required to produce the same amount of work. It is apparent, therefore, that regardless of the approach to the problem, the accomplishment of high current densities with low voltages is economically essential.

Also, as previously indicated, high voltages together with comparatively large work gap spacings produce an electrolytic action that is far less controllable, and therefore the work produced cannot be as precise as the work produced by using the present invention.

Where it is desired to sink a cavity having a considerable area at the bottom, and where it is desired that the bottom be of generally controlled contour, but under con-

ditions where both the bottom and side walls may be allowed to be somewhat rough, a multiple tube electrode of the type illustrated in FIGS. 3, 5, 6, 7 and 8 is highly satisfactory. A smooth finish with this type electrode may be achieved, however, by using small diameter closely spaced tubes or by producing relative movement between the work and the electrode—in addition to simple advance of the electrode—in such manner as to continually expose the end of the electrode to a shifting work surface for this purpose a vibrator mounted so as to shake the electrode may be used. Another example of this approach is illustrated in FIG. 4.

Air jets may be used to prevent unwanted electrolytic action between side surfaces of the electrode and the work, where the electrode is not in close proximity to the work but where electrolyte is caught in stagnant pockets. The air is used to blast away the stagnant electrolyte. The arrangement of FIG. 1 in which the work is positioned above the electrode is also helpful in eliminating stagnant electrolyte pockets as gravity causes the electrolyte to fall away from the work area. This is the cause in forming cavities in the work. Where the part to be produced is a punch or the like so that there is a cavity in the electrode, then the electrode is placed above the work so that gravity helps to clear away the electrolyte except where there is close spacing between the electrode and the work.

A wide variety of electrolytes may be used in the apparatus and processes heretofore described. Some work materials respond to acid solutions of 5% to 25% of the appropriate strong acids such as hydrochloric, nitric and sulphuric. Other materials, such as cemented carbides—e.g., tungsten, tungsten carbide, titanium carbide, etc.—respond better to caustic solutions such as a 20% solution of potassium hydroxide to which may be added 5% sodium tungstate.

To the extent possible without excessive loss of removal rates, it is preferable to use neutral or nearly neutral salt solutions because they are much easier and safer for routine shop handling. A solution of this type which has shown good versatility and good removal rates may be made by adding to 15 gallons of water the following:

|                          |        |
|--------------------------|--------|
|                          | Pounds |
| Potassium chloride ----- | 30     |
| Potassium nitrate -----  | 10     |
| Potassium citrate -----  | 10     |
| Rochelle salts -----     | 10     |

This solution, when supplied to the electrode at a temperature between 120° F. and 150° F., will give good removal rates on a wide variety of steels, including stainless steel, and also a great many of the so-called super-alloys of nickel, cobalt or iron base and containing as alloying materials, in addition to those three, such materials as chromium, molybdenum, tungsten, titanium, columbium, etc.

In addition to removing material at good rates, a good finish is obtained, and particularly on the high alloy stainless steels and the super-alloys, a bright, reflective surface may be created where the surface is exposed to electrolysis under conditions of pressure and high velocity in the electrolyte, as previously explained.

I have found that an essential to good performance of an electrolyte is that the metal salt products of electrolytic decomposition be readily soluble. For example, aluminum is not easily worked by this process with many electrolytes which are usable on other materials, as the anodic action forms aluminium salts which are not very soluble or not soluble at all and form an anodic film on the work. But a simple 5% or 10% solution of acetic acid yields good results because the relatively complex aluminium salts formed are soluble enough to be readily washed out of the work gap.

Where fine detail of pattern is to be reproduced, it is desirable to use a solution which is considerably more dilute than is desirable for maximum removal rates. Thus, the quantities of salts used in the table above are reduced to one fourth to one sixth of the values shown for the same amount of water. The voltage applied is also reduced. The purpose is to accentuate the difference in removal rate between those areas where the electrode is close to the work and those where it is more remote. If the electrolyte is too conductive and the applied voltage is too high, then the difference in resistance path between areas of close proximity and others of greater spacing is not very great, and the detail of pattern becomes blurred.

Referring to the solution in the table, this has been used successfully in a four-to-one dilution to duplicate coin patterns in the following configuration and procedure. First, a coin is positioned opposite an electrode using a disc electrode of porous sintered bronze in the form of a disc about one inch in diameter and 1/8 inch thick. The electrolyte is pumped at about 100 p.s.i. through the electrode disc after passing through a filter designed to remove all particles down to five microns. The electrolyzing current is first connected in a sense to make the electrode positive. The electrode is then advanced until it very nearly touches the coin. Then current is turned on at four volts for one or two seconds, the electrode is then advanced, and this is repeated until ample depth has been reached to embrace all of the coin face pattern. Then the coin is removed and replaced with a piece of die steel, and the power leads are reversed so that the electrode is now a cathode. The electrode is now advanced toward the steel, using a voltage of six volts, and again, very close proximity is used—a few ten thousandths of an inch of spacing—and the electrode is advanced into the steel to a depth great enough to embrace the pattern. By this means, it has been possible to reproduce fairly fine detail, and in comprising the height of the coin pattern above its flat areas with the finished steel replica, it has been possible to bring these measurements within less than .001 inch of difference between the original coin and the steel pattern. So far as I am aware, such close copying by electrolytic removal means has never been approached before.

In the foregoing description, various parameters have been described with respect to the apparatus components and the steps which are embodied in the method of carrying out the present invention. In the following claims it is intended that the language used in describing the apparatus components and the method steps be related within the range of permissible and reasonable equivalency to the description and disclosure. For example, it has been found that reasonably good results can be obtained by furnishing the electrolyzing direct current within the range of approximately four to 15 volts. Within this approximate range, and depending upon the resistance in the work gap, the current density will usually be in the range of 100 to 3000 or more amperes per square inch. The resistance in the work gap is determined by the width of the gap and the character of the electrolyte therein. Work gaps of less than .001 inch, e.g., .0005 inch, and as great as .012 inch have been used. When the electrolyte is pumped through such gaps at temperatures in the range of 120° F. to 160° F., a pressure of several atmospheres must be used to inhibit bubbling or boiling of the electrolyte and the consequent reduction of its conductivity. Therefore, the electrolyte is pumped through the gap at pressures within the range of 50 p.s.i. to at least 200 p.s.i. to obtain high back pressure in the work gap with a resultant high electrolyte velocity through the work gap, thereby substantially to raise the boiling point level of the electrolyte so as to inhibit the formation of gas bubbles in the electrolyte and to flush away the eroded workpiece material.

From the above discussion it will be apparent that although this invention may be used for producing shapes

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and cavities of an irregular character, such that they would be extremely difficult to form by any other process, the invention also has a high order of utility for replacing more conventional machining operations when the workpiece is one of the super-alloys or other material which is for all practical purposes, largely non-machinable. The embodiment illustrated in FIG. 20, for instance, would not be likely to replace an ordinary turning operation on mild steel or other easily machinable materials, but its superiority is evident upon hardened tool steel or super-alloys, or other non-machinable materials.

From the above description of my invention as embodied in several alternative variations, it will be appreciated that many changes may be made both in the apparatus and in the method 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. An electrode for use in electrolytic shaping apparatus, comprising a plurality of closely spaced metallic tubular members adapted to be connected into an electrolyzing electric circuit, each of said members having a working and electrically conductive face at one end thereof adapted to be brought into close spacing relationship with an electrically conductive and electrochemically erodible workpiece to be shaped, each member having an opening opposite said working face through which an electrolyzing fluid is adapted to be pumped, each member having a minor metallic area contiguous to said face exposed laterally to provide controlled lateral electrolytic erosion of the workpiece, and an insulating sheath encasing each tubular member in intimate contact therewith from said laterally exposed area a distance substantially away from said working face.

2. The electrode as claimed in claim 1, wherein said working faces on said tubular members combine to form an electrode working face which is contoured to erode a contoured surface in a workpiece.

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3. The electrode as claimed in claim 2, wherein said electrode working face is contoured to conform to a parti-cylindrical surface.

4. The electrode as claimed in claim 2, wherein said electrode working face is contoured in at least two directions, one transverse to the axes of said tubular members and the other parallel to said axes.

5. The electrode as claimed in claim 1, including means forming a plenum chamber to which said tubular members are mounted at their inlet ends to receive electrolyte.

6. An electrode for use in electrolytic shaping apparatus, comprising a plurality of closely spaced metallic tubular members adapted to be connected into an electrolyzing electric circuit, each of said members having a working and electrically conductive face at one end thereof adapted to be brought into close spacing relationship with an electrically conductive and electrically erodible workpiece to be shaped, each member having an opening opposite said working face through which an electrolyzing fluid is adapted to be pumped, each member having a metallic area contiguous to said face exposed laterally to provide controlled lateral electrolytic erosion of the workpiece, and an insulating sheath encasing each tubular member in intimate contact therewith from said laterally exposed area a distance substantially away from said working face.

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**Dedication**

3,511,767.—*Lynn A. Williams*, Winnetka, Ill. ELECTRODE FOR ELECTROLYTIC SHAPING. Patent dated May 12, 1970. 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.*]