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APPARATUS FOR ELECTROCHEMICALLY REMOVING THE
SURFACE LAYER FROM A WORKPIECE

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Sheet 1 of 2

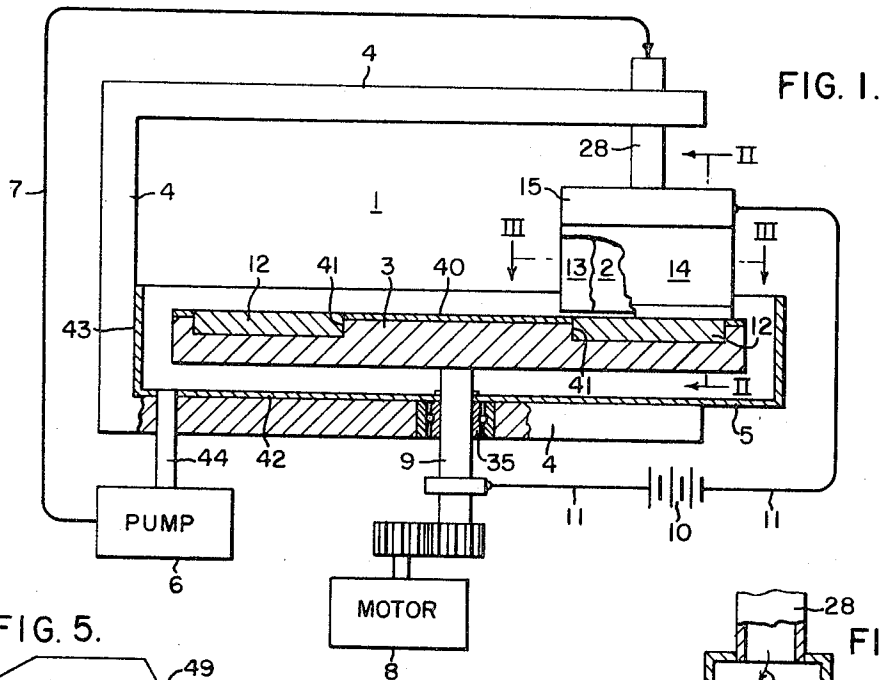


FIG. 5.

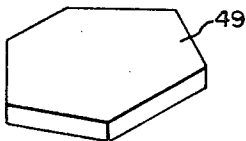


FIG. 3.

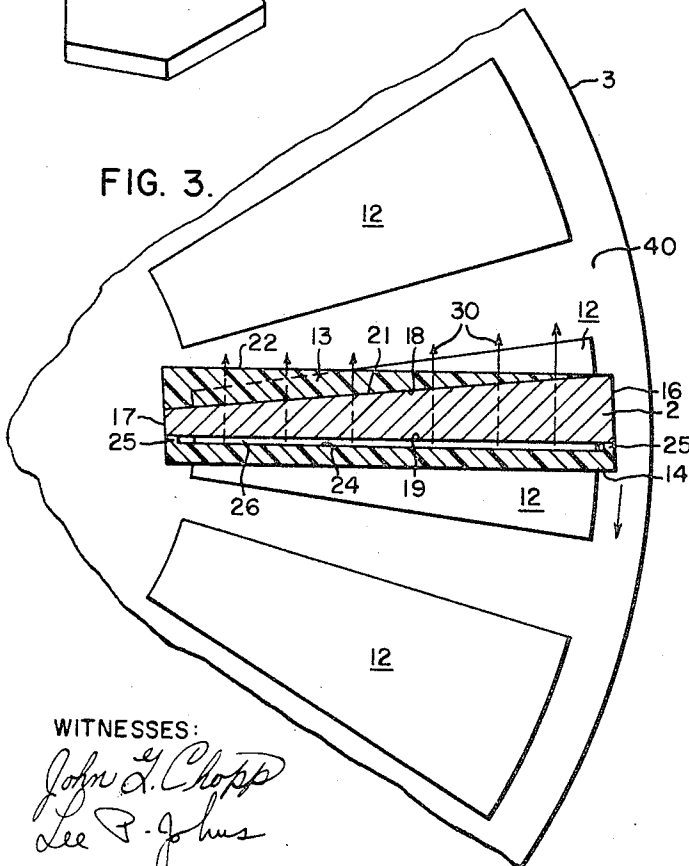


FIG. 2.

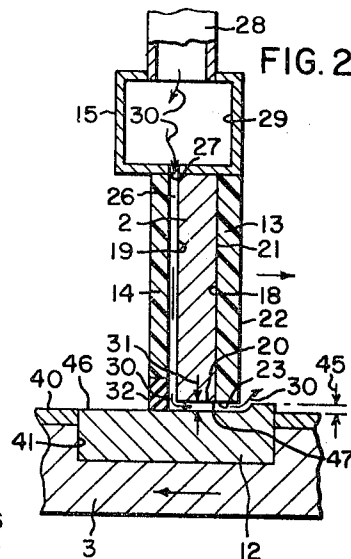
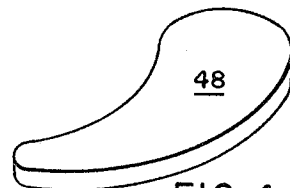


FIG. 4.



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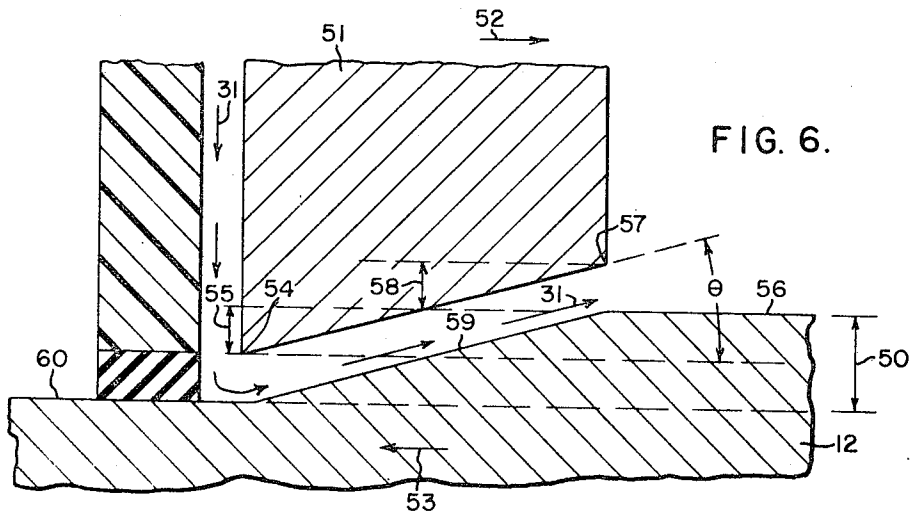


FIG. 6.

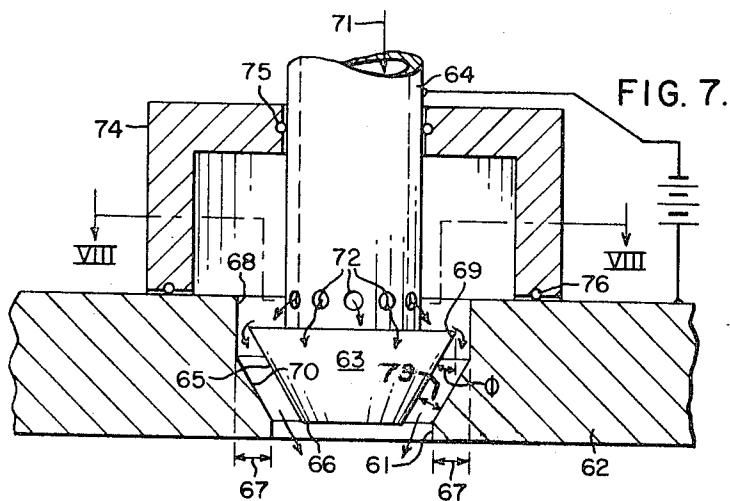


FIG. 7.

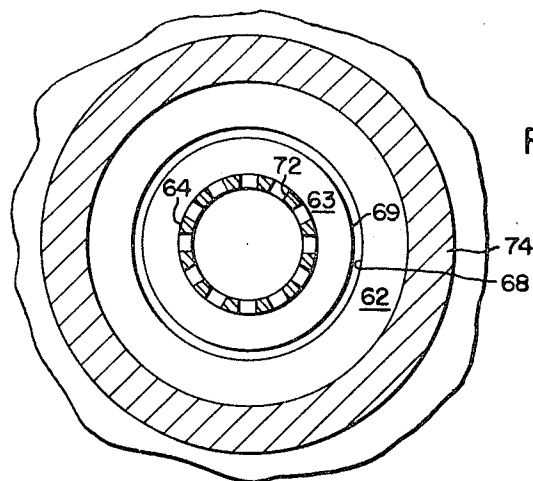


FIG. 8.

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APPARATUS FOR ELECTROCHEMICALLY REMOVING THE SURFACE LAYER FROM A WORKPIECE

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5 Claims

ABSTRACT OF THE DISCLOSURE

An apparatus for electrochemically removing a surface layer from a metal workpiece. The metal is removed by electrolytic dissolution as the working face of a cathodic tool electrode moves across the surface while a working gap is maintained. The electrolyte is fed to the gap in the same direction as the electrode is moving and the electrolyte is prevented from moving rearwardly by a wiper bar at the rear of the electrode.

This invention relates generally to electrolytic methods and apparatus for removing a surface portion from a metal workpiece, and more particularly it pertains to electrochemical machining of metal.

The removal of a surface portion of a metal workpiece by electrolytic technique is known in the prior art such as in Patent No. 3,058,895. Electrochemical machining or removal is essentially deplating because the workpiece is in effect the anode of an electrolytic cell operating at a relatively high current density.

When a metal object is machined by mechanical means, several disadvantages or problems often accompany the procedure. Among others, they include inaccuracies or non-uniform dimensions of cut due to wear of the cutting tool, formation of metal burrs, work hardening of the metal surface areas, and cutting heat developed which may change the metallurgy of the workpiece and produce surface cracking, distortion and other defects.

Electrochemical removal of metal obviates those disadvantages; there are no problems of tool wear, burring, overheating, and distortion due to dimensional changes in a finished surface. Other problems, however, do occur with electrochemical machining for various reasons including relative motion between the electrode and the workpiece when operated in a rotational direction. For rotational applications the conventional procedures and electrodes have not proven satisfactory for obtaining surface finishes free of striations and for obtaining uniform stock removal from the surface of the workpiece.

Another problem has been the maintenance of electrolyte in the cutting gap between the electrode and the workpiece.

Still another problem has been the limitation of feed rates of electrode advance when qualifying, enlarging or reaming holes, such as in precision boring in a workpiece.

It has been found that such problems may be overcome by providing an electrode having a specified shape for a particular rotational procedure. Where the electrode and workpiece involve rotational movement with respect to each other, the relationship of the time at current between the surface area at the outer diameter and the inner diameter of rotation is proportional. In other words, where a workpiece is rotated, the surface areas nearer the outer diameter of rotation move at a greater angular velocity than the surface areas nearer the center of rotation and all areas should be subjected to an equal amount of cur-

rent for a given time interval to obtain a uniform depth of cut from the entire surface of the workpiece.

It has also been found that the feed rates can be accelerated for most types of electrochemical surface machining, whether involving rotational movement or qualifying holes, by providing the electrode cutting face with a surface that is inclined at an angle both to the workpiece surface to be removed and to the direction of electrode advance.

Accordingly, it is a general object of this invention to provide an electrochemical machining method and apparatus for removing a surface layer from a metal workpiece.

It is another object of this invention to provide an electrochemical machining method for removing a surface layer of prescribed thickness from a metal object having any surface configuration about a center of rotation or along the direction of normal advance.

It is another object of this invention to provide an electrochemical machining apparatus for electrolytically removing a surface layer of metal from a workpiece mounted on a rotatable turntable.

Finally, it is an object of this invention to accomplish the foregoing objects and desiderata in a simple and effective manner.

In accordance with the present invention, for rotational technique a plurality of workpieces are mounted on a rotatable worktable in spaced relation with respect to each other. A cathodic electrode is positioned above the path of rotation of the workpieces and spaced therefrom by a distance which is a function of the current density which is used during operation of the apparatus. The cross-section of the electrode is a truncated triangle or sector of a circle, i.e. it is tapered inwardly toward the center of rotation of the workpieces and electrode. Means are provided for circulating an electrolyte between the electrode and each workpiece. Means are also provided for passing an electric current through the electrolyte and between the cathodic electrode and the anodic workpieces as the table is rotated.

Moreover, in accordance with the present invention for qualifying holes a circular electrode is provided with an inwardly tapered cutting surface which surface is inclined at an angle to the surface to be removed. This relationship also applies to external surfaces.

For a better understanding of the invention, reference is made to the drawings; in which:

FIGURE 1 is a diagrammatic representation of one form of apparatus embodying the present invention which is effective for practicing the inventive method;

FIG. 2 is an enlarged vertical sectional view taken on the line II—II of FIG. 1 and having a workpiece in place;

FIG. 3 is an enlarged horizontal sectional view taken on the line III—III of FIG. 1;

FIGS. 4 and 5 are perspective views of various alternate shapes of workpieces which may be used in practicing this invention;

FIG. 6 is an enlarged sectional view through adjacent areas of the electrode and workpiece;

FIG. 7 is a vertical sectional view showing the manner in which an aperture is qualified; and

FIG. 8 is a horizontal sectional view taken on the line VIII—VIII of FIG. 7.

The present invention may be practiced by providing apparatus for electrochemically removing a surface layer from a metal workpiece by a method comprising the steps of placing an anodic workpiece in position for movement in a circular path, positioning a cathodic electrode above the workpiece, moving one of the electrodes and the workpiece with respect to each other, circulating an electrolyte between the electrode and the workpiece, and passing

an electric current through the electrode and between the cathodic electrode and the anodic workpiece as one moves with respect to the other.

In FIG. 1, a device for electrochemically machining a metal surface is generally indicated at 1. It includes an electrode 2, a rotatable worktable 3, means for supporting the electrode and the worktable such as a rigid frame 4, a catch pan 5, means for circulating an electrolyte such as a pump 6 and conduit 7, and means for rotating the worktable including a motor 8 and a shaft 9. There are provided means such as a source 10 of D.C. power and lead wires 11 for passing a current through the electrode 2 and workpieces 12 as the latter move under the electrode 2.

As shown in FIGS. 2 and 3 the electrode 2 is disposed between a pair of insulating or dielectric elements 13 and 14 which are attached to and depend from the underside of an electrode mounting housing 15. The electrode 2 is metallic and the elements 13 and 14 are of a suitable dielectric material such as a plastic—for instance a phenolic resin laminate. The lower (working) end 20 of the electrode 2 has the shape of a truncated triangle or a truncated sector of a circle with an outer edge 16 wider than an inner edge 17. The electrode 2 also includes forward and rear sides 18 and 19 that extend between the outer and inner edges 16 and 17. The lower end of the sides 18 and 19 are located in planes passing through radii of the circle of rotation of the worktable 3.

The dielectric element 13 is preferably composed of plastic and has one side 21 abutting the forward side 18 of the electrode and has another side 22 remote from said forward side. The element 13 is wedge shaped and the sides 21 and 22 converge toward the outer edge 16 of the electrode 2. The side 22 is parallel to the rear side 19 of the electrode 2. A lower end 23 of the element 13 (FIG. 2) is aligned with the lower end 20 of the electrode, whereby a rectangular surface area facing the workpiece is presented by the combined lower ends 20 and 23 of the electrode 2 and the dielectric element 13.

The element 14 is preferably rectangular in horizontal cross section and includes a side 24 which is spaced from the rear side 19 of the electrode 2. The side 24 includes a flange 25 at each vertical edge, which flanges fit snugly against the rear side 19 (FIG. 3) of the electrode. Thus a slot 26 is provided between the electrode 2 and the element 14 and between the flanges 25 which slot extends from the upper end of the electrode where it communicates with an aperture 27 in the underside of the housing 15.

As shown in FIGS. 1 and 2 the housing 15 is mounted on the lower end of a tube 28 that is attached to the upper portion of the frame 4. The tube 28 is connected to the conduit 7. Accordingly, electrolyte is pumped through the conduit 7 and through the tube 28 into a plenum chamber 29 of the housing 15. From there the electrolyte flows through the slot 27 as shown by arrows 30 to the lower end of the electrode 2 where it is directed through a clearance or gap 31 between the workpiece 12 and the lower ends 20 and 23 of the electrode 2 and the element 13. To prevent the electrolyte from flowing under the element 14 a sealing wiper bar 32 is affixed to the lower end of the element which bar is composed of dielectric material and has a low coefficient of friction and sufficient resilience for sealing and wiping the surface of the workpiece.

The worktable 3 is mounted for rotation on the shaft 9 which is driven by the motor 8. The worktable 3 is preferably composed of metal and is faced with a layer 40 of dielectric material. The worktable 3 has a series of spaced workpiece-mounting means such as recesses 41 which are adapted to clamp the workpieces 12 in place. The metal shaft 9 is connected to the lead wire 11 leading from the direct current power source or battery 10. Thus, the worktable 3 and the shaft 9 provide an electrical conducting path to the lead wire 11. As shown in FIG. 1, the

shaft 9 is mounted in a bearing 35 within the frame member 4.

The catch pan 5 is mounted on the frame 4 and includes a bottom wall 42 and a side wall 43 the upper end of which extends above the top of the table 3. The purpose of the catch pan 5 is to collect electrolyte as it drains off of the periphery of the worktable 4 and return the electrolyte to the circulatory system through an electrolyte outlet 44 which communicates with the conduit 7 and the pump 6.

In operation, the workpieces 12 are electrochemically machined or deplated by rotating the worktable 3 while passing an electric current through the electrolyte in the gap 31 between the workpieces and the electrode. The worktable 3 is rotated at a speed of from 0.5 to 50 inches per minute. Although the apparatus of FIG. 1 shows a rotatable worktable with a workpiece mounted thereon, it is understood that the apparatus may be modified by holding the workpiece stationary and moving the electrode with respect thereto. The pump 6 circulates the electrolyte downwardly through the conduit 6, the plenum chamber 29, and the slot 26 from where the electrolyte flows through the gap 31 between the lower end of the electrode and the workpiece. For that purpose, the gap 31 may vary from 0.003 to 0.030 inch and preferably between 0.010 and 0.020 inch. The electrolyte flows through the gap 31 in the direction of the arrows 30; that is, in the direction ahead of the relative movement of the electrode and the workpiece. The wiper bar 32 prevents the electrolyte from flowing backwardly or under the element 14 and effecting post-etching of the deplated surface.

During the deplating the electrolyte must flow at a predetermined rate that is dependent upon the type of metal involved. If the flow rate is too slow, heat develops in the gap 31 which causes the electrolyte to boil. Gas bubbles are thereby created which create an insulated portion and cause sparking due to incurred voltage variations. On the other hand, if the electrolyte flows too fast a passive oxide film may be formed on the metal surface. Such film is insulating and greatly reduces or stops flow of electrical current.

The current density for performing the electrochemical machining may vary from 100 to 8,000 amperes per square inch (a.s.i.) with the preferred range being from 500 to 1,500 a.s.i. The current density, being a function of the electrolyte conductivity and voltage and is inversely proportional to the spacing or gap between the electrode and the workpiece so that the greater the spacing the lower the current density at a given voltage. As deplating proceeds the initial standoff or clearance from the original surface is a function of speed conductivity of the electrolyte, and voltage which control current density. The current density is a function of the gap dimensions.

The pressure of the electrolyte as it enters the gap 31 may be as high as about 500 p.s.i. and the preferred pressure is from 40 to 50 p.s.i. Moreover, the pressure must be maintained at a relatively constant high level to provide a highly reflective metallic finish free of striations. During deplating as the electrode 2 moves across the surface of the workpiece 12 (FIG. 2) a top layer 45 is removed by deplating to provide a finished surface 46. The deplating commences at the forward corner 47 and continues as long as the lower end 20 of the electrode is located over any area of the workpiece. In other words, deplating occurs primarily within the gap 31. Deplating also occurs in the zones just ahead of and behind the electrode, because the electrolyte in those zones provides a path for the current, though at a lower density.

Inasmuch as the clearance or gap 31 is relatively small, such as 0.003 to 0.030 inch, sufficient pressure must be maintained on the electrolyte to not only sustain a continuous flow but to maintain the pressure of from 40 to 500 p.s.i. at the rear corner. To provide an evenly deplated surface without striations the electrolyte must flow

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ahead of the electrode or toward the workpiece surface to be deplated. Equal electrolyte pressure from one edge 16 to the other edge 17 is maintained by the wedge shaped end 23 of the element 13 which together with the under-surface 20 of the electrode 2 provide a gap 31 or restrictive passage of equal length for the electrolyte. Thus striations are avoided.

A closed circuit between the electrode 2 and the workpiece 12 and across the gap 31 is maintained through constantly flowing film of electrolyte in the gap. The electrolyte is preferably an aqueous solution of a neutral salt, such as sodium chloride (NaCl) or potassium nitrate (KNO₃) which may have a specific gravity of about 1.08 when one pound of salt is mixed for each gallon of water.

As the current is applied between the workpiece (anode) and the electrode (cathode) through the electrolyte, the surface of the workpiece is deplated. During deplating, using these salts a hydroxide of the removed metal is formed and carried away by the electrolyte which is unaffected by the presence of the hydroxide until the viscosity of the electrolyte is high enough to reduce its flow. For the purpose of maintaining a low viscosity, the electrolyte may be replaced in whole or in part or filtered to remove the hydroxide which is of a fine suspension or gelatinous nature.

The electrode 2 is composed of metal such as copper. For rotational machining the electrode has a configuration of a truncated triangle or sector of a circle, the sides of which diverge on spaced radii of the path of rotation of the workpiece. The angular velocity of any point in the workpiece increases proportionally with the distance of the point from the center of rotation. In order to obtain uniform deplating of the workpiece surface, all areas of the workpiece are subjected to equal time exposure to the electrode by providing an electrode having the described configuration, i.e. a truncated triangle or sector of a circle. The thickness of the surface layer removed varies with the speed of rotation and the current density and can be appropriately adjusted to meet production requirements. Moreover, a single or multiple electrode may be used. The amount of surface metal removed is proportional to the width of the electrode.

It is to be understood that although the workpiece 12 is shown as having the shape of a truncated sector of a circle or truncated triangle, the workpiece may have any shape, such as workpieces 48 and 49 in FIGS. 4 and 5.

As shown in FIG. 2 the lower end 20 of the electrode 2 is shown as being parallel to the upper surface of the workpiece 12. With such a configuration the electrode may advance at any speed (feed rate) and deplate a surface layer having a thickness which is a function of the width of the electrode and of the current density.

To increase the depth of cut the lower end or face of the electrode may be inclined at an angle θ to the horizontal plane (FIG. 6). Thus, a surface layer 50 is deplated to a greater depth as the electrode 51 advances in the direction of the arrow 52 and/or the workpiece 12 moves in the direction of the arrow 53.

An increased depth of cut, however, is obtained when the heel or rear portion 54 of the electrode 51 is below (see arrow 55) the original surface 56 of the workpiece 12. Moreover, the increased depth of cut obtains only if the toe or front portion 57 of the electrode 51 is above (see arrow 58) the original surface 56 of the workpiece 12. During deplating an inclined surface 59 forms under the electrode and between the original surface 56 and the finished surface 60.

The principle of the inclined angle of the face or lower end of the electrode is applicable not only to electrochemical machining where the relative movement between the electrode and workpiece surface is rotational, but it is also applicable to linear movement. It is applicable to metal removal both from plane or contoured surfaces as well as plunge type machining such as qualifying a hole in a metal plate. As shown in FIG. 7, a hole 61

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in a metal plate 62 may be reamed by an electrode 63 at the lower end of a shaft 64. The electrode 63 has the shape of a truncated cone with a peripheral surface 65 inclined downwardly and inwardly at an angle ϕ to the vertical axis. The hole 61 may be round or any other shape, but for such a hole the electrode must have an appropriate configuration.

In a manner similar to the principle described above with respect to FIG. 6, a forward portion or toe 66 of the electrode 63 is maintained outside of the deplating zone 67 between the original bore surface 61 and the finished surface 68. Likewise, the heel or rear portion 69 of the electrode 63 is maintained in a zone between the finished and original surfaces, whereby an inclined surface 70 is formed during deplating which advances from the upper to the lower sides of the plate 62 as viewed in FIG. 7.

Electrolyte enters the deplating zone through the tubular shaft 64 (arrow 71) from where it flows through radial apertures 72 (FIG. 8) and around the electrode 63 and into the gap 73 between the electrode and workpiece or plate 62. A shield 74 is mounted around the shaft 64 and over the bore 61 to retain the proper electrolyte pressure within the gap 73. Seals 75 and 76 are provided on the shield 74 where it contacts the shaft 64 and plate 62.

Accordingly, the method and apparatus of the present invention provides for the electrochemical removal or deplating of a metal surface without the disadvantages frequently incurred in mechanical machining such as face cutting on a lathe, grinding and the like where tool wear requires resharpener from time to time and the workpiece is frequently overheated which results in a change of metallurgical structure of the workpiece near the removed surface.

Finally, although each metal has a penetration rate at a given current density that could not be exceeded by prior known methods, the apparatus and methods of this invention permit greater machining or deplating speeds while obtaining removal of metal layers of specified thickness.

Other changes and modifications can be made both in the apparatus and in the method above described without departing from the scope or spirit of the present invention.

What is claimed is:

1. Apparatus for electrochemically removing a surface layer from a metal workpiece to provide a finished surface, comprising means for holding a workpiece, means for moving one of the electrodes and workpiece relative to the other, a cathodic electrode mounted above the workpiece and having a deplating surface with forward and rear edges with respect to the direction of relative movement, the electrode also having forward and rear side surfaces extending upwardly from the forward and rear edges, a first imperforate dielectric element mounted in spaced relation to the rear side surface and forming therewith slot means for delivering an electrolyte at the rear edge of the deplating surface, sealing means at the lower end of the first dielectric element engageable with the surface of a workpiece and for directing the electrolyte in the direction of movement between the deplating surface and workpiece, and means for passing an electric current through the electrolyte and between the cathodic electrode and the anodic workpiece, whereby the electrolyte flows only forwardly with the sealing means preventing the electrolyte from flowing rearwardly and thereby providing an evenly deplated surface devoid of striations.

2. The apparatus of claim 1 wherein the electrode and workpiece move in a circular path relative to each other, the deplating surface having a cross-sectional area substantially in the shape of a truncated triangle, and the forward and rear edges thereof being located on the radii of the circular path.

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3. The apparatus of claim 2 wherein a second dielectric element is mounted on the forward side surface of the electrode and having a lower end surface in substantial alignment with the deplating surface, the lower end surface having one edge adjacent to the forward edge of the deplating surface, and the lower end surface also having another edge remote from said forward edge and substantially parallel to the rear edge of the deplating surface, whereby a clearance space between the workpiece and the surface including the aligned deplating surface and the lower end surface of the second dielectric element provides a restrictive passage of equal length for the electrolyte between the rear edge of the deplating surface and said other edge of the second dielectric element.

4. The apparatus of claim 2 wherein a second dielectric element is mounted on the forward side surface of the electrode and having a lower end surface in substantial alignment with the deplating surface and the second dielectric element having a lower edge remote from said forward edge and substantially equally distant

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from the rear edge of the deplating surface throughout its length.

5. The apparatus of claim 3 wherein the second dielectric element provides a clearance gap over the workpiece having a uniform width from the smaller to the larger edge of the truncated triangular shaped ends of the electrode.

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U.S. Cl. X.R.

20 204—143, 224, 288, 284