# United States Patent

**Williams**

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## [54] ELECTROLYTIC DEMETALLIZING APPARATUS HAVING ELECTROLYTE-PRESSURE-RESPONSIVE LOAD-COMPENSATING MEANS


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[21] Appl. No.: **762,077**

**Related U.S. Application Data**

[63] Continuation-in-part of Ser. No. 680,811, Nov. 6, 1967, abandoned.

[52] **U.S. Cl.** ..... **204/224,** 204/143 M, 204/225

[51] **Int. Cl.** ..... **B23p 1/02,** B23p 1/12

[58] **Field of Search** ..... 204/225, 224, 143



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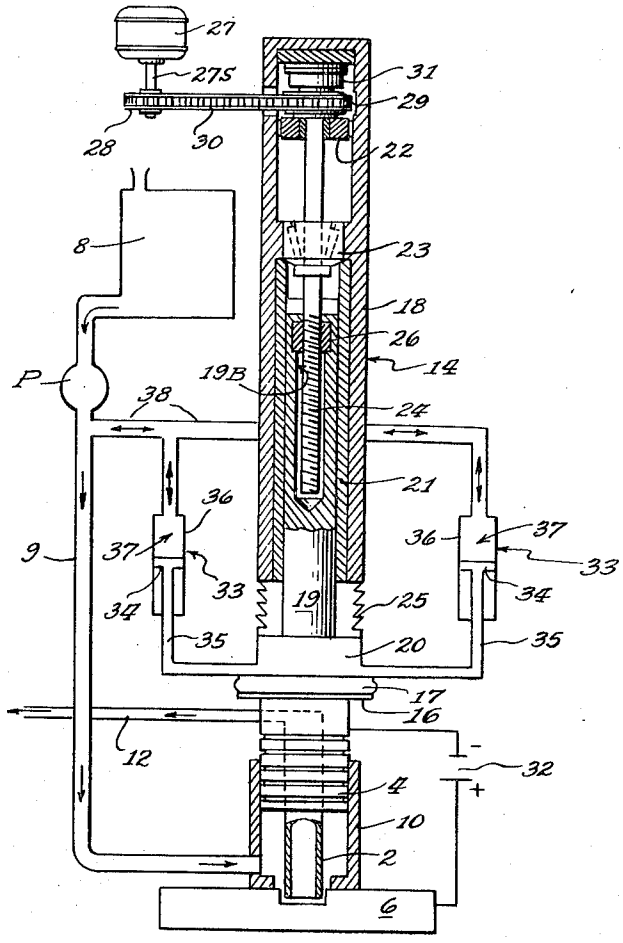
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[57] **ABSTRACT**

This application discloses an electrolytic demetallizing apparatus adapted to drive a shaping cathode toward and into a conductive metal workpiece, with a gap that is maintained between the cathode and workpiece being filled by pressurized, rapidly flowing electrolyte through which electric current flows between the cathode and workpiece. The apparatus contains drive means for producing relative movement of the cathode and workpiece at a constant rate along a path that determines the shaping of the workpiece. Also, a hydraulic load-compensating means urges the cathode forward into the workpiece to at least partially counteract the tendency of the electrolyte pressure to produce relative retracting movement between the cathode and the workpiece. The load-compensating means is directly responsive to a change of electrolyte pressure between cathode and workpiece, so that the load-compensating force is relieved upon a sudden decrease in the electrolyte pressure such as may be occasioned when the electrode breaks through the workpiece upon completion of the shaping step.


**9 Claims, 7 Drawing Figures**



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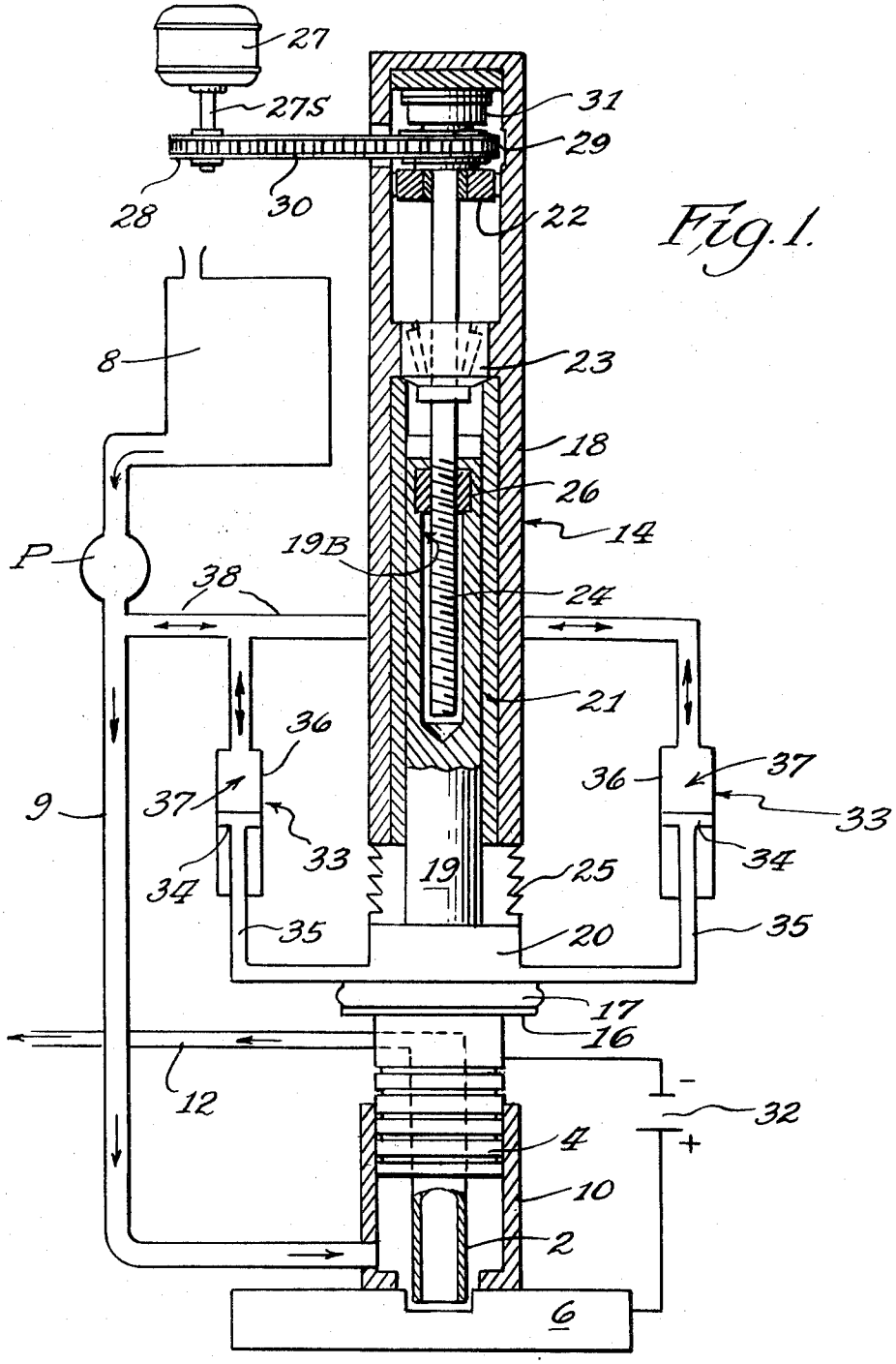
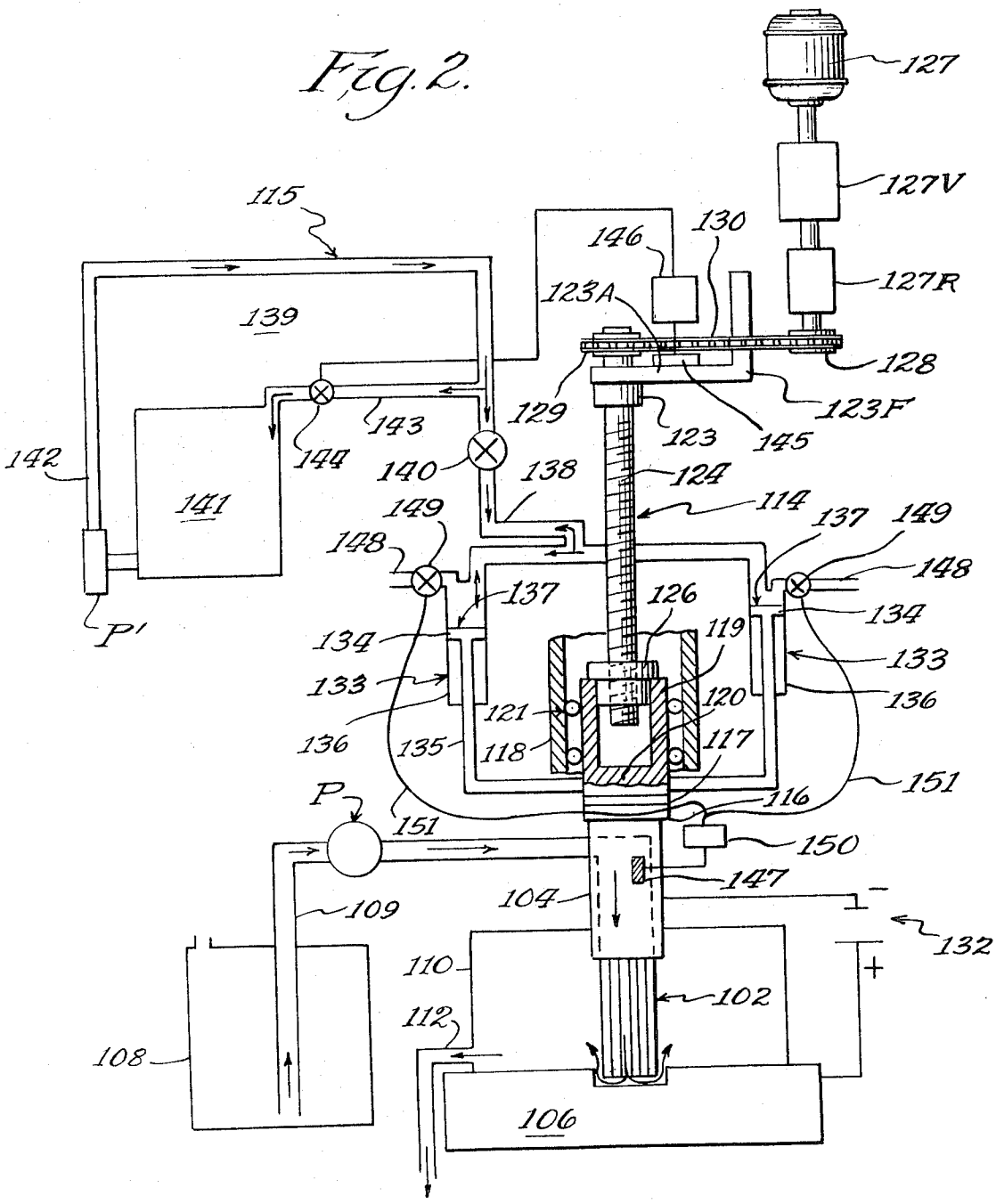



Fig. 1.

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Fig. 2.




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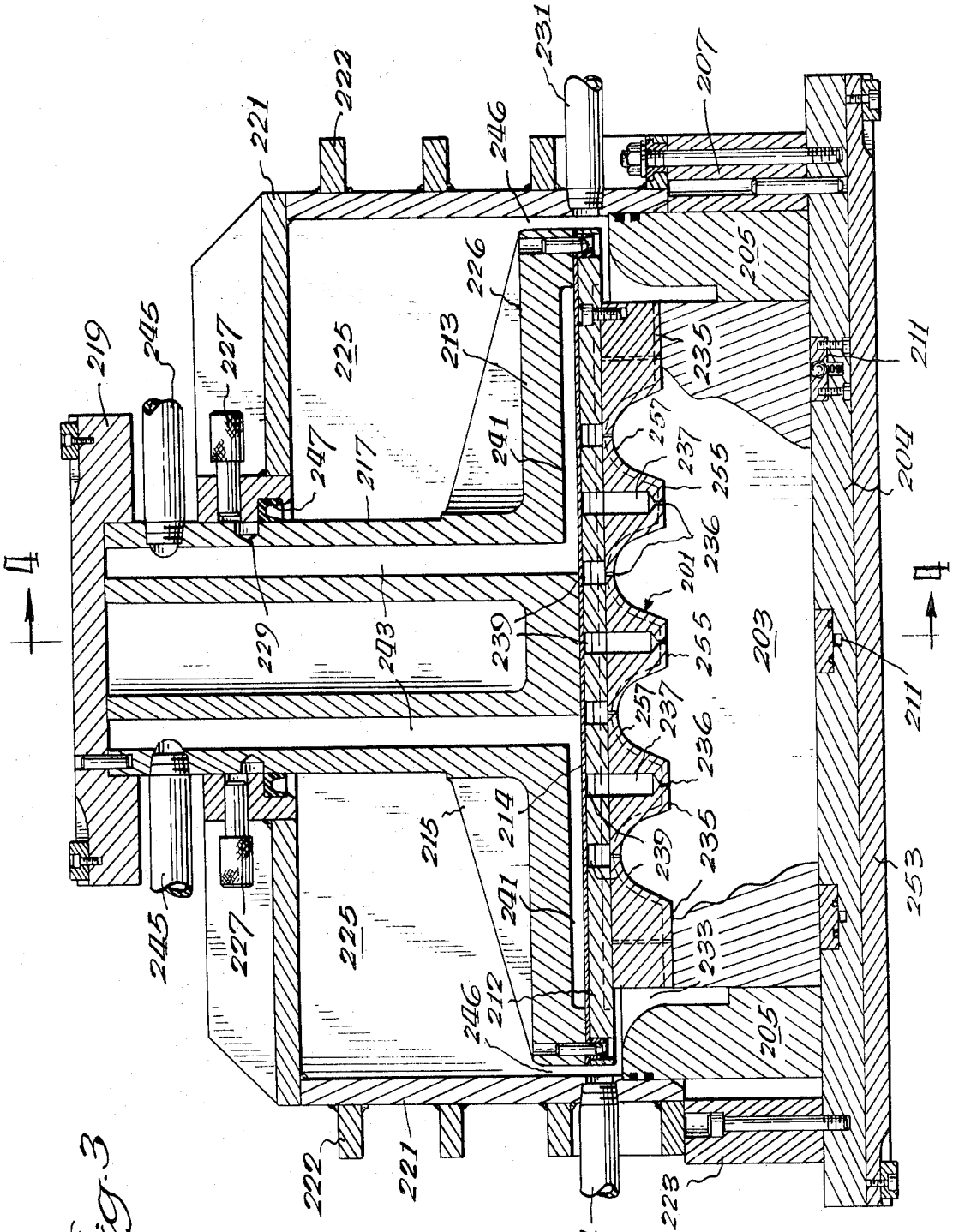



Fig. 3

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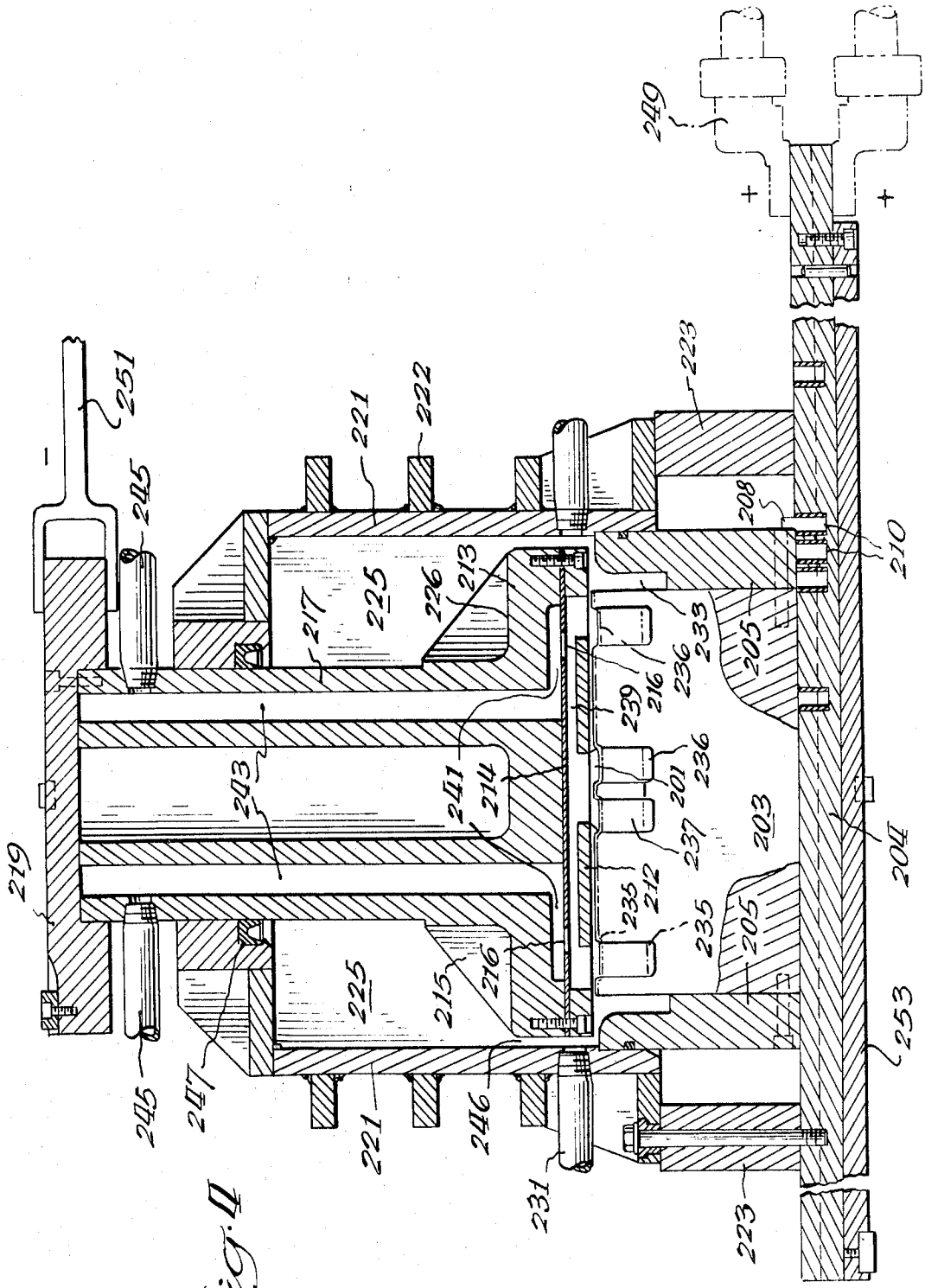



Fig. 4

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Fig. 7

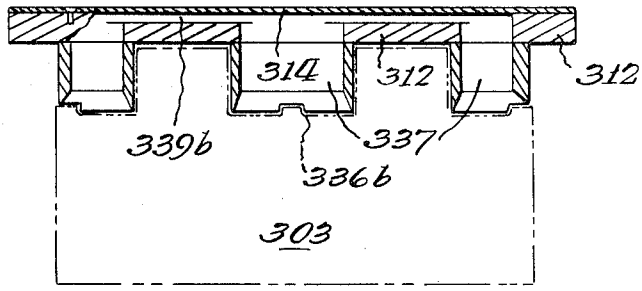
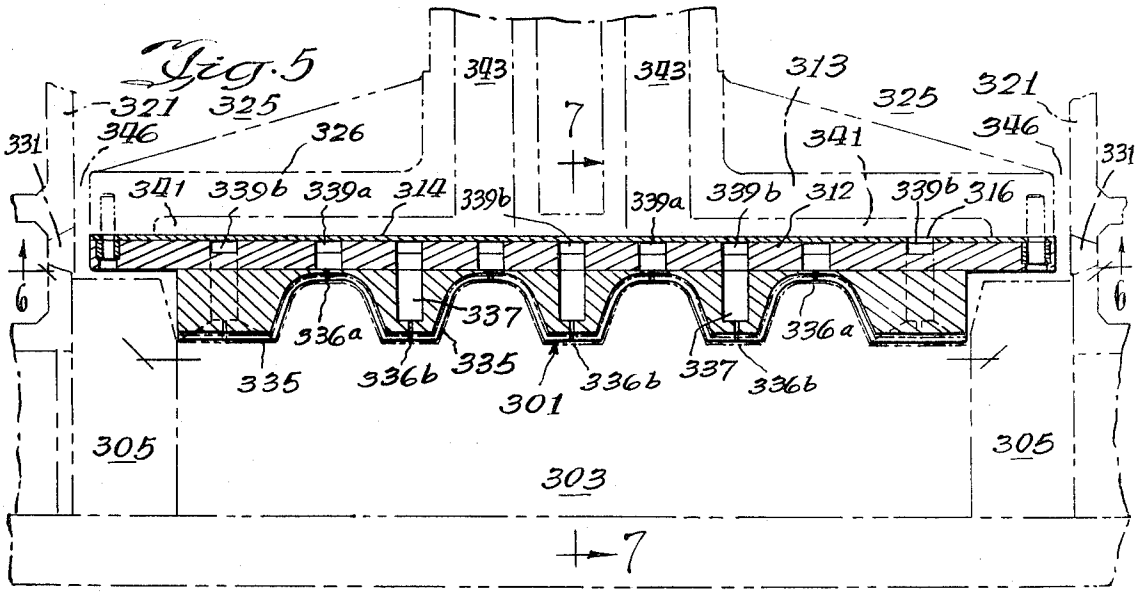



Fig. 5



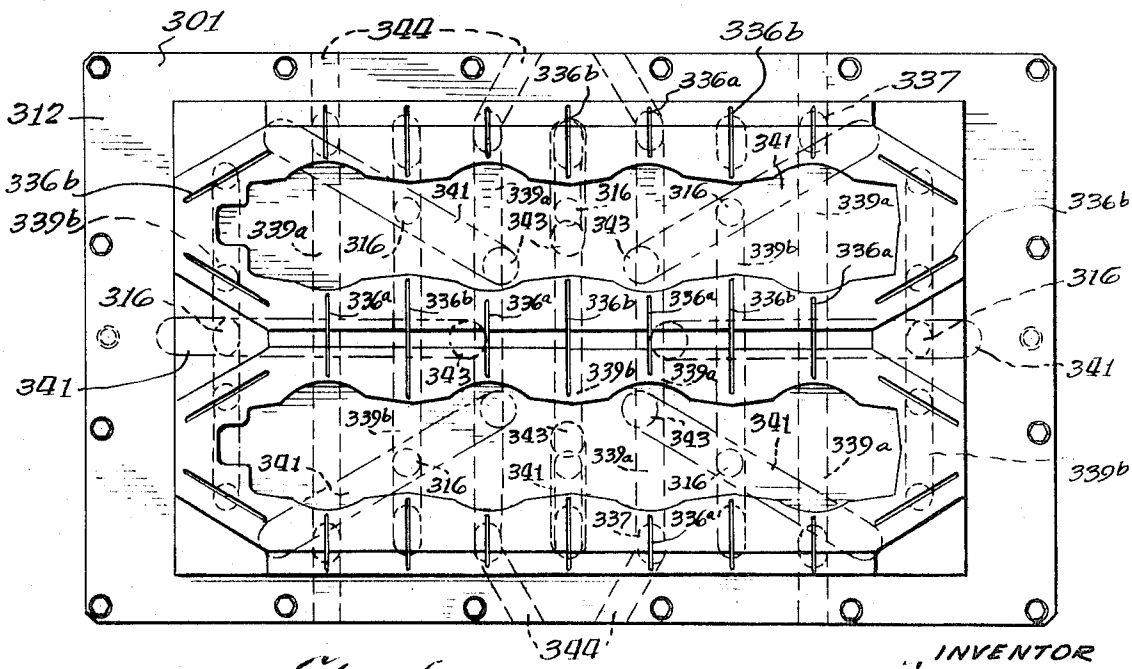




Fig. 6

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# ELECTROLYTIC DEMETALLIZING APPARATUS HAVING ELECTROLYTE-PRESSURE-RESPONSIVE LOAD-COMPENSATING MEANS

## CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of our copending application Ser. No. 680,811, filed Nov. 6, 1967, now abandoned.

## BACKGROUND OF THE INVENTION

### Field of the Invention

Electrolytic demetallizing is a now well-known process involving the removal of metal from an anodic workpiece by maintaining a stream of electrolyte between the workpiece and a shaping cathode which is not in mechanical contact with the workpiece, while passing direct current therebetween through the stream of liquid electrolyte. See, for example, U.S. Pat. Nos. 3,058,895 and 3,130,140.

Electrolytic demetallizing can be used to sink cavities and to produce shapes in metal, including hard alloys which are machined conventionally with the utmost difficulty.

## OPPOSING FORCE FROM HIGH ELECTROLYTE PRESSURE

The best results are obtained in the electrolytic demetallizing process when the workpiece is spaced only a very short distance from the shaping cathode, and electrolyte flows through the gap between workpiece and cathode at a high velocity and relatively high pressure, frequently 200 p.s.i. or above.

In the use of cathodes of large cross-sectional area, the hydrostatic force tending to push the cathode away from the work becomes quite large. If, for example, the effective cross-sectional area of the cathode is, say, 100 square inch, and if the effective hydrostatic pressure of electrolyte between the cathode and the workpiece is, say 200 p.s.i., then the total force rises toward 20,000 lbs., the exact value being dependent upon the extent of the Bernoulli effect and the consequent static pressure in the work gap. The mechanism required to move the cathode toward the workpiece against the force in a smooth and uniform manner is heavy and expensive. Also, it becomes extremely difficult to move the cathodes at a uniform rate of advance against such high back pressures, although a uniform rate of advance is generally important for the erosion of uniformly shaped cavities.

## NEED FOR PROMPT SHUTOFF OF LOAD-COMPENSATING MEANS

It is also known to provide an additional load-compensating means for an electrolytic demetallizing apparatus having a cathode of large cross-sectional area that is subject to strong reaction forces as just described.

While the known load-compensating means, such as a hydraulic system arranged to augment the drive system in accordance with the actual electrolyte pressure, successfully assists the drive means in providing a steady advance of the cathode by partially compensating for the hydrostatic force opposing such advance of the cathode, a problem arises at the point where the cathode fully penetrates the workpiece and breaks through the back surface. The electrolyte pressure between cathode and workpiece immediately drops, suddenly reducing the opposing reaction force on the cathode. If the load-compensating means is not deactivated immediately when the electrolyte pressure falls, the continued forward force applied by the load-compensating means will cause the cathode to impact with the workpiece, causing damage to both.

## ADVANTAGES OF THE INVENTION

This invention provides electrolytic demetallizing apparatus which is particularly suitable for use with shaping cathodes of large cross-sectional area, against which opposing reaction forces of up to 10 tons or more can be developed by the pressurized electrolyte without the above-stated undesirable effects taking place.

The apparatus of this invention can be used to erode large cavities in metal workpieces, and upon a sudden drop in in electrolyte pressure, caused for example, by a breakthrough at the back of the workpiece, the cathode does not surge forward into contact with the workpiece, and thus does not damage the cathode or workpiece.

## SUMMARY OF THE INVENTION

This application relates to an electrolytic machining apparatus which contains means for mounting a shaping cathode in predetermined position with respect to a conductive metal workpiece to define a gap therebetween, means for flowing electrolyte between the cathode and the workpiece and through said gap under positive pressure, the electrolyte pressure tending to produce relative retraction between the cathode and the workpiece, and means for controlling relative movement between the cathode and the workpiece to maintain a predetermined gap in the presence of the electrolyte pressure, said last-named means including drive means for producing relative movement of the cathode and workpiece along a path that determines the shaping of the workpiece, load-compensating means for at least partially opposing said tendency to relative retraction between the cathode and the workpiece, and means connected in load-controlling relation to said compensating means and directly responsive to electrolyte pressure between the cathode and the workpiece for relieving the load-compensating means upon a sudden decrease in said electrolyte pressure.

## THE DRAWINGS

In the drawings:

FIG. 1 is a diagrammatic lengthwise section showing one embodiment of the apparatus of this invention in the operation of eroding a cylindrical hole through a conductive metal workpiece.

FIG. 2 is a diagrammatic lengthwise section showing another embodiment of the apparatus of this invention in the same operation of eroding a cylindrical hole through a conductive metal workpiece.

FIG. 3 is a sectional view taken along a vertical plane passing through another embodiment of the apparatus of this invention.

FIG. 4 is a sectional view, taken along line 4—4 of FIG. 3, of the same apparatus.

FIG. 5 shows a modification of a portion of the apparatus of FIGS. 3 and 4, taken in section along a vertical plane.

FIG. 6 is a sectional view taken along line 6—6 of FIG. 5.

FIG. 7 is a partial view taken along line 7—7 of FIG. 5.

## DESCRIPTION OF SPECIFIC EMBODIMENTS

Referring to FIG. 1, a hollow, cylindrical-shaping electrode 2 is carried by a hollow holder 4 to be advanced toward a conductive metal workpiece 6 to form a narrow gap therebetween.

A pressurized liquid electrolyte supply system for maintaining a stream of electrolyte flowing across the gap includes an electrolyte storage container 8, a feedline 9 equipped with a pressure pump P, and a slidable feed bushing 10. The feed bushing 10 serves as a guide cylinder for the electrode holder or mounting means 4 and is adapted to engage in sealing relation against the workpiece and provide an annular flow space that surrounds the gap and confines the electrolyte against escape. A return line 12 for the electrolyte leads from the holder 4 to complete the primary electrolyte flow path. This path is shown to lead reversely through the electrode and electrode holder, i.e., from outside the electrode through the work gap between the electrode and the workpiece and then into the interior of the electrode.

The slidable feed bushing **10** may be of any suitable electrically insulating material. It houses the holder **4** and cathode **2** in a relationship to permit electrolyte pressure to cause the bushing to be held in sealed engagement against the workpiece **6**.

The feed mechanism for advancing the electrode and electrode holder is designated generally at **14** and includes adapter plates **16**, **17**, plate **16** being of any suitable electrically insulating material connected in thrust-transmitting relation to the rear end of the electrode holder **4**. If the electrode cathode assembly is large, there will be a high force against advance of the cathode. The drive system may then be augmented by a load-compensating means to be described below that is capable of producing a strong additional forward thrust.

Variations in electrolyte pressure at the gap region, whether caused by variation in the supply pressure or by other environmental changes in the electrolyte flow system, impose transient demands upon the drive system that could, in the absence at such a load-compensating means, lead to erratic advance of the electrode **2**. In the most extreme situation, when the electrode bores through the bottom face of the workpiece **6** and allows direct escape of electrolyte, the effective electrolyte pressure at the gap region falls abruptly, and the load-compensating means, no longer balanced by the electrolyte reaction force, tends to push the electrode against the workpiece by driving it forward with sudden surge which is independent of the slow forward motion caused by the drive means. This happens because the electrode usually breaks through the bottom of the workpiece at a localized region so that the hole is not full size to permit the electrode to pass through without touching the workpiece. Typically, the normal gap clearance between the electrode and the workpiece is small, and upon release of the electrolyte pressure at the gap, the resilience of the drive mechanism, and the play in the drive parts, allows the electrode to jump forward into damaging contact with the workpiece when urged by the load-compensating means.

In the drive system, there is shown a main guide housing **19** of elongated cylindrical open-ended form, a ram **19** slidably mounted therein and projecting through the open end thereof, and an enlarged ram head **20** carried externally on the ram and secured to the adapter plate **17**. The main housing **18** is fitted with a sleeve bushing **21** within its open end for slidable guiding engagement with the ram shaft **19** and housing **18** is also fitted with a radial bearing **22** and an intermediate thrust bearing **23** rotatably mounting the end and intermediate journal portions of a drivescrew **24**. A collapsible protective boot **25** of bellows form is anchored between the ram head **20** and the guide housing **18** to enclose and protect the exposed portion of the ram shaft **19**. The ram shaft **19** has a stepped diameter axial bore **19B** forming a mounting socket for a drive nut **26** that cooperates with the drivescrew to advance and retract the ram head **20**.

A drive motor **27** is shown with a shaft **27S** carrying a sprocket **28** for driving a sprocket **29** on the drivescrew shaft. A suitable link chain **30** is shown trained about the sprockets **28**, **29** and an electric brake **31** is shown within the guide housing **18** to engage the extreme end of the drive shaft.

In normal operation, the motor **27** drives the ram head **20** to advance it at a constant rate of speed during machining operations, or to retract it, the drive being from the sprocket **28**, through the chain **30** to the sprocket **29** to rotate the drivescrew **24**. The drive nut **26** is fixed within the ram shaft to control the ram shaft **19** in accordance with the speed and direction of rotation of the drivescrew.

Electrolyte is supplied through the feedline **9** to the feed bushing **10** and flows across the gap between the workpiece **6** and the electrode **2**, and then through the electrode **2** and holder **4** to the return line **12**. The electrolyte pressure at the gap and acting on the differential area presented by the electrode and electrode holder is determined by the pump P and typically may be about 250–200 p.s.i. A direct current power source is represented at **32** and is shown connected to the workpiece **6** and the electrode holder **4** in a sense to make the workpiece anodic and the shaping electrode cathodic.

As described thus far, the shaping cathode is arranged to sink a hole in the workpiece. Current flow across the electrolyte gap between the shaping cathode and the workpiece removes metal from the workpiece as the drive system advances the electrode. It is desirable that the drive system not be subjected to the high-opposing reaction force which may be present with large work areas. It is also desirable that the drive system be capable of adapting to rapid changes in electrolyte pressure to prevent surges in the movement of the drive system.

In accordance with the present invention, a load-compensating system is associated with the ram head **20** to develop hydrostatic forces assisting advance of the ram head to at least partially counteract the reaction force occasioned by the high-pressure electrolyte acting at the gap region. A balanced array of hydraulic piston and cylinder mechanisms each designated generally at **33** is shown connected directly to the ram head **20** to assist its advance. Each mechanism, as shown for purposes of illustrative disclosure, has a single ended piston **34** and piston rod **35** in rigid driving engagement with the ram head **20** and a cylinder **36** housing the piston and defining a pressure chamber **37** therefor.

Hydraulic pressure is applied to the pressure chamber **37** to produce a compensating force proportional to the reaction force. The relationships of pressure and area in the hydraulic mechanisms **33** are generally selected to partially compensate for the reaction force caused by pressurized electrolyte in the gap region so that the drive system is subjected to a reduced unbalanced reaction force resulting from electrolyte pressure.

In the particular arrangement disclosed herein, the electrolyte feed system has a branch line **38** leading from the discharge side of the pump P and connected to the pressure chambers **37** to utilize electrolyte at the actual feed system pressure as the actuating medium for the hydraulic compensators **33**. Any changes in the electrolyte pressure occur substantially simultaneously at the gap region and in the compensating chambers **37**, so that such changes automatically cancel out and do not present surge conditions to the drive. For example, when the shaping electrode **2** breaks out through the rear face of the workpiece, the close clearance gap conditions and the through flow electrolyte path are disrupted and there is a sudden drop in pressure at the gap region with a consequent sudden drop in the electrolyte reaction force on the ram head **20**. This drop in electrolyte pressure is immediately reflected in a loss of pressure at the discharge side of the pump P so that the pressure acting in the chambers **37** of the hydraulic mechanisms also drops proportionately, to maintain the desired balance of forces at the ram head and thereby prevent contact with the workpiece. Other changes in system pressures due to variation in pump output pressure or for other reasons are reflected rapidly between these regions to maintain the desired balance and allow the drive system to determine and maintain a uniform and steady advancing movement of the electrode.

Another embodiment of the invention is shown in FIG. **2** for producing a compensating force that partially counteracts the reaction force occasioned by the electrolyte pressure acting on the area presented by the electrode and holder assembly. Corresponding reference characters in the "**100**" series are used to identify corresponding parts.

Accordingly, in FIG. **2**, a hollow-shaping electrode **102** is carried by a hollow holder **104** to be advanced toward a conductive workpiece **106** to maintain a narrow gap therebetween. A pressurized liquid electrolyte supply system for maintaining electrolyte flow at the gap includes a storage container **108**, a feedline **109** equipped with a pressure pump P and leading into the upper end of the electrode holder **104**. A splash shield **110** is shown contacting the workpiece **106** and encircling the holder **104** to accommodate relative advancing and retracting movement of the electrode and holder assembly. A return line **112** is shown leading from the splash

shield 110 to complete the electrolyte flow path which, in this embodiment, is shown to extend forwardly through the holder 104 and the electrode 102, then out of the electrode and through the work gap between the electrode and the workpiece.

The drive mechanism for the electrode assembly, designated generally at 114, includes a pair of adapter plates 116, 117, the plate 116 being of any suitable electrically insulating material mounted in thrust relation to the end of the holder 104. In this system, the differential area exposed to electrolyte pressure by the electrode assembly again results in a high opposing reaction force action to resist steady advance of the electrode by the drive mechanism toward the workpiece. A typical load-compensating system is shown herein to partially balance out these electrolyte reaction forces and allow the drive system to effect a uniform advance of the electrode. However, variations in electrolyte pressure at the gap region, whether caused by supply pressure variations or by breakthrough of the electrode through the workpiece or by other environmental changes in the electrolyte flow, impose transient demands upon the drive 114 leading to erratic advance of the electrode unless the load-compensating system instantaneously balances such variations.

In the drive system disclosed in FIG. 2, there is shown a main guide housing 118 (represented only fragmentally) and a ram 119 shiftably mounted therein. Ram 119 includes a ramhead 120 projecting through the lower end thereof, and is guided by antifriction-bearing elements 121 mounted within the guide housing 118. A drivescrew 124 engages a drive nut 126 carried in the upper end of the ram, the upper end of the drivescrew being shown projecting through a thrust bearing 123 shown mounted on a frame structure 123F.

A drive motor 127 is shown powering a variable speed drive 127V and a gear-reducer unit 127R to rotate a drive sprocket 128 for powering a sprocket 129 by means of a link chain 130. The sprocket 129 is mounted directly on the upper end of the drivescrew 124.

The load-compensating system 115 includes a pair of hydraulic mechanisms 133 each of which comprises a single-ended piston 134 and piston rod 135 that is in rigid driving engagement with the ramhead 120, and a cylinder 136 housing the piston and defining a pressure-chamber 137 therefor. Hydraulic pressure is applied to the pressure chambers 137 through a feedline 138 from a recycling hydraulic fluid system 139, the feedline 138 being shown with a supply valve 140.

The hydraulic recycling system 139 includes a storage tank 141, a discharge line 142 leading from the bottom of the tank 141 and equipped with a hydraulic fluid pressure pump P and a return line 143 leading to the storage tank and equipped with an adjustable pressure-regulating valve 144. Thus, the pressure maintained in the recycling system is selectively adjustable to provide control of the pressure acting on the pistons 134 and thereby acting to assist advance of the ram head 120. Typically, the pressure and area relationships established in the compensating system 115 provide a compensating force to partially neutralize the opposing reaction force caused by pressurized electrolyte in the gap region. Thus, the load seen by the drive is limited to a range at which the drive system can produce a uniform advance of the electrode. Exact balance between the reaction force and the compensating force is not necessary so long as the load on the drive system is not excessive.

In the disclosed arrangement, the drive system load is monitored, and automatic adjustment of the hydraulic pressure is effected to maintain the drive system load within a prescribed range. For this purpose, a strain gauge 145 of any suitable type is mounted upon a transverse support arm 123A of the frame 123F to sense bending strain produced on the arm 123A by the effective drive system load. The strain gauge controls the operation of an amplifier 146 which governs the setting of the adjustable pressure-regulating valve 144.

When the bending strain sensed by the gauge 145 rises due to an increased electrolyte back pressure, the amplifier 146 progressively throttles the valve 144 to increase the pressure in the hydraulic-recycling system and correspondingly to increase the compensating force applied through the piston rods 135. When the bending strain drops below a predetermined minimum valve, indicative of overcompensation, the gauge 145 signals the amplifier 146 to open the valve 144 to effect a reduction of pressure in the hydraulic-recycling system and allow the drive system to accept its normal load.

A direct current power source is represented at 132 and is shown connected to the workpiece 106 and the electrode holder 104 in a sense to make the workpiece anodic and the exposed end face of the electrode cathodic.

In the general operation of the system, current flow is maintained through the pressurized electrolyte at the gap to erode the workpiece as the cavity-sinking electrode 102 advances. During this action, the high-reaction forces associated with the high-electrolyte pressures required for efficient demetallizing are partially balanced by the compensating force applied through the hydraulic mechanisms 133. Continuous control over the compensating action is effected by the strain gauge 145 and amplifier 146.

While the described system is effective for maintaining a steady advance of the electrode in the presence of minor or gradual variations in electrolyte pressure, sudden and significant pressure drops require a more rapid compensating system response. When the electrode breaks through the remote face of the workpiece, a sudden drop in the electrolyte back pressure results due to the interruption of the electrolyte throughflow path. The compensating force would immediately predominate and push the electrode against the workpiece to the damage of both parts, before an adjusting response through the strain gauge, amplifier and pressure valve system could occur.

In accordance with the present invention, sudden drops in electrolyte pressure are directly sensed, and controls are provided for directly and rapidly reducing the hydraulic pressure acting in the compensating system. For this purpose, a pressure-sensitive transducer such as piezoelectric element 147 (protected, of course, from corrosion by electrolyte) is mounted within the electrode holder 104 upstream of the gap to be exposed to the electrolyte pressure in the stream of electrolyte flowing to the gap and to produce a control signal proportional to such pressure. The hydraulic-compensating system has exhaust lines 148 leading from the cylinders 136 and equipped with pressure relief valves 149. Control signals from the transducer 147 are applied through a control circuit 150 adapted to pass rapid signal changes but not slow signal changes. Control circuit 150 is connected by control wires 151 to effect rapid opening of relief valves 149, in response to a rapid signal change from transducer 147, to relieve hydraulic pressure from the load-compensating system immediately upon sudden loss of electrolyte pressure at the transducer.

The relief of hydraulic pressure precludes any sudden forward thrust of the electrode, thereby preventing damaging impact with the workpiece. The sudden loss of pressure due to workpiece breakthrough usually occurs before the cavity is completely cleared of workpiece material. Upon loss of electrolyte pressure, the drive balance is restored by immediately relieving the hydraulic pressure on the compensating system, and the main drive system 114 continues its steady advance of the electrode accompanied by final erosion of the workpiece, all without any contact with the workpiece.

FIGS. 3 and 4 disclose another embodiment of the apparatus of this invention, which has a large electrode capable of being moved by a drive mechanism into a workpiece at a uniform rate of advance, and which also has load-compensating means for partially neutralizing the retroactive force generated by pressurized electrolyte located between the electrode and the workpiece. The load-compensating means comprises a chamber at the rear of the electrode into which pressurized fluid can be admitted to pressurize the back of the electrode, providing load-compensating force to neutralize a portion of the retractive force.

Electrode 201 is shown to be a large plate having a three-dimensional contour to its bottom surface. This type of electrode is typically used to prepare large dies having a contour to their working surface of shape generally complementary to the contour of the lower surface of the particular electrode used.

Electrode 201 is shown in adjacent relation with workpiece 203 which is shown already shaped by electrode 201 through operation of the apparatus. The workpiece rests on table 204, and is surrounded by insulating spacer 205, which has a central space in which the workpiece closely fits. Spacer 205, in turn, abuts against wall 207 which serves as a position-locating means for the workpiece along one horizontal axis, while one or more pins 208 (seen in FIG. 4) serve to locate the workpiece along a second horizontal axis. Thus, workpiece 203 can be precisely positioned under the electrode by simply abutting it against wall 207 and pins 208.

Sockets 210 are used to hold pins 208. Only one socket 210 is shown in use, the remaining sockets being put to use when it is desired to position a workpiece of different size or to position a workpiece at a different location.

In the embodiment shown, the workpiece is sufficiently large and heavy so that no means for positively holding it in one position is required.

Table 204 carries conventional airlift devices 211 to facilitate the sliding of workpiece 203 on and off table 204.

Electrode 201 is held by adapter plate 212, which, in turn, is carried by electrode mount 213, to constitute a cathode member. Apertured plate 214 is held between plate 212 and mount 213. Mount 213 is stiffened and rendered inflexible by a plurality of vertical fins 215 which extend from the mount 213 to push rod 217, which is shown to be an integral part of mount 213. The horizontal area of push rod 217 is substantially less than the horizontal area of mount 213 for a reason explained below.

A ramhead 219 is affixed to the top of push rod 217, and ram head 219 is in turn affixed to a conventional ram (not shown), which is typically operated in the manner of FIGS. 1 or 2 by a drivescrew, a thrust bearing, and a motor to provide a uniform rate of advance of the electrode 201 toward the workpiece 203 during electrochemical machining.

While only one push rod 217 is shown in this embodiment, it is contemplated that a plurality of push rods can be used in this invention to engage electrode mount 213 so that the electrode can be advanced with a minimum of bending due to electrolyte back pressure. A plurality of push rods would desirably be used in cases where electrode 201 and mount 213 are of exceptionally large area.

Cover 221 surrounds push rod 217 and is affixed to wall 207 and other supports 223, typically by bolts, to define a pressure chamber 225 in cooperation with the back side 226 of electrode mount 213. Stress members 222 limit bulging of the cover when chamber 225 is heavily pressurized. Push rod 217 extends through an aperture in the top of cover 221 in sliding relation thereto to permit push rod 217, mount 213, and electrode 201 to be raised and lowered with respect to cover 221 and the workpiece 203.

Plungers 227 can be inserted into recesses 229 in push rod 217 to hold the push rod 217 and cover 221 together. The cover 221 can then be unbolted from wall 207 and supports 223, and the push rod and cover can be raised together to obtain access to the workpiece 203.

In the embodiment shown in FIGS. 3 and 4, pressurized electrolyte is fed through inlets 231, passing through the region 233 between electrode 201 and insulating spacer 205, and from there passing to work gap 235 between electrode 201 and workpiece 203. The pressurized electrolyte is drained from the work gap 235 by electrolyte flow channels which comprise slots 236, some of which lead into chambers 237. The electrolyte passes into slots 236, through electrode 201, and into horizontal channels 239 (best seen in FIG. 4) in the adapter plate 212. Channels 239 are closed at their ends.

The pressurized electrolyte passes along horizontal channels 239 to a point underneath an aperture 219 in plate 214. The electrolyte then flows through apertures 216 into one of a plurality of radial channels 241, formed in the interior of electrode mount 213, and which pass over horizontal channels 239. The electrolyte then passes from radial channels 241 into vertical channels 243 in push rod 217 and out of the device by exit ports 245. In the disclosed embodiment, eight radial channels 241 diverge in an equiangular manner out from push rod 217 to pass over horizontal channels 239.

If desired, the apertures 216 in plate 214 can be so arranged that electrolyte flowing into slots 236 in high areas 255 of electrode 201 (see FIG. 3) is transported to different radial channels 241 and vertical channels 243 than the electrolyte flowing into slots 236 which are located in low areas 257 of the electrode.

The advantage of this is that the channels 243 which carry electrolyte from slots 236 located in low areas 257 of the electrode can then be blocked to prevent the flow of electrolyte during the initial stage of electrolytic machining, before the workpiece has substantially assumed the configuration of the working face of the electrode.

The reason that this is desirable is that, in the initial stage, high areas 255 are in close proximity with the workpiece 203, but low areas 257 are not, leaving wide spaces at various places between the electrode and the workpiece. Depending upon the configuration of the electrode, it is possible that wide channels between the electrode and the workpiece can become accessible to the electrolyte to permit it to flow through the electrode and out of the apparatus without being forced under high pressure between the narrow work gap 235, which at this point exists only in the vicinity of high areas 255. This can cause the electrolyte pressure to drop substantially, interfering with the operation of the apparatus.

To counteract this, the above modification can be used in conjunction with valves to close those vertical channels 243 which connect with slots 236 in the low areas 257 of the electrode, to prevent the flow of electrolyte therethrough. After sufficient electrolytic demetallization has taken place in the vicinity of high areas 255 to cause the workpiece to assume the general configuration of electrode 201, the valves are opened to permit electrolyte to flow through slots 236 in low areas 257. Electrolytic demetallization then takes place uniformly over the entire working face of the electrode.

Pressurized electrolyte which is passed into the apparatus by inlets 231 also passes into pressure chamber 225 via the passage 246 defined between the periphery of adapter plate 212 and electrode mount 213, and cover 221. Pressurized electrolyte is prevented from escaping chamber 225 between push rod 217 and the wall of the aperture in cover 221 through which rod 217 passes by annular seal 247. Seal 247 is carried by cover 221 and surrounds push rod 217, providing a pressure seal through which the push rod can slide. A seal to prevent the escape of electrolyte can also be placed between the bottom of cover 221 and insulating spacer 205.

Thus, as pressurized electrolyte is provided to the work gap 235 to permit the flow of electric current between electrode 201 and workpiece 203 for demetallizing and shaping the workpiece, pressurized electrolyte also flows into chamber 225. The back pressure against electrode 201 which is created by pressurized electrolyte in work gap 235 is thus partially neutralized by a forward pressure exerted on back 226 of the electrode mount 213 by pressurized electrolyte in chamber 225. The resulting back pressure which is sensed by push rod 217 and the drive means for the rod is theoretically the product of the mean pressure of the electrolyte in work gap 235 multiplied by the transverse area of push rod 217, since the back pressure of electrolyte in work gap 235 against the remaining area of electrode 201 and the other parts exposed to electrolyte back pressure is counterbalanced by the electrolyte pressure on back 226 of the electrode mount.

In the event of a change in electrolyte pressure in the system, caused, for example, by a failing or shutting off of the

pump sued to provide pressurized electrolyte, the drop in electrolyte pressure at the work gap 235 and chamber 225 takes place in an essentially simultaneous manner, since there is an electrolyte conduit permitting free flow of electrolyte between the two regions. Thus the danger that a drop in pressure at the work gap may cause the load-compensating means to overbalance the system and drive the electrode 201 into damaging contact with workpiece 203 is essentially eliminated.

Direct electric current passes through the apparatus in a sense to make electrode 201 cathodic with respect to workpiece 203. Cables 249 and 251 (shown in FIG. 4) connected the apparatus with a source of electric current. The current passes between the cables by way of table 204. Workpiece 203, work gap 235 through which pressurized electrolyte passes, electrode 201, plates 212 and 214, mount 213, push rod 217, and ram head 219.

The underside of table 204 is shown to be covered with an insulating pad 253 to prevent short circuits, and the top of ram head 219 typically contains a similar insulating pad (not shown) to prevent the passage of electric current into the ram and drive means. Other insulating members are spacer 205, wall 207, and supports 223, which prevent the direct flow of electric current between table 204 and cover 221, limiting the current flow path to travel through workpiece 203 and work gap 235. The insulating members used herein can typically be made of composites of epoxy resin and glass fiber.

Another embodiment of this invention is shown in FIGS. 5 through 7. The basic plan and function of the apparatus shown therein is similar to the apparatus of FIGS. 3 and 4, except that the electrolyte flow path is somewhat different. Corresponding reference characters is the "300" series are used to identify corresponding parts.

Electrode 301 is shown in adjacent relation to workpiece 303, which is shown in an advanced stage of electrolytic machining, wherein the upper surface of workpiece 303 conforms to the lower surface of electrode 301. Workpiece 303 rests upon table 304, and the workpiece is surrounded by insulating spacer 305.

Electrode 301 is held by adapter plate 312 to electrode mount 313, with apertured plate 314 mounted between them. Mount 313 is carried by push rod 317, which extends through an aperture (not shown) in cover 321 to define a pressure chamber 325. As in the embodiment of FIGS. 3 and 4, pressurized electrolyte is permitted to flow into pressure chamber 325 to press against the back 326 of electrode mount 313 to partially neutralize the retractive force created by pressurized electrolyte at the work gap 335 between electrode 301 and workpiece 303.

Pressurized electrolyte enters the apparatus of FIGS. 5 through 7 at inlet 331 to pass into chamber 325 and also to pass horizontally above spacer 305 into the loop-shaped passage 346 between adapter plate 312 and cover 321. Electrolyte also passes into the outer portions of work gap 335.

The electrode of this embodiment has alternating slots 336*a* and *b* and outlets 337, while the adapter plate 312 has alternating horizontal channels 339*a* and *b*. Channels 339*b* only lead under apertures 316 in plate 314 to permit flow of electrolyte between each horizontal channel 339*b* and a radial channel 341, which, in turn, leads into a vertical channel 343. There is no aperture connecting channels 339*a* with radial channels 341.

As described above, the apparatus of FIGS. 5 and 6 is quite similar to the apparatus of FIGS. 3 and 4, differing primarily in the arrangement of apertures 316 in plate 314. A major difference between this and the previous embodiment is that horizontal channels 339*a* in this embodiment pass through the sidewall of adapter plate 312 to define electrolyte entry ports 344 (shown in FIG. 6) for receiving pressurized electrolyte which occupies the passage 346 (shown in FIG. 5) between adapter plate 312 and cover 321. The pressurized electrolyte flows into the horizontal channels 339*a* from entry ports 344, the electrolyte flowing along channels 339*a* and then downwardly and out slots 336*a* into the work gap 335. The slots 336*a* thus constitute electrolyte inlet channels.

The electrolyte then migrates along the work gap 335 to a slot 336*b* in the electrode which serves as an outlet channel for the electrolyte from the work gap. The electrolyte passes upwardly through these slots, through chambers 337, to one of horizontal channels 339*b*, along which it passes until it encounters an aperture 316 in plate 314, flowing through the aperture into a radial channel 341. From there it flows into a vertical channel 343 and out of the apparatus.

Thus, this embodiment of the apparatus provides an electrolytic machining apparatus in which the electrolyte is both fed into and removed from the work gap by electrolyte channels which lead through the electrode. An advantage of this is that electrolyte is provided to work gap 335 at points distributed across the face of electrode 301, rather than only at the periphery as in the embodiment of FIGS. 3 and 4. This reduces the possibility of an electrolyte shortage at the center of the work gap 335.

In another embodiment of the apparatus of this invention, insulating spacer 305 can be modified to tightly fit against the side of electrode 301, to prevent fluid flow between inlets 331 and work gap 335. Electrolyte entry ports 344 are also sealed. The apertures 316 in plate 314 can be so arranged in conjunction with radial channels 341 and horizontal channels 339 that electrolyte can be pumped down some of the vertical channels 343 (shown in FIG. 6) to pass out some of the slots 336 in the electrode, passing across work gap 335 to be collected in other slots 336. The electrolyte then passes into other horizontal channels 339, radial channels 341, and vertical channels 343, and out of the apparatus.

Two separate pressurized fluid systems are used in this particular embodiment, one consisting of pressurized electrolyte flowing to and from the work gap 335 via separate vertical channels 343 in the push rod 317, and the other system consisting of electrolyte or another fluid passing through inlet 331 into chamber 325 to provide load-compensating force to the back 326 of the electrode.

In this embodiment, a separate control system is generally required to rapidly cut off the pressure of the fluid in chamber 325 upon a drop in the pressure of the electrolyte at work gap 335 in order to prevent electrode 301 from moving forward into damaging contact with workpiece 303 upon a drop in electrolyte pressure at the work gap 335. This can be accomplished through the use of a valve in cover 321 connected to a pressure-sensing means, similar to the arrangement shown in FIG. 2. From the foregoing, it will be observed that numerous variations and modifications may be effected without departing from the true spirit and scope of the novel concept of the invention. It is, of course, intended to cover by the appended claims all such modifications as fall within the scope of the claim.

What is claimed is:

1. In electrolytic machining apparatus, mounting means for locating a shaping cathode in predetermined position with respect to a conductive metal workpiece to define a gap therebetween; means for flowing electrolyte between the cathode and the workpiece and through said gap under positive pressure, the electrolyte pressure tending to produce relative retraction between the cathode and the workpiece, drive means connected to said mounting means for producing relative movement of the cathode toward the workpiece in the presence of the electrolyte pressure; and load compensating means cooperating with said drive means and separate and spaced from said mounting means for at least partially opposing said tendency to relative retraction and responsive to said electrolyte pressure, to be rendered inactive upon loss of said electrolyte pressure.

2. In electrolytic machining apparatus, mounting means for locating a shaping cathode in predetermined position with respect to a conductive metal workpiece to define a gap therebetween, means for flowing electrolyte between the cathode and the workpiece and through said gap under positive pressure; the electrolyte pressure tending to produce relative retraction between the cathode and the workpiece; drive means for causing relative movement of the cathode toward

the workpiece along a path that determines the shaping of the workpiece and in the presence of the electrolyte pressure; load-compensating means for providing opposing force to counteract at least a portion of the force tending to cause relative retraction between the cathode and the workpiece; said load compensating means being separate and spaced from said mounting means; and means connected in load controlling relation to said compensating means directly responsive to electrolyte pressure between the cathode and the workpiece for actuating said low compensating means in response to elevated electrolyte pressure and for relieving the load compensating means upon a decrease in said electrolyte pressure.

3. In electrolytic machining apparatus, mounting means for locating a shaping cathode in predetermined position with respect to a conductive metal workpiece to define a gap therebetween; means for flowing electrolyte between the cathode and the workpiece and through said gap under positive pressure, the electrolyte pressure tending to produce relative retraction between the cathode and the workpiece; drive means for moving the cathode toward the workpiece in the presence of the electrolyte pressure; load-compensating means for at least partially opposing said tendency to relative retraction between the cathode and the workpiece, and means connected in load-controlling relation to said compensating means and directly responsive to electrolyte pressure between the cathode and the workpiece for rapidly relieving the load-compensating means upon a sudden decrease in said electrolyte pressure.

4. In electrolytic machining apparatus, mounting means for locating a shaping cathode in predetermined position with respect to a conductive metal workpiece to define a gap therebetween; means for flowing electrolyte between the cathode and the workpiece and through said gap under positive pressure, the electrolyte pressure tending to produce relative retraction between the cathode and the workpiece; drive means for producing relative movement between the cathode and the workpiece in the presence of the electrolyte pressure; load-compensating means responsive to said tendency to relative retraction to at least partially oppose the same; said load-compensating means comprising at least one piston and cylinder mechanism interposed between relatively movable elements of said drive means and means for directing pressured fluid to said cylinder.

5. In electrolytic cavity-sinking apparatus, a hollow, electrically conductive electrode adapted to be advanced toward and into an electrically conductive and electrochemically erodable workpiece to establish a work gap for flow of high-pressure electrolyte to support electrolytic current flow between said workpiece and said electrode; means for establishing an electrolyte flow path passing through said electrode and having said gap located intermediately therein; means for flowing electrolyte under positive pressure through said path, the electrolyte pressure between the cathode and workpiece tending to produce relative retraction movement between the cathode and the workpiece; means for passing low voltage, high-density direct current between the cathode and the workpiece in a sense to make the workpiece anodic, and drive means for producing relative movement between the cathode and the workpiece in the presence of the electrolyte pressure, the improvement of load-compensating means for opposing reacting against said drive means due to electrolyte pressure along said path, said load-compensating means being spaced from said electrode and connected to said drive means, said load-compensating means being directly responsive to electrolyte pressure between the cathode and the workpiece and rendering the load-compensating means inactive upon sudden escape of electrolyte from said path at the region of said gap.

6. The apparatus of claim 5 wherein said load-compensating means is hydraulic and includes piston means operable in cylinder means to define a pressure chamber communicating with said path to be actuated by electrolyte under positive pressure from said path.

7. The apparatus of claim 5 wherein said load-compensating means is hydraulic and includes piston means operable in cylinder means to define a pressure chamber communicating with said path upstream of said gap to be actuated by electrolyte under positive pressure from said path.

8. The apparatus of claim 5 wherein said load-compensating means includes a separate hydraulic fluid-pressure system having pressure-control means responsive to load reaction at said drive means to maintain predetermined balance during gradual variations in electrolyte pressure in said path.

9. The apparatus of claim 5 wherein said load-compensating means further includes load control means comprising a pressure-sensitive transducer exposed to electrolyte pressure at a region upstream of said gap to sense sudden variations in electrolyte pressure in said path.

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