United States Patent

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[33] **Japan**
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Continuation-in-part of application Ser. No. 859,532, Apr. 21, 1969, now Patent No. 3,533,928, which is a continuation of application Ser. No. 598,391, Dec. 1, 1966, now abandoned. This application Mar. 19, 1968, Ser. No. 714,252

[54] **METHOD OF AND APPARATUS FOR THE DEBURRING OF WORKPIECES**
13 Claims, 11 Drawing Figs.

[52] **U.S. Cl.** **204/202,** 204/213, 204/199, 204/198, 204/201
[51] **Int. Cl.** **B01k 3/00,** C23b 3/00, C23b 3/06
[50] **Field of Search** 204/212, 213, 214, 201, 204, 202, 203, 205, 200; 134/120, 121, 159; 259/89; 51/163, 13; 118/418, 602

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ABSTRACT: Apparatus for the electrochemical deburring of metallic workpieces in which a drum of endless band forms a continuously displaceable surface for the workpieces which, together with carbon particles and/or other abrasive particles, are agitated in an electrolyte. The drum is rotated about its horizontal axis while a pair of disks form electrodes closing the drum. When the endless belt is used, it then passes into a vessel retaining the electrolyte and thereafter carrying the workpieces to a collecting trough while carbon particles are continuously added or removed from the system whose electrodes are connected in pair to respective phases of the power supply. A drum system may also have a perforated-wall drum or other means for enabling gases to be withdrawn from the system while a stationary vessel system may effect the agitation of the electrolyte by pulsed jets. A gas is injected into the electrolyte to distribute the electric current path more uniformly and dilute nascent gases produced by electrolysis.

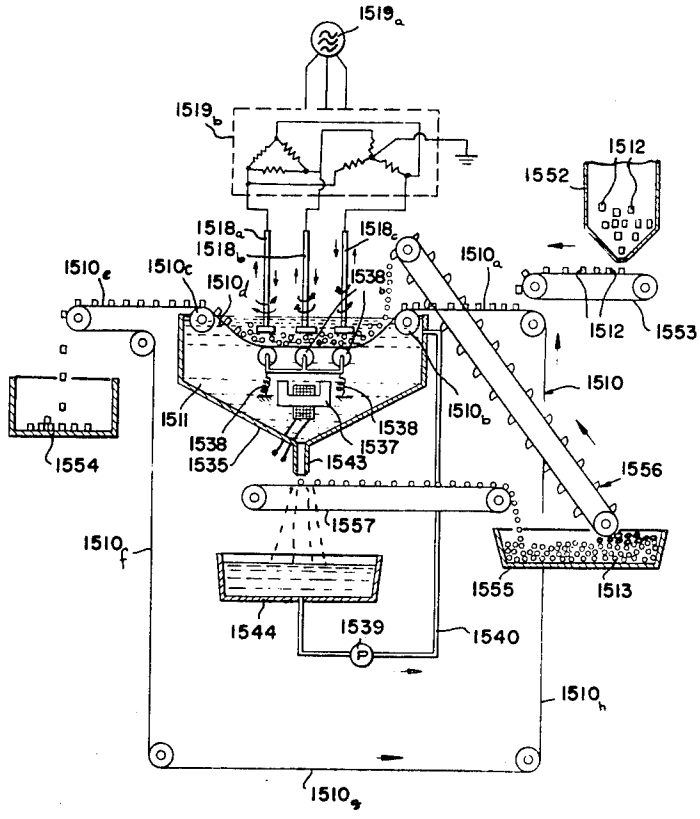
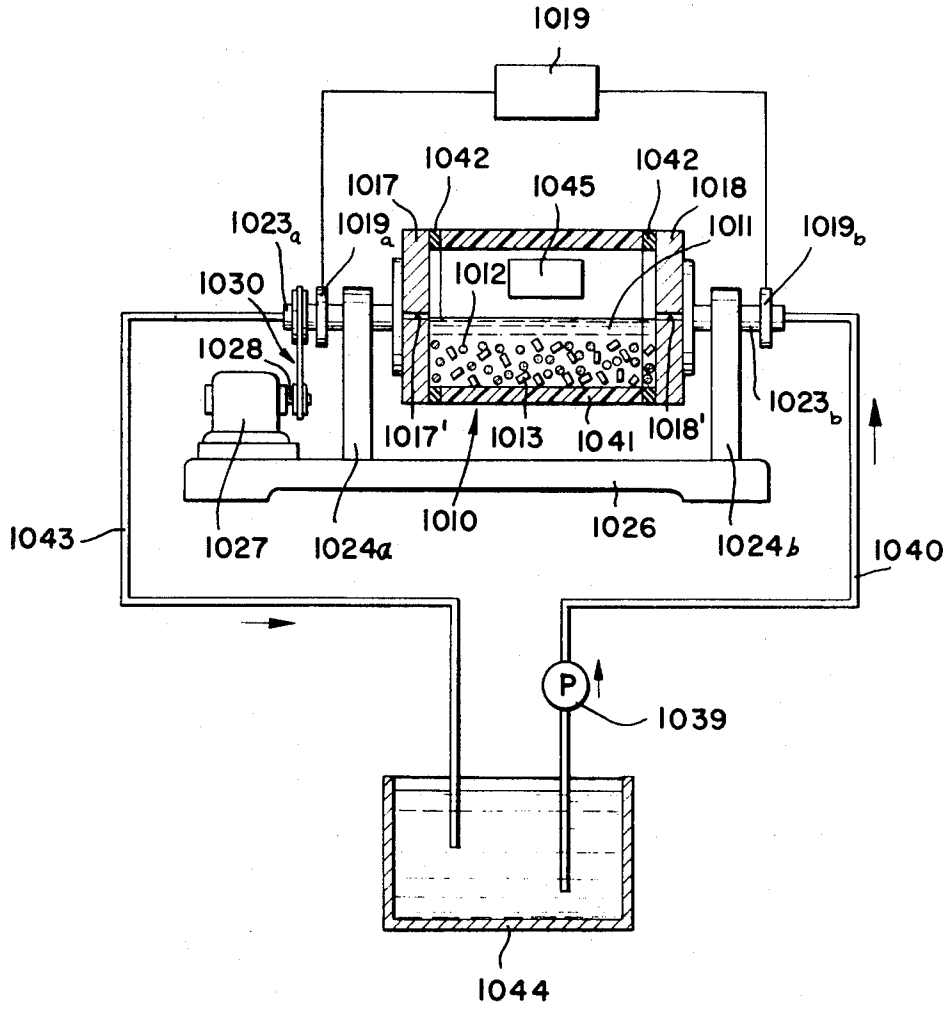


FIG. 1



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FIG.2A

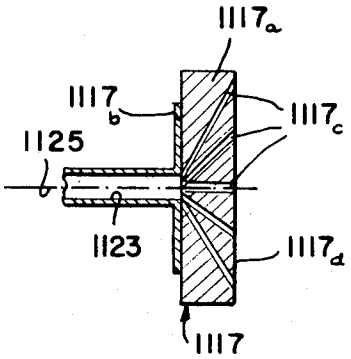


FIG.2B

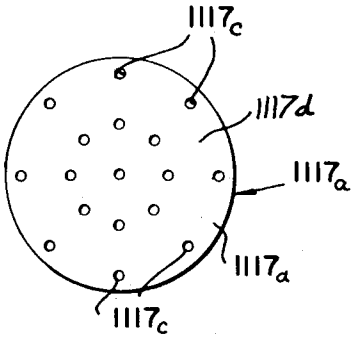


FIG.3A

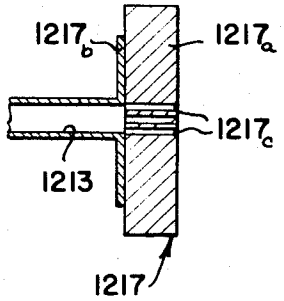
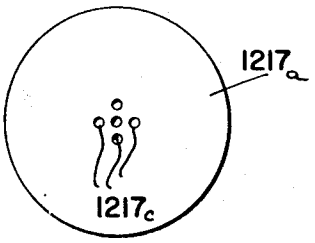


FIG.3B



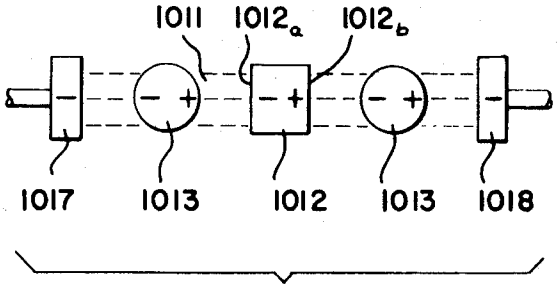


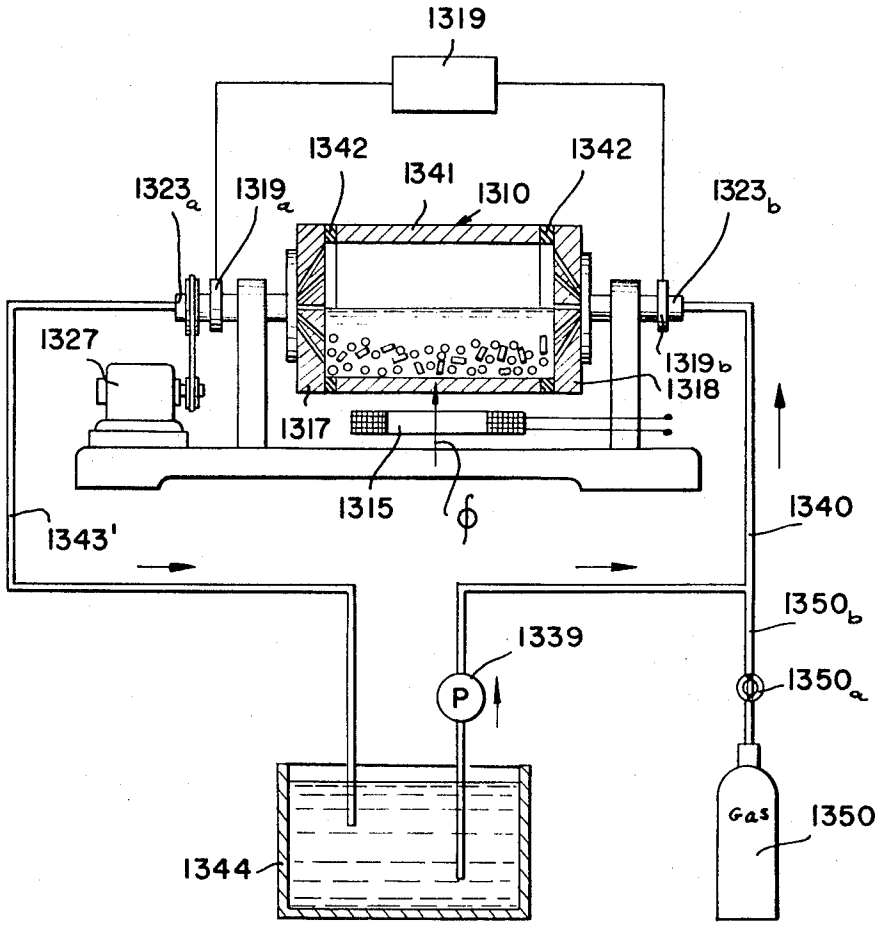
FIG.4

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FIG. 5



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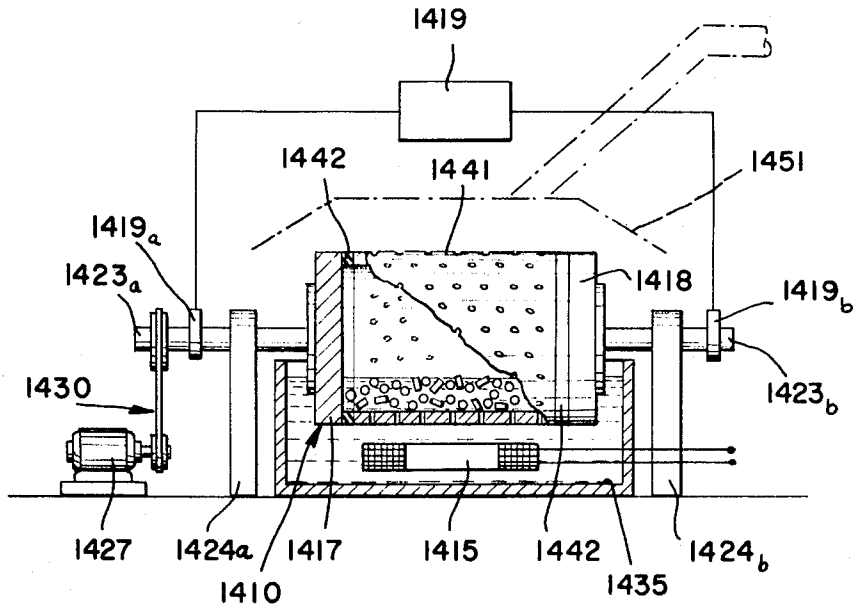


FIG. 6

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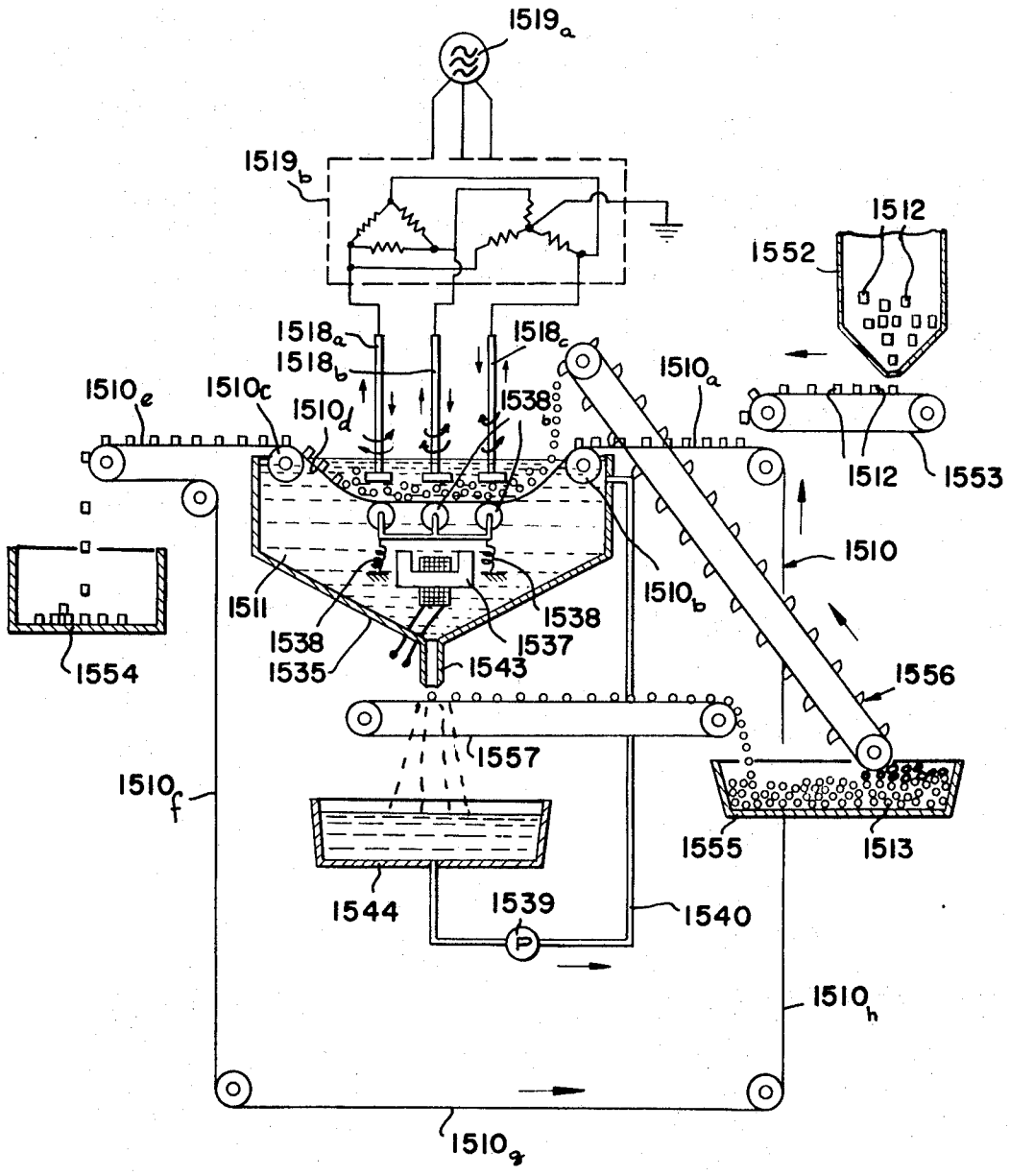


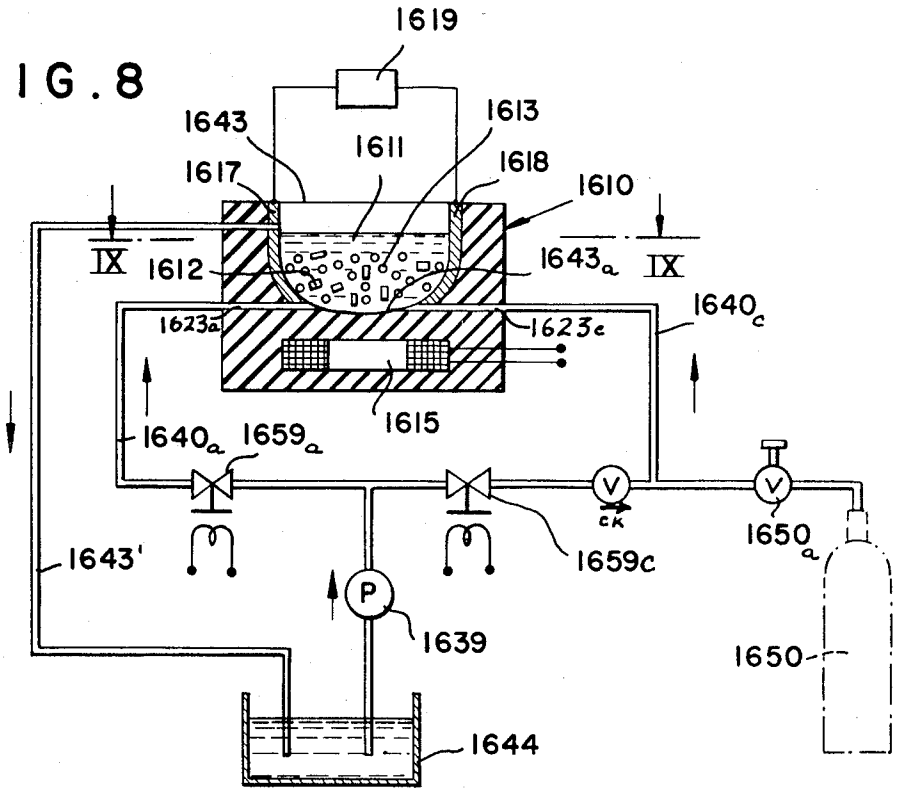
FIG. 7

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FIG. 8



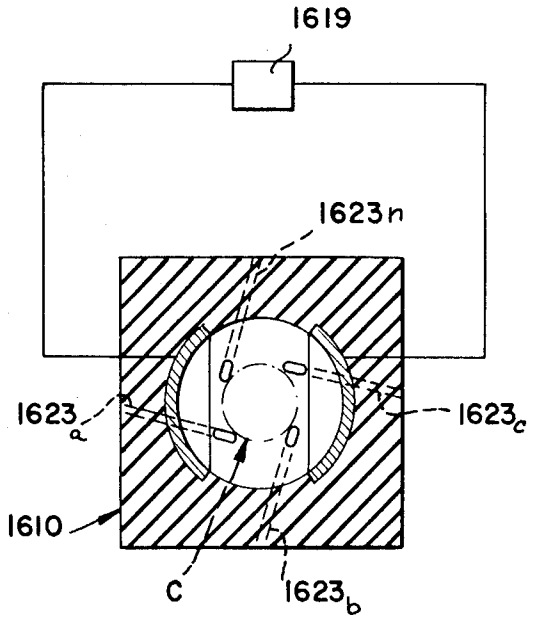


FIG. 9

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METHOD OF AND APPARATUS FOR THE DEBURRING OF WORKPIECES

This application is a continuation-in-part of application Ser. No. 859,532, Apr. 21, 1969, now Patent No. 3,533,928, which is a continuation-in-part of application Ser. No. 598,391 filed 1 Dec. 1966.

My present invention relates to a method of and an apparatus for the deburring of metallic and other conductive workpieces whereby surface irregularities of such workpieces are eliminated.

Deburring apparatus of several types are commonly in use in the metal-working field, primarily for the removal of surface irregularities in cast, machined and molded metallic workpieces. For the most part, such apparatus includes a tumbling drum provided with agitating means for repeatedly casting the workpieces, generally in a liquid vehicle and sometimes in the presence of an abrasive, into contact with one another, against the walls of the vessel or drum or into contact with other bodies (e.g. of abrasive material) mixed with the charge in the drum. This tumbling action mechanically dislodges adherent materials while rounding off irregular portions and projections integral with the metallic bodies. These systems, however, are relatively slow and even defective when the deburring operation is to remove substantial amounts of material.

It is, therefore, the principal object of the present invention to extend principles originally set forth in the above-identified copending application and to provide a method of deburring metal workpieces whereby the rate of material removal and the surface finish of the treated objects is significantly increased and improved.

Another object of this invention is to provide relatively simple and inexpensive apparatus for a high rate deburring of metallic workpieces while yielding a relatively high-quality surface finish.

Yet another object of this invention is to provide a method of and an apparatus for the deburring of relatively large-dimension workpieces of such nature that tumbling may be impractical.

These objects and others which will become apparent hereinafter are attained, in accordance with the present invention, by a method of deburring metallic workpieces in which the liquid vehicle is agitated in contact with the workpiece to be deburred while mechanical contact between the surfaces of the latter and at least some other bodies is carried out concurrently with an electrochemical material-removal step. As set forth in application Ser. No. 598,391, I have found, surprisingly, that electrochemical techniques hitherto used primarily for the electrochemical machining (ECM) and electrochemical grinding (ECG) of metallic bodies, wherein close tolerances are a necessity, can be used effectively in conjunction with a tumbling or agitating operation to debur metallic workpieces or objects having electrolytically soluble surface portions. The surprising nature of this discovery will become all the more apparent when it is recognized that the present method does not require a stationary electrode urged against the workpiece or juxtaposed therewith via a predetermined machining gap.

In accordance with the principal feature of this invention, an electrochemical machining current, which may be direct or periodic (e.g. raw-rectified alternating current, pulsating direct current and ordinary AC) is passed through the liquid vehicle which is constituted as an electrolyte and may contain abrasive particles or merely additional bodies to facilitate mechanical deburring of the workpieces concurrently with the electrochemical action. While, in some cases, the workpiece may be stationary and is connected with a pole of the electrochemical machining sources, I have found that it is not necessary to connect the workpieces directly thereto, and that the more tumbling of such workpieces in an electrolyte and in a drum having spaced-apart contact portions bridged by the electrolyte but not shortcircuited by the drum itself, can effect electrochemical removal of material from the workpiece surfaces.

While I do not wish to be bound by any theory in this regard

and the precise reasons why the current flow through the electrolyte is effective to remove material from the surfaces of the conductive workpieces are not yet clear, it may be hypothesized that each of the workpieces acts as an electrode for the machining of others or as objects undergoing electrolytic erosion against other conductive bodies. Since electrolytic oxidation of the workpiece at its surface is essentially nonreversible in the sense that agitation and mechanical action of the electrolyte carries away the oxide film as soon as it is formed and, even upon electrical (polarity) reversal, metal is not materially redeposited from the oxide onto the machine surface, the electrolytic action is carried out as if a wire were directly connected to each workpiece.

According to a more specific feature of this invention, the agitation of a multiplicity of workpieces is effected in a tumbling drum which may be provided at its base with one electrode portion and with a second contact or electrode, at a location spaced therefrom but in contact with the electrolyte, the electrodes being connected across an AC or DC electrochemical-machining source e.g. of the type described and illustrated in any of my copending applications Ser. No. 512,338, (U.S. Pat. No. 3,475,512) Ser. No. 535,268, (U.S. Pat. No. 3,417,006) Ser. No. 562,857, No. 3,420,759) filed 8 Dec. 1965, 19 Jan. 1966 and 5 July 1966, respectively. The tumbling drum can be upwardly open and rotatable about an axis tilted upwardly at an angle of, say, 30 degrees from the horizontal. In this case, the agitation is effected purely by rotation of the drum.

I have also found it to be possible, in conjunction with such a tumbling drum, or when a stationary vessel is employed, to effect the agitation at least in part by magnetic means. Thus, if the workpieces treated in the deburring operation or the other bodies involved are magnetically permeable, I apply a magnetic field to them so as to effect their displacement in the electrolyte. I also may distribute in the deburring vessel among the workpieces, particles or bodies of a magnetically permeable material. Such bodies may be abrasive or electrically conductive to facilitate electrochemical erosion of the workpieces or produce the friction necessary for the deburring action. In fact, the particles or bodies serving as the agitating means need not be magnetically permeable under some circumstances, since the particles in the electrolyte tend to respond to a rapidly changing magnetic field by rotating about the axis thereof. Thus, agitation may be promoted with the aid of conductive as well as magnetically permeable particles. According to still another feature of this aspect of the invention, the particles which are magnetically or electrically displaceable in the liquid vehicle, can be coated with abrasive material, incorporated in or mixed with abrasive particles which are not influenced by an electromagnetic field.

Preference is given, in accordance with this invention, to pulsating or alternating electromagnetic fields for controlling the movement of particles and inducing electrochemical erosion of the workpiece surfaces since purely direct current has a tendency to produce agglomeration of magnetic particles in the deburring vessel.

According to another aspect of the basic invention, more fully described in application Ser. No. 598,391, the agitation is carried out by rotating an electrode immersed in the electrolyte by, for example, rotating an electrode member in an irregular die cavity to deburr the machined surfaces thereof. Abrasive particles are here included in the deburring vehicle while an electrolytic machining current is applied between the workpiece and this rotating element. Inasmuch as this electrode member is not closely juxtaposed with the workpiece surface and is rotated relatively rapidly, a more or less uniform surfacing is effected. In accordance with this aspect of the invention, I prefer to incorporate in the vehicle a multiplicity of conductive particles which here act as intermediate electrodes and as they are dispersed by the agitation into the rotation of the die surfaces, each particle acts as an individual electrode to facilitate smoothing of the die surface. The rotary electrode member imparts a centrifugal force to the abrasive and conductive particles contained within the electrolyte so that these

particles are dynamically urged outwardly and forcefully brought into contact or close juxtaposition with the surfaces to be treated to augment the resulting mechanical deburring action.

According to yet another aspect of this invention, deburring is carried out as augmented by a magnetic field pressure which, when combined with the dynamic flow of rapidly moving particles, with the centrifugal force of tumbling or electrolyte displacement by a stirrer and with gravitational forces, magnetically urges the abrasive bodies against the workpieces and the workpieces against one another. This magnetic field pressure is, advantageously, supplied by electromagnetic means disposed externally of the deburring vessel and capable of applying inward magnetic forces to the magnetically permeable particles and workpieces. When the abrasive particles or auxiliary bodies serving to facilitate mechanical removal of irregularities and projections upon the workpieces are magnetically permeable and/or the workpieces are of such permeability, a high frequency magnetic field applied from without, in accordance with this invention, induces an oscillation and/or a magnetostrictive expansion and contraction of the bodies so that the simple tumbling action is accompanied by a magnetic vibration or pulsation of the body to improve the erosive operation. In this connection it can also be stated that the field may be of such nature that vibration of the individual particles by the magnetic field is coupled with a tumbling action of a rotary drum or a vibration thereof to increase the mechanical abrasion.

Another feature of this invention resides in the use of chemical action in removing surface irregularities in combination with the electrochemical and mechanical deburring action as described above. Thus I have found that surprisingly effective results can be obtained when a chemical mordant or etchant for the workpiece material is incorporated in the electrolyte. For as yet unknown reasons, the surface finish and deburring rate obtained when, for example, ferric chloride is used as the chemical etchant in the electrolyte, is better than that which would be expected with either the etchant or the electrochemical action alone, while the rate of material removal exceeds the sum predictable from the individual actions of the etchant and the electrochemical erosion.

According to a further feature of the present invention, the electrochemical deburring of metallic workpieces is carried out concurrently with agitation of the bodies in an electrically nonconductive tumbling drum rotatable about a recumbent axis (preferably horizontal or near horizontal) containing liquid electrolyte and the conductive (i.e. carbon) particles, together with the workpieces as described therein. A pair of electrodes are in constant contact with the electrolyte during rotation of the drum and are preferably disposed at remote ends of the electrolyte bath and are composed of a material insoluble in the electrolyte and free from electrolytic attack thereby. I have surprisingly found that excellent results can be attained when the conductive electrodes are constituted by the end walls of the drum and rotate therewith, the cylindrical drum wall forming the insulating spacer for these electrodes. At least one but preferably both of these end walls are provided with a passage for circulating the electrolyte through the drum, the axial passage terminating in a fanlike array of bores opening into the drum at the face of the end wall contacting the electrolyte. The drum may further be provided, at least at regions extending above the electrolyte level therein with apertures or vents enabling evacuation of the gaseous products of the electrolytic deburring of the workpieces.

Still another aspect of this invention resides in my discovery that irregular deburring can be avoided by injecting an inert gas into the electrolyte bath with the recirculating electrolyte stream. It appears that the inert gas creates labyrinthian paths for the electric current flowing through the electrolyte, i.e. the ion mobility paths, thereby distributing the electrochemical action substantially uniformly. This technique has the additional advantage that the inert gas upon evolution from the electrolyte acts as a diluent for the nascent gases generated by electrolysis and let off through the vents above the electrolyte level. The inert gas may be admixed with the electrolyte in the bath or with the liquid prior to its introduction into the tumbling drum. Furthermore, in accordance with the principles already discussed above in general terms, I provide a magnetic flux radially through the drum, i.e. vertically when the drum is horizontal, preferably at a location intermediate the electrode, to facilitate the agitation of the electrolyte, the workpieces, and the carbon particles forming intermediate electrodes for the deburring action. These carbon particles have an abrasive or semiabrasive character so that they mechanically cooperate with the workpieces to supplement the electrochemical deburring by mechanical erosion of the rough surfaces. Thus the carbon particles may be carbonaceous materials of relatively high hardness (e.g. synthetic diamond as produced by the system described in my U.S. Pat. No. 3,207,582 or the non-diamond but high-hardness carbon particles obtained when synthetic diamond is made in accordance with that process).

The above and other objects, features and advantages of the present invention will become more readily apparent from the following description, reference being made to the accompanying drawing in which:

FIG. **1** is an axial cross-sectional view through a tumbling drum of a deburring apparatus in accordance with this invention;

FIG. **2A** is an axial cross-sectional view of an electrode forming an end wall of the drum;

FIG. **2B** is an elevational view thereof;

FIG. **3A** is a cross-sectional view through a modified electrode;

FIG. **3B** is an elevational view of this latter electrode;

FIG. **4** is a diagram of the electrochemical deburring system of the present invention;

FIG. **5** is a view similar to FIG. **1** of a modified system for deburring metallic workpieces;

FIG. **6** is an axial cross-sectional view through a tumbling system embodying other principles of this invention;

FIG. **7** is a diagram of a continuous deburring apparatus in accordance with the principles of this invention;

FIG. **8** is an axial cross-sectional view through a deburring apparatus using a stationary system and diagrammatically showing the electrolyte-circulating means therefor; and

FIG. **9** IS A cross-sectional view along the line IX—IX of FIG. **8**.

In FIG. **1**, I show a rotary tumbling system for the deburring of metallic workpieces in which a closed drum **1010** has a pair of end walls **1017** and **1018** forming electrodes and retaining the electrolyte **1011** in the drum. Between the conductive electrodes **1017** and **1018**, the drum is formed as a nonconductive sleeve **1041** composed of or lined with electrically insulating material such as a hard rubber or an electrolyte-resistant synthetic resin (e.g. a polyacrylate). Electrically insulating rubber gaskets **1042** are provided between the drum body **1041** and the electrodes **1017** and **1018**. The drum may also be formed with a door **1045** to permit the workpieces and intermediate electrodes to be introduced into the interior of the drum. The electrodes **1017** and **1018**, which are inert to the electrochemical action and to the electrolyte, are composed of graphite or an insoluble metal (e.g. stainless steel or monel). The drum **1010** is mounted upon a pair of trunnions **1024***a* and **1024***b* extending upwardly from a base **1026** and defining for the drum a horizontal axis. The drum is, in turn, carried by a pair of tubular shafts **1023***a* and **1023***b* affixed to the respective electrode end walls **1017** and **1018** as described in connection with FIGS. **2A**, **2B** and FIGS. **3A**, **3B**.

The drive means for the drum comprises a motor **1027** whose output shaft **1028** is connected by a V-belt transmission **1030** with the hollow shaft **1023***a* to rotate the drum about its horizontal axis. The electric current for the electrochemical deburring operation is provided by a power supply **1019** and is applied via a pair of brushes **1019***a* and **1019***b* to the electrodes **1017** and **1018** via their shafts **1023***a* and **1023***b*. Electrolyte is circulated through the drum by a pump **1039** and a

circulating system including an inlet pipe **1040** connected with the tubular shaft **1023***b*. The tubular shaft **1023***a* leads electrolyte from the drum to a return tube **1043** ending at a surface **1044**.

The electrode **1017** and **1018** may be provided with a fan-shaped array of bores (FIGS. **2A** and **2B**) or a central array of mutually parallel bores (FIGS. **3A** and **3B**), while means may be provided for injecting a gas into the liquid-circulating stream (FIG. **5**) and a magnetic field may be applied in the radial direction (FIGS. **5** and **6**). In the embodiment illustrated in FIG. **1**, however, the end walls and electrodes **1017** and **1018** are provided with axially extending bores **1017'** and **1018'** communicating with the hollow shafts **1023***a* and **1023***b*, respectively.

Within the drum, as described in my copending application Ser. No. 598,391, I provide, in addition to the electrolyte **1011**, a mass of metallic workpieces **1012** (shown as rectangles) accompanied by conductive particles **1013** (hatched circles) and if desired magnetic and abrasive particles as described in copending application Ser. No. 598,391. The electrolyte may be any of the electrochemical machining solution described in applications Ser. Nos. 512,338, 535,268 and 562,857, all having been mentioned earlier. The particles **1013** are composed of carbon and act as intermediate electrodes. An important aspect of this invention resides in the fact that the carbon particles are formed of relatively high-hardness carbonaceous material capable of withstanding metallic abrasion in the tumbling of the workpieces. Suitable particles may be made by sintering pyrolytic carbon or by the electric discharge technique set forth in my U.S. Pat. No. 3,207,582. In addition, the carbon particles may contain silicon carbide or the like abrasive powder dispersed therein prior to sintering. As a result, the electrochemical action is augmented by a mechanical smoothing of the workpieces concurrent with electrochemical removal of projecting portions of the workpieces (i.e. burrs). The deburring power supply **1019** may be any electrolysis source as described in application Ser. No. 598,391 and the other applications mentioned earlier. Suitable sources may be alternating current, pulsating direct current or filtered direct current as there described.

EXAMPLE I

Using the system of FIG. **1**, deburring was carried out in a 15 percent sodium chloride solution upon a mass of 35 percent by volume of steel workpieces having a diameter of 10 mm. and a length of 5 mm. Conductive particles, i.e. sintered pyrolytic graphite and silicon carbide particles with a diameter of about 5 mm. were used in a ratio to the workpiece quantity of about 1.15:1; it was possible to increase the deburring rate over conventional systems using only aluminum oxide abrasive particles and a similar drum (diameter 300 mm., axial length of 7 mm., electrolyte quantity 5 liters, current 80 amp.), in terms of the quantity of material removed per unit time, from 10 to 30 times and the yield improved surface finish.

In FIGS. **2A** and **2B**, I show a modification of the terminal electrode for the drum of FIGS. **1**, **5** and **6**, the electrodes **1117** generally comprising a disk **1117***a* of graphite of other electrochemically inert material attached at a flange **1117***b* to the tubular shaft **1123**. A fanlike array of bores **1117***c* is formed in the disk **1117***a* and open at the inner face **1117***d* in contact with the electrolyte within the drum. From FIG. **2B** it is apparent that the bores are distributed in conical arrays about axis of rotation of the drum (represented at **1125**) so that a number of these bores open into the drum above the liquid level (see FIG. **1**) at each of the electrodes **1017** and **1018**. Thus gas forming above the electrolyte path can pass through the uppermost bores and can be entrained with the liquid stream leaving the drum and flowing to the reservoir **1044**. In this reservoir, which is open to the atmosphere, the gases entrained in the liquid can evolve into the atmosphere. The fanlike array of bores has the additional advantage that, at the inlet electrode (e.g. electrode **1018**), the bores disperse the liquid and any gases entrained therein (FIGS. **5** and **6**) to insure fine distribution of gas bubbles in the electrolyte bath and even deliver some gas above the electrolyte to act as a diluent for the electrolytically evolve gases. The bores **1117***c* converge axially away from the drum to communicate with the tubular shaft **1123** and thus form a manifold.

Electrode **1217** of FIGS. **3A** and **3B** represents a modified construction in which the disk **1217***a* is formed with a plurality of mutually spaced parallel bores **1217***c* which are located in the region of the center of the disk and communicating with the hollow shaft **1223** which is attached to the disk **1217***a* at a flange **1217***b*. This embodiment has the dispersing advantages mentioned in connection with the electrodes of FIGS. **2A** and **2B** but does not evacuate gases from above the electrolyte level as effectively. Either of the electrodes of FIGS. **2A** and **2B** and of FIGS. **3A** and **3B** can be used in the drum deburring systems of FIGS. **1**, **5** and **6**.

In FIG. **4**, there is shown a diagram of the principles of the present invention as discussed in greater detail in application Ser. No. 598,391. In this Figure, I show the workpieces **1012** as fortuitously located between a pair of carbon particles **1013** and the electrodes **1017** and **1018**. If electrode **1017** is positive as shown for the purposes of the explanation of this electrochemical phenomenon, it will be seen that a proximal carbon particle **1013** received an inducted charge so that its region juxtaposed with surface **1012** in the electrolyte **1011** acts as an electrode to sustain electrochemical machining of this workpiece surface. The random distribution of conductive particles and workpieces between the electrodes is effective to insure practically uniform electrochemical treatment of all workpiece surfaces.

However, burrs or other projections invariably lie at a shorter distance from one of the terminal electrodes or an effective intermediate electrode than the other portions of the surface from which they project. The electrochemical machining current density is substantially higher at these protuberances and machining preferably occurs in these regions. Any mechanical smoothing is cumulative to the electrochemical action. It will be appreciated also that the presence of gas bubbles in the electrolyte augments the machining action and its specific attack upon protuberances and the burrs. It has been found that the gas bubbles tend to adhere to the surface of the workpiece in regions between the burrs and effectively insulate these regions while increasing the current density at the burrs. This too improves the surface finish and can be controlled by injecting inert gases into the system as was described in connection with FIG. **5**. The term "inert," however, must be construed in term of the activity performed here. When the evolved gases include hydrogen, it will not be advisable to add oxygen and vice versa. Even normally active gases may be considered inert if they are nonexplosive when used in the presence of gases evolved from the deburring bath.

In FIG. **5**, there is shown a horizontal drum **1310** with a central body **1341** held between a pair of gaskets **1342** and electrodes **1317** and **1318** of the type shown in FIGS. **2A** and **2B**. The electrodes are carried between the tubular shafts **1323***a* and **1323***b* whose slip rings are in contact with brushes **1319***b* and **1319***a* of the electrochemical machining power supply **1319**. A motor **1327** drives the drum about its horizontal axis while electrolyte is circulated through the drum via a pump **1339** from the reservoir **1344** and a line **1340** communicating with hollow shaft **1323***b*. The electrolyte from the drum is returned via line **1343'** to the reservoir.

In accordance with the principles of the present invention, gas is injected into the electrolyte prior to its passage into the drum, the gas-supply source being shown at **1350** in FIG. **5**. The source is a tank of air, argon, carbon dioxide, nitrogen or the like which is connected via a valve **1350***a* and a line **1350***b* with the hollow shaft **1323***b* of electrode **1318**. When the gas if forced under high pressure into the electrolyte which, in turn, is under pressure of pump **1339**, the liquid/gas mixture entering the drum through the electrode **1318** expands to evolve

the gas in the form of bubbles and, in part, to induce some of the gas into the drum above the electrolyte, thereby diluting the nascent gases released by electrolysis. The gas bubbles within the electrolyte adhere to the workpiece surfaces and augment the deburring action. An electromagnet **1315**, whose flux can be represented by arrow Φ is provided beneath the drum **1310** and is effective to increase the electrochemical machining action.

As described in the copending application Ser. No. 598,391, the magnetic field may be of unidirectional or alternating type while the magnet itself may be stationary or reciprocating. The magnet may be energized by a high-frequency AC source in addition to a low-frequency vibrating or oscillating source. The high frequency source preferably operates at 400 kHz. to 50 kHz. and end above sonic frequencies while the low frequencies source operates at, say 30 to 40 Hz. It appears that the magnetic field has a two-fold action whereby it induces a dynamic flow of liquid electrolyte and secondly, imparts magnetically attractive or repulsive motions to the workpieces when they are permeable.

In the system of FIG. **6**, the drum **1410** has a cylindrical body **1441** which is perforated to evolve gases and permit electrolyte to enter the drum as the latter is rotated in a bath **1435**. A hood **1451** overlies the bath **1435** and collects the evolved gases. Here too, the tumbling drum **1410** has a pair of disk-shaped electrodes **1417** and **1418** which are insulated from each one another by the gaskets **1442** although the electrodes are here not perforated. Nontubular shaft **1423***a* and **1423***b* rotatably support the drum **1410** in a pair of trunnions **1424***a* and **1424***b*. The drive means is constituted by a motor **1427** and a V-belt transmission **1430** connecting this motor with shaft **1423***a*. An electrolysis power supply **1419** applies electric current to the electrodes **1417** and **1418** by the brushes **1419***a* and **1419***b*. A magnetic field is applied, as previously described, by the coil **1415** in the vessel **1435**.

FIG. **7** shows a continuous system for the deburring of metallic workpieces wherein a succession of workpieces is deposited from a hopper **1552** upon a belt **1553** which directs these workpieces to a perforated endless belt **1510** which functions similarly to the drum of the preceding embodiments. The endless belt **1510**, which has horizontal stretch **1510***a* receiving the workpieces **1512** from the conveyor **1553**, passes over an idler pulley **1510***b* into the electrolyte bath **1511** in a vessel **1535** of funnel-shaped construction prior to emerging from the bath over a further pulley **1510***c*. Within the vessel **1535**, I provide agitating means in the forming electromagnet **1537** which vertically displaces an armature **1530** against a pair of compression **1538***a* to jumble the workpiece and carbon particles contained on the stretch **1510***d* of the belt passing through the electrolyte bath. The armature **1538** carries a number of rollers **1538***b* which support the belt in this region without frictionally impeding its movement.

Upon leaving the electrolyte bath **1511**, the conveyor **1510** has a horizontal stretch **1510***e* overhanging a collecting receptacle **1554** in which the deburring workpieces are caught, the band being then returned to the horizontal stretch **1510***a* by downward stretch **1510***f*, a horizontal stretch **1510***g* and a vertical stretch **1510***h*.

Intermediate electrodes are formed by a mass of carbon particles **1513** as previously described. The carbon particles are retained in a supply trough **1555** and are carried by a bucket conveyor **1556** to the vessel **1511** where they are deposited upon the mass of workpieces entering the bath. The bank **1510** is, as previously indicated, perforated and has openings through which the carbon particles may pass as they settle from the electrolysis zone. Thus carbon particles which settle through the belt **1510** are discharged at an outlet **1543'** of the vessel and are collected upon a sieve conveyor **1557** which carries them to the trough **1555**. The electrolyte passing through the sieve conveyor **1557** is collected in the reservoir **1544** and recirculated by a pump **1539** and a line **1540** to the bath **1511**.

The electrodes may, as described in Ser. No. 598,391, comprise vertical rods **1518***a*, and **1518***b*and **1518***c* which can be angularly oscillated about respective vertical axes and vertically reciprocated by the mechanism shown for similar electrodes in the last-mentioned application. I have found, moreover, that improved power utilization can be obtained when a polyphase power supply is available and the number of electrodes is equal *n* x P where P is the number of phases (usually three) available at the supply and *n* is an integer. In this system, each phase is applied between one pair of electrodes or the corresponding electrodes of a pair of sets, each set having *n* electrodes. In the simplified system of FIG. **7**, the power supply comprises a three-phase source **1519***a* which supplies a conventional Y or Δ transformer diagrammatically represented at **1519***b* each of the output faces of which is applied across a pair of the electrodes **1518***a* through **1518***c*. The connections to these electrodes are shown both for Y and Δ systems although it will be understood that only one of these systems may be in use at any time. In the Y system, the neutral pole may be grounded at the transformer. This arrangement permits each phase of a three-phase current to be effective and provides a greater effectiveness of the supply power without the expense rectifier systems which would be necessary to produce direct current and the complex circuitry which would be necessary to convert the three-phase force current to single-phase balanced current is operating the deburring device. It has been found that the system is particularly desirable when a large number of workpieces with a relatively large total volume is to be deburred at one time.

In FIGS. **8** and **9**, I show another embodiment of the present invention in which no continuously displaceable endless surface is provided and the agitation of the electrolyte, carbon particles and workpieces, is carried out by means of pulsed jets or high-velocity streams of electrolyte directed tangentially into the vessel at the deburring region. This system, while affording some mechanical smoothing by contact of the workpieces with the carbon particles and the electrodes and walls of the vessel, primarily is effective to promote electrochemical removal of material from workpiece surfaces without any movable apparatus members. The freedom of this system from vibrational and rotational movement of electrodes, containers and the like eliminates the need for drive motors journaling assemblies and the like, thereby making the entire apparatus more practical and less expensive, especially where small quantities of workpieces are to be treated.

In accordance with the principles of the present invention, the apparatus comprises a stationary vessel **1610** of electrically insulating material having an upwardly open pot-shaped chamber **1643** with an arcuately concave bottom **1643***a*. A pair of electrodes **1617** and **1618** disposed at diametrically opposite locations along the inner wall of the chamber and energized by an electrochemical machining deburring power supply **1619** of the character previously described. The vessel contains an electrolyte **1611** in which the workpieces **1612** (diagrammatically shown as rectangles) and carbon particles **1613** (diagrammatically shown as circles) are distributed. The carbon particles **1613** are composed of sintered carbon to which abrasive powder has been added and may be used in conjunction with abrasive particles which contain no conductive material. When a number of pairs of electrodes are provided in this system, the considerations discussed in connection with FIG. **7** apply and the power supply may include a polyphase-current source each phase of which is connected across a respective pair of electrodes or a respective pair of electrode sets.

In the present embodiment, the agitation of the electrolyte, workpieces and carbon particles is carried out by a fluid stream and the bottom **1643***a* of the vessel may thus be provided with a plurality of liquid inlets **1623***a*, **1623***b* **1623***c*, ... **1623***n* forming electrolyte jets oriented generally tangentially to an imaginary circle C centered upon the vertical axis of the chamber and tangential as well to the curvature of the floor of the vessel as will be apparent from FIGS. **8** and **9**. These inlets

individually extend through the vessel **1610** and communicate via lines **1640***a*... etc. with a pump **1639** drawing electrolyte from the reservoir **1644**. Electrolyte is returned to the reservoir via a line **1643'**. Each of these lines is provided with a respective electromagnetically operable valve **1659***a*,... etc., which successively pulse the electrolyte jets introduced into the vessel. Consequently, a vortex agitation of the electrolyte is provided which dynamically coacts with gravitational force to produce the desired turbulence. When more turbulence is desired, the jets can be pulsed in random sequence rather than in succession as indicated. The deburring electrolyte may be admixed with inert gas (see FIG. 5) from a cylinder **1650** and a valve **1650***a* which may be injected into the electrolyte stream or may be added exclusively through one of the inlet passages (i.e. passage **1623***c* in the system of FIGS. 8 and 9).

EXAMPLE 2

A series of comparative tests were carried out with the stationary vessel arrangements of FIGS. 8 and 9, with a rotary vessel system and with a vibratory vessel system as described below. The electrolyte was an aqueous solution of 15 percent by weight of potassium nitrite and the workpieces were hexagonal nuts composed of iron and of 8 mm. diameter. The nuts were of first grade JIS standard, black, class 4 M8SS41B–D with a total volume of 500 cc. The deburring elements added to the system were carbon particles of 15 mm. diameter or abrasive particles of alumina or silica, each of 15 mm. diameter. When particles were added, a total quantity of 2,000 cc. of such particles were used. The rotary system involved vibrations of 1,500 cycles per minute and the jet system made use of a electrolyte pressure of 5 and 15 kg. per cm.^{2}. Four jets were employed in each case and the following tables give the total quantity of material removed in the deburring process, the voltage and amperage provided for the electrochemical action and the particle wear in percents by weight.

1. Rotary System

Particles	Voltage	Amperage	Particle wear (percent by weight)	Deburred quantity (grams)
(a)---- Carbon only	37	88	3	48
(b)--- Carbon 50 vol. percent, Al_2O_3 50 vol. percent.	72	35	4	20
(c)--- Al_2O_3 50 vol. percent, SiO_2 50 vol. percent.	90	35	0.1	20

2. Vibratory System

(a)---- Carbon only	30	80	5	42
(b)--- Carbon 50 vol. percent, Al_2O_3 50 vol. percent.	65	40	6	25
(c)--- Al_2O_3 50 vol. percent, SiO_2 50 vol. percent.	85	40	0.1	22

3. Jet System—with 5 kg./cm.^{2} electrolyte pressure

(a)---- Carbon only	18	90	4	52
(b)--- Carbon 50 vol. percent, Al_2O_3 50 vol. percent.	45	60	3.6	38
(c)--- Al_2O_3 50 vol. percent, SiO_2 50 vol. percent.	62	45	0.2	26

4. Jet System—with 15 kg./cm.^{2} electrolyte pressure

(a)---- Carbon only	15	100	3	56
(b)--- Carbon 50 vol. percent, Al_2O_3 50 vol. percent.	43	62	4	39
(c)--- Al_2O_3 50 vol. percent, SiO_2 50 vol. percent.	71	40	0.1	24

In addition, an electromagnet **1615** may be provided below the vessel as shown in FIG. 8 to augment the dynamic movement produced by the liquid jets by electromagnetically induced movements. It will also be understood that various combinations of the several systems may be provided as well. Thus, the systems of FIGS. 1, 5 and 6 may provide pulsed electrolyte jets to increase agitation while similar jets may be provided in the system of FIG. 7. A conveyor belt may be passed through the vessel of FIG. 8. The vessel of FIG. 8 may also be vibrated by electromagnetic means as shown in FIG. 7 or may cooperate with angularly oscillatable and vertically reciprocable electrodes as there shown.

The invention described and illustrated is believed to admit of many modifications within the ability of persons skilled in the art, all such modifications being considered within the spirit and scope of the appended claims.

I claim:

1. An apparatus for deburring an electrolysis soluble workpiece, comprising:
- means forming a container for an electrolyte;
- support means for positioning said workpiece with at least a surface thereof in contact with the electrolyte within said container;
- supply means for introducing into said container a multiplicity of conductive particles to distribute them in contact with the electrolyte in the region of said workpiece;
- means for imparting random movement to said particles relative to said workpiece interspaced by the electrolyte; and
- means for applying an electric current through said electrolyte, said particles and said workpiece to solubilize electrolytically portions of said surface against said particles functioning as counterelectrodes.

2. The apparatus defined in claim 1 wherein said support means comprises a workpiece carrier for carrying said workpiece in an electrolyte, said container forming an enclosure around said support means for retaining the electrolyte in the form of a bath.

3. The apparatus defined in claim 2 wherein said workpiece carrier is an elongated element, further comprising means for displacing said element through said electrolyte.

4. The apparatus defined in claim 3 wherein said element is a conveyor band having a stretch for extending beneath the electrolyte level and stretches upstream of and downstream of the electrolyte for carrying said workpiece into said electrolyte and removing said workpiece from said electrolyte.

5. The apparatus defined in claim 2 wherein said means for imparting random movement to said particles relative to said workpiece includes means for injecting gas bubbles into said electrolyte.

6. The apparatus defined in claim 2 wherein said means for imparting random movement to said particles relative to said workpiece includes an electrolyte circulation system for displacing said electrolyte past said surface.

7. An apparatus for deburring an electrolyte-soluble metallic workpiece, comprising:
- means forming a container for an electrolyte;
- support means for positioning said workpiece with at least a surface thereof in contact with the electrolyte;
- means for distributing in the electrolyte a multiplicity of conductive particles;
- means for agitating the electrolyte in contact with said surface to impart random movement to said particles relative to said workpiece; and
- means for applying an electric current to said electrolyte to solubilize electrolytically portions of said surface against said particles functioning as counterelectrodes, said support means comprising a workpiece carrier bearing said workpiece in the electrolyte, said apparatus further comprising means forming an enclosure around said support means for retaining the electrolyte in the form of a bath, said means for retaining the electrolyte in the form of a bath said means for distributing said conductive particles in said electrolyte comprising conveyor means for entraining said particles in depositing them in said electrolyte.

8. The apparatus defined in claim 2 wherein said means for imparting random movement to said particles relative to said workpiece comprises an oscillatory element coupled with said container, and means for oscillating said element.

9. The apparatus defined in claim 2, further comprising means for continuously separating said particles from said electrolyte bath.

10. An apparatus for electrolytically deburring a multiplicity of metallic workpieces, comprising:

a container for receiving a multiplicity of conductive particles distributed in an electrolyte;

a support means for positioning said workpieces in said container in the region of said conductive particles and said electrolyte;

means coupled with said container for imparting random movement to said particles relative to said workpieces interspaced by the electrolyte within said container; and

means for applying an electrochemical machining current through said electrolyte, said workpieces and said particles to electrolytically solubilize at least portions of the individual bodies of said workpieces against said conductive particles functioning as counterelectrodes.

11. The apparatus defined in claim 10 wherein said support means includes a workpiece carrier for transporting said workpieces successively past said region of said conductive particles and said electrolyte in said container.

12. The apparatus defined in claim 11, further comprising feed means for introducing said conductive particles into said container.

13. The apparatus defined in claim 10 wherein said support means includes an elongated supporting surface for carrying said particles and said workpieces within said container while said random movement is imparted between them.

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