APPARATUS FOR ELECTROPLATING
A CURVED SURFACE

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ABSTRACT

Apparatus for electroplating a curved surface of a workpiece wherein a relative rotatable and reciprocable motion is provided between the anode and the surface to be plated for controlling variations in plating thickness, with the rotary motion being precessed to provide a constant phase shifting to cancel out plating irregularities. The anode is fabricated of a plurality of longitudinally spaced annular segments, with means to independently control the current to each segment.

6 Claims, 6 Drawing Figures
APPARATUS FOR ELECTROPLATING A CURVED SURFACE

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

This invention relates to apparatus for electroplating a curved surface of a workpiece, and more particularly to such apparatus wherein variations in plating thickness over the entire curved surface can be controlled.

The present technique of plating a curved surface, such as a bore surface, is to custom-make an anode out of suitable material for insertion into the bore for the plating operation. The anode is normally fabricated in a cigar shape in accordance with the best estimate of an experienced anode technician to account for well-known edge effects. The anode is then re-shaped by a trial-and-error method. That is, a series of workpieces are successively test plated with the anode being re-worked by machining between each trial plating until a passable compromise anode design is achieved, at which time further refinements are foregone in order that the anode maker meet other anode fabrication requirements. When plating a bore surface, the anode is usually provided with a hollow longitudinal core with connecting transverse holes to enable fresh plating solution to be circulated up through the core and be distributed out of the transverse holes to the cylindrical space between the anode and the surface to be plated. This flow of plating solution is normally circulated only by convection. The surface area to be plated opposite the transverse anode holes, being more effectively presented to the plating solution, tend to build-up in plating thickness. Because of the uneven build-up in plating on such areas, as well as variations in plating thickness due to imperfections in anode design, substantial post grinding operations are required to meet dimensional tolerances.

SUMMARY OF THE INVENTION

The present invention provides an electroplating apparatus in which variations in plating thickness can be controlled. This apparatus eliminates the need for custom fabrication of the anodes thereby reducing the lead time, maintenance costs, and the storage of a supply of such anodes. In addition, the amount of post-machining operations is reduced substantially as well as overall production costs.

These unique results are achieved by fabricating an anode having a plurality of longitudinally spaced electrical segments extending for a length greater than the length of the surface to be plated, and variable means for independently controlling the plating current to each segment. In other words, the predetermined distribution of the plating thickness is accomplished electrically by controlling the current, rather than by mechanically machining the anode by a trial-by-error configuration. Therefore, the shape of the invention anode need not conform to the configuration of the surface to be plated. In addition, by providing a relative rotational and longitudinal movement between the anode and the workpiece, variations due to plating irregularities can be minimized. A further refinement can be achieved by the use of a plating thickness indicator which can signal the completion of the plating cycle and/or stop the plating operation.

OBJECTS OF THE INVENTION

A principal purpose of the invention is to provide an electroplating apparatus which will enable the plating thickness to be selectively controlled over the entire curved surface of a workpiece, and a correlative object is to achieve the selective control by electrical means.

Another important object is to provide an anode which can be made in a standard design without the need for custom fabrication.

Still other objects are to provide electroplating apparatus which will achieve greater uniformity in plating thickness thereby reducing post machining operations as well as reducing the overall time and cost of plating operations.

Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a front elevation view of the novel electroplating apparatus.

FIG. 2 is a side elevation view of the apparatus of FIG. 1, showing a workpiece in broken lines.

FIG. 3 is an enlarged front elevation partially in section of the cam drive assembly taken generally along line III—III of FIG. 2.

FIG. 4 is a longitudinal section of the anode.

FIG. 5 is a top sectional view of the apparatus along line V—V of FIG. 1 showing a transverse section of the anode and of the workpiece in broken lines.

FIG. 6 is a perspective view of a representative anode conductor segment.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings where like reference numerals refer to similar parts throughout the figures there is shown in FIG. 1 a novel electroplating apparatus 10 constructed according to the teaching of this invention. Apparatus 10 is adapted to be supported within a conventional plating tank (not shown) with the lower portion thereof immersed within a plating solution the level of which is indicated generally at 12.

The entire electroplating apparatus is suspended from a back plate 14 which is secured in a stationary condition during the plating operation. Although back plate 14 is intended to be stationary during the plating operation it is not necessarily integrally fixed to the tank that would prevent the apparatus from being lifted out of the solution at the end of the plating operation or for other reasons. Back plate 14 and all structural parts hereinafter described are preferably constructed of a material resistant to the corrosive environment of the plating solution, such as polypropylene or polyvinyl chloride.
The curved surface to be plated is illustrated as a bore surface 16 of a tubular workpiece 18 shown in broken lines in FIGS. 2 and 5. It should be noted, however, that the invention apparatus is not limited to plat- 5 ing a bore surface since the principles of the invention can be utilized to plate the outer peripheral surface of workpiece 18 in which case suitable changes to the anode construction must be made to provide the necessary male-to-female relationship between the anode and surface to be plated.

One of the principal features of the invention apparatus is to provide during the plating operation a predetermined relative motion between the anode and the surface to be plated to control variations in the plating thickness. In the illustrated embodiment an anode assembly 19 of the apparatus is designed to be movable in a manner presently to be described, and workpiece 18 is supported in a stationary condition by a fixture comprising a pair of opposing V-shaped clamping members 20 secured by bolts 21 to a stationary back plate 14. Bolts 21 are adjustably positioned in slots in back plate 14 to accommodate workpieces of different diameters.

The only other component of apparatus 10 that is also stationary during the plating process is a cam-follower roller 22 rotatably supported on a shaft 24 bolted to back plate 14 (FIG. 2). Cam-follower 22 through a bevelled circular cam 26 supports the entire anode assembly 19 for rotating and reciprocating (note symbol 28) with respect to fixed workpiece 18. Cam 26 is an integral part of anode assembly 19 and the weight of the entire assembly maintains said cam 26 in rolling contact with follower roller 22.

Referring to FIGS. 1 and 3, circular cam 26 is rotatably supported by a bearing 30 freely about a shaft 32 and is locked thereto at its upper end by a nut 34. Shaft 32 is bolted at its lower end through a circular flange 37 to a long rod-shaped anode 36 which is adapted to project into workpiece 18. Anode 16 will be described later in greater detail with reference to FIG. 4. Cam 26 and the entire anode assembly 19 depending therefrom is rotatably driven freely about shaft 32 through a spacer hub 37 by a pair of pinion gears 38 and 40 connected by a bevelled gear train 41 to a motor 42 bolted to a motor mount 44.

Because the entire anode assembly 19 is actuated in an up and down reciprocable movement by rotation of bevelled circular cam 26, the entire motor 42 and its drive mechanism must be supported for reciprocable movement with respect to back plate 14. This is accomplished through a T-bar 46 (FIG. 2) which is secured to motor mount 44 via bolts 48 freely guided in vertical slots 50 in back plate 14.

If desired suitable bushings 52 can be secured on motor mount 44 and T-bar 46 to engage with and provide a smooth sliding contact with stationary back plate 14, although the use of bushings 52 are not believed necessary where the structural parts are made of the aforementioned plastic material having a very low coefficient of friction. Thus, by means of the above described motor drive mechanism anode assembly 19 is provided an up and down reciprocating movement.

In addition to the vertical reciprocating motion, anode assembly 19 is also provided a rotary motion about a vertical axis by a second pair of pinion gears 54 and 56 which are also driven by motor 42. Whereas upper pinion gear 54 is freely journaled about shaft 32 by bearing 30 for rotating cam 26, lower pinion gear 54 is keyed at 58 to shaft 32 for rotating shaft 32 as well as the depending anode assembly 19 (FIG. 3). Thus, motor 42 through the two pinion gear trains described above simultaneously provide both a rotary and reciprocable motion to anode assembly 19 in relation to stationary workpiece 18. It is preferred that lower and upper pinion gears 54 and 38 respectively have a slightly different number of teeth to provide a constant phase shifting between the rotary and reciprocating motions. That is, the locus of any single point on the anode projected on the bore surface to be plated will precess in rotation in order that electrical and mechanical irregularities in the plating process will be cancelled and a uniform current distribution over the entire workpiece be achieved.

As shown in FIGS. 2 and 3, at the lower end of apparatus 10 is positioned a propeller 60 driven by a sealed motor 61 journaled in a box 62. The propeller functions to achieve better circulation of the plating solution upwardly in the space between anode 36 and workpiece 18 to ensure a supply of fresh plating solution throughout the plating operation. Propeller box 62 is integrally joined to a bracket 64 bolted at 66 to T-bar 46, bolts 66 extending through and slidable in a slot 68 in stationary back plate 14. Thus, the propeller assembly is provided the same guided vertical reciprocable motion with respect to the workpiece as is anode assembly 19, but without the rotational movement of the anode assembly.

As best seen in FIGS. 1, 2, and 4, anode 36 consists of three integral portions, namely, an upper input portion 70, a lower output portion 72, and an intermediate connecting portion 74. Upper anode portion 70 is designed to remain above the lever of the plating solution 12 for electrically connecting the anode to the source of plating current via a set of six electrical brushes 76, cables 78, and programmable current controllers 80, one for each of said electrical brushes (FIG. 1). Controllers 80 are connected to a conventional high current power supply to enable the current to each of the six brushes to be programmed in a selective manner to vary and control the distribution of the plating thickness over the surface of the workpiece.

The upper portion of electroplating apparatus 10, including the upper input portion 70, is enclosed within a housing 82 secured to back plate 14. The lower end of housing 82 has an opening 83 (FIG. 2) through which anode 36 moves, a washer 84 making wiping contact therewith to protect the upper portion of the apparatus from the corrosive fumes and splashing of the plating solution. The lower portion of apparatus 10, including workpiece 18, which is immersed in the plating solution is enclosed within a protective screen 85 (FIG. 1) also secured to back plate 14 to prevent undesired stray currents from flowing to adjacent plating set-ups that may be in the same plating tank.

The details of anode 36 are best illustrated in FIGS. 4–6. The upper anode portion 70 consists of six vertically spaced electrical slip rings, 70A–70F separated by insulator rings 86, each slip ring being electrically connected to the plating current source by its respective brush 76 (FIG. 1). Although the anode illustrated util-
izes 6 sets of brushes and corresponding slip rings (70A to 70F), the number of sets may vary depending on the length and configuration of the workpiece surface, and the degree of control desired distribution of the plating thickness.

The six upper electrical slip rings 70A-F, which can be referred to as current input rings, are electrically connected by a series of vertical segmental conductors 88 to six corresponding lower rings 72A-F, which similarly can be called current output rings for transmitting the current through the plating solution to the surface to be plated. Lower rings 72A-F are also separated by insulator rings 86. A representative sample of conductor segment 88 is illustrated in FIG. 6, the actual length will vary depending on the distances of the electrical paths between the respective input-output rings. As will be noted in FIGS. 5 and 6, conductor segments 88 are less than semi-circular in cross-sectional configuration to allow two separate conductors to extend in parallel relation, the adjacent conductor segments being insulated from each other by filling the voids 90 therebetween with a potting compound or the like. This parallel arrangement of segmental conductors 88 allows a pairing of input-output rings on both the left and right sides of the anode which provides a more compact anode construction.

As shown in Fig. 4, three input slip rings 70A-C by conductors 88 extending on the right side of Fig. 4, whereas, input slip rings 70D-F are inversely paired with output rings 72D-F on the left side of FIG. 4. Arrows 91 have been utilized as a means of graphically illustrating one of each of said electrical paths on both sides of the anode. The six separate electrical paths via the corresponding segmental conductors 88 between each pair of input-output rings are concentrically disposed in the anode with suitable vertical segmental insulation segments 92 disposed between the various conductors 88 to prevent short-circuits between the concentrically adjacent electrical paths. Insulation segments 92 may be similar in configuration to conductor segments 88. As a manufacturing expedient, it may be noted that where the lateral ends of segmental conductors 88 are positioned immediately adjacent the various input and output rings 70A-F and 72A-F, these parts, which may include spacer conductors, are brazed together to form an integral electrical conductor, for example as illustrated at 96. A central core opening 94 is provided in anode 36 to accommodate a drive shaft in the event it is desirable to position motor 61 above the lever of the plating solution.

The plating thickness on the workpiece surface can be controlled through a conventional amp/hr meter (not shown) or by means of a laser 98, such as the type manufactured by Perkin-Elmer, Model INF-1. As shown in FIG. 1 laser 98 is mounted on a suitable portion of the reciprocable structure in operative relation to a fixed mirror 100, and a series of five mirrors 102 mounted in successively staggered relation on each of the insulator rings 86 separating the lower output rings 72A-F. A laser micro switch 104 is secured to stationery back plate 14 in a position to contact a laser actuator pin 106 mounted to any portion of the reciprocable anode assembly 19, such as the drive mechanism, when the assembly is reciprocated to the uppermost position. When microswitch 104 is thus activated, it pulses laser 98 sending a light beam to the surface of the workpiece via mirrors 100 and successively to mirrors 102 and back to the laser. The total travel time of the laser beam is measured by a suitable laser controller 108 in an established manner and the plating build-up thickness can be periodically registered digitally for continuous monitoring on register 110 corresponding to the respective measurement points.

**OPERATION**

The workpiece 18 is properly centered in its fixture and apparatus 10 suspended in an immersed condition within the plating solution in the tank. Current controllers 80 having been properly programmed are turned on initiating a low current density startup. Propeller motor 61 and drive motor 42 likewise are energized. Anode assembly 19 will simultaneously rotate and reciprocate with respect to the fixed workpiece in a changing phase relationship due to precession. The current to the anode segments are gradually increased to the running level according to their individual programmed settings. When the desired plating thickness is reached as determined by the laser or other indicator a warning device 112 may be sounded at which time the plating current is reduced to a low maintenance level to prevent etching. Apparatus 10 can be manually or automatically lifted out of the plating tank to complete the plating cycle.

The novel electroplating apparatus 10 greatly improves on existing plating methods by decreasing plating thickness variations from the present commercial norms of 20%± at optimum conditions, to an order of accuracy approaching one-tenth of the present commercial tolerances. Thus, post-plating grinding operations are reduced, especially important when heavy plating is required, such as during aircraft rework. By having a segmented anode in which the current can be programmed and controlled at a plurality of stations throughout its length, the same anode can be used for plating different workpieces thereby eliminating long lead time in manufacturing and the expense involved with custom made anodes.

Better uniformity of plating thickness is also achieved by providing a reciprocating and rotating motion between the anode and the workpiece. In the preferred embodiment, the workpiece is held stationary and the anode provided the reciprocating and rotating motion. However, a reverse condition may be desired, that is, the anode assembly can be held stationary and the workpiece moved, in which construction a deeper plating tank would probably be required. Uniformity in plating thickness is also enhanced by arranging for precession in the rotation of the anode with respect to the workpiece.

Use of a propeller pump permits faster plating rates due to less depletion of the plating solution ion content in its circulation over the workpiece surface; scrubbing of hydrogen bubbles; and finally assists uniformity of plating by equalizing the temperature gradients produced by the heating of the plating solution for various reasons.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.
What is claimed is:

1. Apparatus for electroplating a curved surface on a workpiece by immersion in a plating solution which comprises:
   - anode means positionable relative to said workpiece in spaced relation to said surface;
   - said workpiece serving as a cathode;
   - means for supporting the workpiece in operative relation to said anode means;
   - one of said means being both rotatable and reciprocable with respect to the other of said means;
   - means for precessing the rotary motion to provide a constant phase shifting to cancel out plating irregularities;
   - whereby variations in the plating thickness over the entire surface of the workpiece can be controlled in a uniform manner.

2. The apparatus of claim 1 wherein:
   - said reciprocable motion is provided by a cam member and cam roller member, one of which members is fixed to a stationary support, and the other member is integrally mounted to the movable means;
   - a pair of pinion gear trains for driving the movable member to provide the reciprocable and rotatable motions;
   - said pinion gears in each pair having a different number of teeth to provide the phase shifting.

3. The apparatus of claim 1 wherein:
   - said anode is fabricated of a plurality of longitudinally spaced annular electrically conductive segments, and
   - means for independently controlling the plating current to each of said segments whereby a distribution of current can be programmed over the entire plating surface in a selectively variable manner.

4. The apparatus of claim 3 wherein a laser thickness indicator is provided each of said electrically conductive segments provided with a mirror in successively staggered relationship around the anode and so oriented that the plating thickness opposite each segment can be ascertained optically.

5. The apparatus of claim 3 wherein:
   - said means including a plurality of slip rings longitudinally mounted on an extension of said anode, a separate slip ring provided for each of said conductive elements.

6. The apparatus of claim 5 wherein:
   - a plurality of conductors for electrically connecting the slip rings to the conductive segments, each conductor being less than semi-cylindrical in configuration to enable them to be mounted longitudinally and concentrically on the anode to provide a plurality of independent electrical paths between the corresponding slip rings and conductive segments so as to occupy a minimum space.

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