

The invention relates to a process for electroplating a selected surface of a workpiece, in which an electroplating solution containing metal cations or an electrolyte solution is passed at high velocity through an elongated gap which is limited by an anode and that surface of the workpiece which is to be plated and through which there flows an electric current having a current density of more than 0.3 A/cm^2 transversely from the anode to the workpiece surface. The invention furthermore relates to a device for electroplating a selected surface of a workpiece by the process according to the invention, having support devices which support the workpiece and the anode in such a way that an elongated gap is formed between anode and that surface of the workpiece which is to be plated, having a pump which forces electro-plating solution at high velocity through the gap in the longitudinal direction and having an electric plating current source connected to the workpiece and to the anode which allows an electric current having a current density of more than 0.3 A/cm^2 to flow transversely through the gap from the anode to the workpiece.

From "Electroplating Engineering Handbook" (edited by L. J. Durney, 4th edition, van Nostrand Reinhold Company, New York, 1984), it is known to plate steel strips or the like at high speed, high current densities of over 0.3 A/cm^2 and high relative velocities of over 1 metre per second between the plating solution and the cathode being used in order to achieve high deposition rates, for example, during the dip or bath plating of a workpiece. This citation describes only the rapid, complete plating of comparatively simple components, such as steel strips, piston rings and the like.

In contrast to tank or bath plating, in which a distantly arranged, consumable or non-consumable anode

is arranged together with a workpiece to be treated in a container, the invention relates to gap electroplating. In bath plating, the metal is deposited by electrolysis technology on all the surfaces of the workpiece which are contained in the tank. In order to plate only a selected surface in such a tank or container process, the workpiece has to be masked, provided with a protective coating or protected from the bath solution contained in the tank in some other way. In gap electro-plating, a completely different concept is adopted. In this case, an anode is given that shape and surface which is substantially adapted to the shape and the selected surface of the workpiece to be plated. The current flows between anode and cathode through a predetermined gap which results from the geometry of the anode surface insofar as the latter is adapted to the workpiece surface to be plated. Said gap electroplating can be carried out in a container and is also often carried out in a container for electrolytic surface treatment; gap electroplating does not, however, necessarily require a tank. On the contrary, it can also be carried out by passing a plating solution into the gap between anode and cathode while a current is allowed to flow between these two electrodes for as long as a closed or uninterrupted flow of plating agent flows through the gap. This type of gap plating is the subject of the present invention.

A closed-circuit gap electroplating such as is the subject of the present invention is described quite generally in the US Patents 4 111 761 of LaBoda and 4 441 976 of Iemmi, where an anode having a cylindrical outer circumferential surface is concentrically arranged in a cylindrical area of a workpiece to be plated, with which it forms a gap or a plating cell. The remainder of the workpiece, including its complete external surface is not to be plated. In order to prevent the

remainder of the workpiece from being plated, the electroplating solution is not brought into contact with that surface of the workpiece which is not to be plated. In the process according to US Patent 4 345 977 of Blanc, a modified container system is used. Plating of the external part of the workpiece is in this case prevented by seals. The internal cylinder surface is primarily plated in this device because of the anode arrangement and the flow of solution, but other parts of the workpiece are also plated because the tank actually encloses more than the selected internal cylinder surface. This patent does not disclose a gap electroplating but it reveals in general form a device for plating a selected surface.

The gap electroplating process has already been known for several years. The clamping devices for this process were, however, comparatively expensive and the working results were not uniform, in particular in the case of elongated, generally inaccessible bores in complicated workpieces. For this reason, to repair and reconstruct oversize bores in various workpieces, tank plating or brush plating was often carried out. Tank plating proceeds extremely slowly and, without extensive, expensive masking, does not provide uniform results on selected subsurfaces. The success of brush plating depends substantially on the experience of the worker and can be used only in the case of very particular, exposed surfaces. There is therefore a real need for a plating system with which a plating can be applied uniformly up to an appreciable thickness of over 1.27 mm (0.050") in various bores of a complicated workpiece, for example in a forged piece of an aircraft undercarriage. In addition, it is important for such a plating process to be capable of being carried out rapidly and at low installation costs by staff having average experience.

There was also a need to plate sites in a large workpiece with somewhat difficult access in order to provide a very wear-resistant lubricant area of considerable thickness in order to salvage complicated workpieces such as, for example, forged pieces in which only certain surfaces had been worn beyond the acceptable tolerances. Chromium cannot always be used to meet these requirements because microscopically fine cracks occur at the thickness which is necessary to bring an oversize bore to within acceptable tolerances. Even if chromium is generally used in salvaging or repairing worn subsurfaces in the case of complex workpieces, chromium is not always an ideal material. In addition, tank plating of such surfaces with chromium cannot be universally applied. This is the case, in particular, in repairing holes which have become unduly large in steel forged pieces of extremely high strength (240 KSI or over), such as those used in space vehicles and aircraft parts. In view of these limitations and requirements, chromium obtained by container plating is not completely satisfactory for the repair of workpieces, i.e. for plating the internal surface of a bore in a high-strength steel forged piece. Furthermore, even if it is possible and/or desirable, chromium plating requires extremely long plating times for the repair of worn surfaces. Higher current densities intended to reduce this plating time do not substantially increase the rate at which the chromium is deposited because the efficiency drops rapidly at increased current density.

Even if tank plating of chromium on surfaces of a complex workpiece was used to repair, salvage or finely size surfaces, this process is nevertheless not completely satisfactory. In some cases, it cannot actually be carried out efficiently. Tank plating

employing nickel is also difficult and expensive as a repair, salvaging or final-sizing process.

In view of the many difficulties experienced in the attempt to repair worn or overdimensioned bores in complicated workpieces such as, for example, in high-strength steel forged pieces for landing gears, a plating process was developed which requires no chromium and which can be carried out without high capital expenditure, without long coating times and without specially trained personnel, as is the case in the generally known tank plating process.

The plating process and the plating device according to the invention was provided in order to achieve substantial advantages over special plating for a specific application in which it is important to plate selective surfaces while the workpiece itself requires no special treatment and in which the long coating time which is required in the case of tank plating is unnecessary. With the process and the device according to the invention, a remarkably thick metal layer is rapidly deposited on a selected surface of a workpiece even if the workpiece has a complicated shape, and masking and other complicated, lengthy and time-consuming pre-plating processes are unnecessary.

The invention provides an electroplating device for rapidly depositing a metal on a selected surface of a workpiece, which device has one anode having an anodically active surface part of selected shape which, together with the selected surface shape of the workpiece forms an elongated gap measuring at least 1.27 mm (0.050"). In addition, the electroplating device has a carrier which fixes said anode in position so as to form an elongated gap. Furthermore, a circulating device is provided which forces an

electroplating solution loaded with metal ions through the gap in a substantially closed circuit at a rate such that the electroplating solution in the gap is replaced at least 25 times per minute. Furthermore, a current source is provided in order to allow a current having a current density of more than 0.31 A/cm^2 (2.0 A/in^2) to flow between the selected workpiece surface and the active surface of the anode.

This novel device according to the invention is primarily suitable for plating a cylindrical internal surface in an essentially complicatedly shaped, high-strength steel forged piece in which the gap has an annular cross-section and a first and a second end face. The plating solution is forced at an ultra-high volume replacement rate from the first end face of the gap to the second end face.

It is particularly expedient if the anode is a non-consumable anode and the plating solution is composed of nickel sulphamate. The volume replacement rate through the gap can be described as "ultra-high rate" or "high-velocity flow rate" since the volume replacement rate or the liquid exchange through the gap is higher than hitherto. Preferably, the volume replacement rate is in the order of magnitude of 200 to 1000 replacements of solution in the gap per minute. The ultra-high liquid replacement rate may amount to up to 2500 times per minute, it being limited only by the equipment and the obtainable pumps. If such an ultra-high volume replacement rate is used, current densities of over 0.31 A/cm^2 (2.0 A/in^2) can be used between the surfaces of anode and workpiece which are matched to one another in their shape, without overheating the electroplating solution in the process or affecting the uniformity of the plating solution in any way while the latter is flowing from one end of the gap to the other. This

ultra-high volume flow ensures the separation of gas bubbles, the maintenance of the low temperature and the high contact pressure of the solution at the anode surface and the workpiece surfaces. The radial width of the gap, which forms the plating cell, is at least 1.27 mm (0.050") and is preferably between 12.7 and 25.4 mm (0.50 and 1.0"). Gap widths which reach more than 63 mm (2.5") can be used in the process according to the invention if the volumetric flow is increased.

According to the invention, a gap is provided between the selected surface of a fixed anode and the selected surface to be plated. Said gap guides the flow of solution over these surfaces. Ultra-high velocities permit high current densities which, in turn, result in a rapid metal deposition from the flowing plating solution, which metal is preferably nickel. Under any circumstances whatsoever, a fresh, unconsumed plating solution having a controlled temperature is available in all the cross-sectional areas of the gap for a uniform plating, which plating solution exerts a high contact pressure on the surfaces limiting the gap. In practice, the plating solution is forced vertically upwards so that all the gas developed in the gap during the electrolysis migrates upwards in the same direction as the plating solution and is expelled.

The process according to the invention, which makes use of the device explained above, serves to gap-plate a selected surface of a workpiece. In this process, said selected surface to be plated forms one boundary of the above-mentioned plating gap.

The main object of the invention is to provide a process and device for gap plating, which method uses ultra-high volume replacement velocities or flow rates of the plating solution through the gap. The gap is the

plating cell between a fixed anode and that particular surface of the workpiece which has been selected for the plating.

As explained above, the invention has the advantage that current densities can be used which exceed 0.31 A/cm^2 (2.0 A/in^2) so that the plating rate is substantially increased and the plating time decreases, as a result of which a coating process which hitherto lasted over three days in a tank can now proceed in less than two to four hours.

The invention makes it possible to deposit a thick metal layer on a selected surface of a workpiece rapidly and uniformly over the entire area in such a way that the process can be repeated from one workpiece to another without the changes which are caused by the limits of dexterity.

A further advantage of the invention is that thick, uniform surfaces can be produced which have hitherto been achievable by tank plating only with difficulty, if at all, without substantial clamping and/or masking.

According to a further feature of the invention, a whirling flow of the plating solution through the annular gap is used at the point where the flow is generated by the plating solution itself.

A further advantage of the invention is that the plating solution can be kept at a uniform, relatively low temperature over the entire length of the gap in order to ensure a uniform plating over the entire gap.

Further features and advantages of the invention emerge from the following description and the drawings, in which preferred embodiments of the device according to

the invention and of the process carried out with the latter are explained. In the drawing:

- Figure 1 shows a preferred embodiment of the device according to the invention when a special workpiece is used in a side view and partly in longitudinal section,
- Figure 2 shows the subject of Figure 1 in section, in an enlarged representation, certain dimensions and parameters corresponding to an embodiment of the invention,
- Figure 3 shows the subject of Figure 2 in a cross-section along line 3-3,
- Figure 4 shows the subject of Figure 3 in a section along line 4-4,
- Figure 5 shows the subject of Figure 2 in a cross-section along line 5-5,
- Figure 6 shows the subject of Figure 2 in a cross-section along line 6-6,
- Figure 7 shows the anode used in the preferred embodiment according to the invention in a side view,
- Figure 8 shows a diagrammatic representation indicating certain flow characteristics of the preferred embodiment according to the invention, and
- Figure 9 shows a graph which illustrates an operating parameter obtained by using the present invention.

Figure 1 shows a device A according to the invention, which device serves to apply a uniform layer of an electroplatable metal such as, for example, nickel to a selected surface S in the form of a cylindrical wall 10 which has a lower, conically receding part 12 and an upper, conically receding part 14 in a complicated workpiece W. For the purpose of simplification, these three parts of the surface to be selectively plated are described below as "surface S". Although the present invention can be used to plate selective surfaces of comparatively simple workpiece shapes, one of its remarkable advantages is that it can be used in the case of a complicated workpiece such as that represented by the workpiece W, which, in the embodiment shown, is a high-strength steel forged piece for aeroplane undercarriages, in which the surface 10 is a bearing surface which may be subjected to a wearing corrosion and has to be repaired from time to time by replenishment plating of metal in order to restore the serviceability of the main forged piece. In the implementation of the invention, the selectively plated surface S is generally cylindrical as shown in the case of the workpiece W, which has many surface regions which are not to be plated, for example the entire external surface which includes, as examples of unplated shapes, a gear part 20, an elongated bush 22, outwardly projecting regions such as a shoulder 24, a lower flange 26, an outwardly projecting supporting protuberance 28 and many other external and internal surface regions which are not to be plated. It is evident that, if said forged piece W were to be plated in a plating tank as cathode, the entire surface of the forged piece would normally be plated to a certain extent. In order to plate only the surface S, a considerable expenditure on fixing and masking would be necessary if a tank plating process were used. In addition, chromium was normally plated onto the surface S in the past. If, however,

chromium is also plated onto a selective surface, this requires a considerable plating time. An increased current density does not substantially increase the efficiency and the deposition rate of chromium in a tank or even in the case of a modified tank plating system. In addition, chromium cannot easily be plated in a thickness greater than, for example, 1.27 mm (0.050"). It is therefore advantageous to apply a nickel coating to the surface S in the coating process shown.

The present invention now provides a method in which the current density in a plating process can be markedly increased in order to increase the deposition rate of a material such as, for example, nickel on the surface S. In this process, the preferred material deposits at a rate which substantially increases with increasing current density, even if the efficiency may be somewhat less than that which is achieved at lower current densities such as, for example, at less than 0.15 A/cm^2 (1.0 A/in^2).

The device A according to the invention is capable of plating a selected surface S with its receding parts 12 and 14 and it uses a high current density of over 0.31 A/cm^2 (2.0 A/in^2) in order to reduce the plating time which is necessary to achieve a predetermined metal thickness up to a value of over 1.27 mm (0.050"). In the case of the invention, a high current density can be maintained so that the deposited layer grows proportionally with the plating time. The invention is applicable, in particular, to the deposition of nickel on the selected surface S since the deposition increases with the current density without a substantial drop in the efficiency, such as that observed in chromium plating in a tank. The workpiece W is one of many complicated forged pieces in which internal bores often have to be built up again after they have worn or if

they have been machined to oversize. In many cases, internal bores in such forged pieces are actually initially produced so as to be oversized so that a metal plating layer can be applied to the surface in order to achieve a good corrosion resistance, a better wear resistance and a finer surface. In the past, a tank or a modified tank was normally used in this salvaging or build-up process, chromium or chromium and nickel layers being deposited on the internal surfaces of the bores of the forged piece. This process was very time-consuming and three days were often necessary to plate the particular surface S, which is the subject of the exemplary embodiment shown in Figure 1, in the tank. If the device A is used in applying the invention, a nickel coating is produced on the surface S to the same depth and with better uniformity in less than six hours and generally between two and six hours. The resultant nickel coating is uniform, forgeable and smooth and can be produced with greater thickness than a chromium coating, which may acquire microfine cracks as the thickness increases. To summarize, if the invention is used, the device A is capable of repairing, eliminating or correcting faults in a complicated workpiece in a relatively short time with the result that the expensive forged piece W can be maintained in an economical manner. This saves many such forged pieces from being scrapped because, in the past, the re-working often cost more than a new forged piece, the re-working was often impossible or it was possible for forged pieces to be severely damaged by immersion in tank plating solutions, in particular if the masking had not been properly carried out. The invention makes it possible to plate the same bore in similar forged pieces with the same device without realignment.

The device A has components which have been produced for the surface S. Other bores or surfaces require

modified, but functionally identical components such as those shown in Figure 2. A lower or first end cap 30 fits into the gap g, which forms the plating cell which is limited by the surface S and the anode 40, and seals it. An upper or second end cap 32 seals the other end of the plating cell at the receding part 14 of the surface S. The end caps are clamped together and are seated tightly on the mutually opposite ends of the surface S, the anode 40 being concentrically surrounded by the surface S and extending axially through the plating cell parallel to the cylinder surface 10. To hold the workpiece W and the two clamped end caps 30 and 32 in an undisplaceable position, there a suitable fixing device is provided which is shown as supporting base 50. Said supporting base supports an upwardly directed, rigid metal tube 52 which links the supporting base 50 to the cap 32, as shown in Figures 1 and 2, so that the workpiece W and the end caps 30 and 32, along with the surface S, are arranged in between in a fixed position in sandwich fashion in such a way that the first end cap is situated beneath the second end cap. A liquid pump 60 having an ultra-high throughput volume and having a reservoir for the electroplating solution, which is nickel sulphamate in the preferred embodiment, pumps the solution in a closed circuit P through the plating cell limited by the end caps 30 and 32. This liquid flow has an ultra-high volume.

In the embodiment shown, the liquid pump 60 pumps 0.315 - 0.74 l/s (600 - 700 gallons/h) liquid so that the solution flows along the path indicated by the arrows in Figures 1 and 2 at such a high rate that the solution in the plating cell is replaced at a rate in the order of magnitude of 200 to 1000 times per minute. According to the invention, the pump has an ultra-high volume throughput in order to force a liquid flow through the annular gap g at a rate which results in a complete

change of the liquid at least 25 times/minute. This extremely high volumetric flow makes it possible for nickel to deposit on the surface S from the plating solution if a current density of over 0.31 A/cm^2 (2.0 A/in^2) is used. Since the flow rate or flow velocity increases, the current density can also be increased to approximately 1.6 A/cm^2 (10.0 A/in^2) in order to increase the amount of nickel deposited on the surface S from the plating solution substantially. The anode 40 is a non-consumable anode. For this reason, the gap g remains constant over the plating cycle, which lasts less than six hours in the exemplary embodiment shown. The same deposit of nickel hitherto required approximately three days with plating by the tank plating system, if it was achievable at all.

In order to force the ultra-high volumetric flow or the ultra-high fluid flow through the closed circuit P, the pump 60 delivers the nickel sulphamate solution or a similar plating solution into a high-pressure plastic feed conduit 62 which extends upwards into the tube 52 up to the lower end cap. The liquid flow then moves upwards through the plating cell, which is limited by the surface S and the anode 40, and passes through the upper end cap 32 into two outlet conduits 64 and 66, which discharge into a larger return conduit 68. The use of two outlet conduits 64 and 66 arranged diametrically at a distance from one another distributes the outflow through the upper end cap 32 more uniformly in order to prevent cavitation and to achieve a smooth flow of the plating solution through the plating cell concerned.

In accordance with the standard design, direct current from a standard, portable plating current source is passed through the annular gap g. In this process, an anode connecting terminal 80 is connected to the anode

40 and a cathode connecting terminal 82 to the workpiece or forged piece W. In the practical design, a cathode is connected alongside the end caps 30 and 32 of the device A by placing a clamp around the workpiece W in the vicinity of the surface S. The particular structure for applying a current which flows through the fixed, annular gap g is not part of the invention and can be implemented by means of various electrical connections.

During operation, the electrical current flow between the connecting terminals 80 and 82 is adjusted so that the desired plating power is reached, which current is extremely high and at least about 0.31 A/cm^2 (2.0 A/in^2) in order to achieve the greatest utilization of the invention. The current density can be increased as far as the flow rate delivered by the pump 60 can be increased. The pumps available at present deliver about 18.9 - 50.5 l/s (300 to 800 gallons/min) and, as explained above, create an ultra-high volumetric flow so as to achieve a replacement of the electroplating solution in the gap g about 200 times/min.

The lower end cap 30 is designed in such a way that it ensures a uniform distribution of the plating solution in the gap g at the ultra-high flow rate. As a consequence, all the cross-sectional surfaces of the cylindrical anode surface and the surface S are continuously and uniformly supplied with a fresh plating solution in intimate, direct, uninterrupted physical and electrical surface contact. For this purpose, the end cap 30 has a nose 100 having an external circumferential surface which is shaped and dimensioned in a special way so that it is adapted to the contour 102 of the workpiece W. In the drawing, this contour has annular concentric shoulders 104 and 106, which form a part of the overall shape of the workpiece. Said shoulders are concentric with the surface S and determine the external

circumferential surface of the nose 100, which is shaped for the bore shown. A second part, namely a lower base plate 110 is clamped to parallel, laterally extending end faces 112 and 114 by means of a plurality of bolts 116 which are arranged at a distance from one another and which pull the nose 100 and the base plate 110 together. An O-ring 118 seals the internal flow openings of the cap 30. Said flow openings receive the high-pressure plating solution, which flows through the inlet conduit 62 at an ultra-high flow rate. The solution moves through the cap 30, as is indicated by the arrows in Figure 2.

The base plate 110 has a central threaded bore 120 which receives the end 122 of the inlet conduit 62, which end is provided with a thread and serves to connect said high-pressure pipe to the base plate 110. A concentric, second threaded bore 130 receives the end 132, provided with a thread, of the rigid support tube 52 which supports the device A and the workpiece W in its vertical position.

The nose 100 is provided with the base flow openings of the lower end cap 30 and has an outwardly directed shoulder 140 which rests against the concentric shoulder 106 of the workpiece W in order to align the cap 30. In a recess 144 of the nose 100, an O-ring 142 of rectangular cross-section is arranged in such a way that its external circular edge 146 coincides with the edge 148 at the outermost end of the conical recess part 12 in such a way that the edge 146 limits the outer edge of the plating region of the plating cell. The edges 146 and 148 can be caused to coincide exactly with one another by moving the workpiece manually on the nose 100 before the anode 40 clamps the upper end cap 32 in its position.

The internal flow openings of the cap 30 include a concentric plenum chamber 150 having a diameter $\underline{e}$ and a height of 12.7 mm (1/2"). The diameter $\underline{e}$ is about equally as large as the diameter $\underline{a}$ of the cylindrical part 10 of the surface S, with the result that a large volume of solution arriving from the inlet conduit 62 is able to collect in the plenum chamber 150 before it is passed out of the plenum chamber into a distributor chamber 160 at the upper, exposed end of the nose 100. As a result of the arrangement of a plenum chamber and a distributor chamber, a very large flow rate can be distributed by the distributor chamber after it has been uniformly pressurized in the plenum chamber.

According to a further feature of the invention, a novel nozzle arrangement is provided for conveying the solution out of the lower plenum chamber 150 into the upper distributor chamber. This nozzle arrangement generates a plurality of mutually separate and different, spiral flows of plating solution 170, which are shown diagrammatically in Figure 2 as spiral arrows 170. The nozzle device for generating this spirally configured flow through the annular gap $\underline{g}$ is generated by a plurality of holes or bores 180 arranged at a distance from one another in the circumferential direction, eight of said holes or bores being shown at an equal circumferential distance from one another. These holes are inclined with respect to the longitudinal axis at an angle of approximately 30° (in practice 27°) in such a way that the liquid flows 170 are directed into the gap $\underline{g}$ and not towards the anode 40 or the surface S. In this way, the nozzle jets or flows of the plating solution run helically, essentially in the centre of the gap through said gap $\underline{g}$ in order to prevent anything but the normal uniform flow of liquid along the anode surface and the surface to be plated. The special preferred helical design of the flow

channels according to the invention increases the surface velocity of the solution to a value which is still greater than the replacement rate generated by the pump 60. The actual velocity of the liquid flowing through the plating cell or the gap is determined by the distance which the solution traverses and the time which the solution needs to flow through the gap. This velocity of the flow through the cell is even greater than the ultra-high velocity of the ultra-high flow rate in the remaining region. The holes 180 in the preferred embodiment of the invention have a diameter of approximately 6.35 mm (1/4"), which is shown diagrammatically as dimension f in Figures 2 and 4.

To connect the lower end cap 30 to the anode, a central threaded bore 190 is provided which receives the end 192, provided with a thread, of the anode 40 and which supports the lower end of the anode of the device A when the two caps are in the plating position. As is indicated in Figure 2, the nose 100 and the base plate 110 are composed of a suitable plastics material which is non-conducting and forms an insulation between the positive anode 40 and the negatively polarized workpiece W.

From Figures 2 and 6, it emerges that the upper end cap 32 has an essentially flat plastic body containing an annular recess 204 in which there is a downwardly extending O-ring 202 which is rectangular in cross-section and whose lower inner edge 206 coincides with the outer edge 208 of the conical receding part 14 to be plated. The O-ring 202 has the same function as the O-ring 142 of the lower end cap so that these two rectangular O-rings limit the outermost extent of the selected surface to be plated during the operation of the device A.

To assemble the two end caps, the body 200 has a centred middle opening 210 which receives the cylindrical shank 218 of the anode 40. Arranged in the centred opening 210 is a standard O-ring 212 which seals said opening with respect to the shank 218 of the anode, which is able to slide in the opening. An upper collar 214 is attached to the shank 218 with a suitable aid, for example a clamping screw 216.

The flow openings for the electroplating solution in the upper cap 32 are designed so that they collect all the gas which may form during the plating process. This gas is able to proceed upwards into the cap 32 from the cap 30 as a result of its buoyancy. So that the liquid is able to collect after the plating process and in order to provide a collector for any type of gas produced during the plating process, the body 200 has a conical upper collecting space 220 which widens outwards and has an essentially flat surface which intersects two bores 222 and 224 at a distance from one another, which bores receive the nipples 230 and 232, provided with a thread, of the outlet conduits 64 and 66. These conduits have relatively large cross-sections and must be situated at a distance from the anode 40. The bores 222 and 224 therefore cut downwards into the conical surfaces 240 and 242 and form an inclined intersection with the conical surface forming the cavity 220, which is best revealed by Figures 2 and 6. In this way, the solution flowing through the gap g is collected in the cavity 220, which widens in the transverse direction, i.e. in a direction perpendicular to the direction of travel on the path P . This reduces the velocity of the solution in the cavity 220 for the purpose of distribution over the two outlet conduits 64 and 66. This velocity-reducing part which widens outwards permits the collection of all the gases which form during the plating process, but the cross-section enlargement of

the cross-sectional area of the surface 10 is insufficient to reduce the velocity substantially.

During the assembly of the device A shown in Figure 2, the end 192 of the anode 40 is screwed into the bore 190 of the lower end cap 30. The workpiece W is then centred on the square O-ring 142 and positioned in such a way that the edges 146 and 148 lie against one another. Then the body 200 is pushed over the shank 218 of the anode and guided downwards into a centred position in which the edges 206 and 208 lie against one another. The collar 214 is then fixed on the shank 218 by means of the clamping screw 216. Subsequently, the anode 40 is rotated at its upper, polygonal part 250 in order to clamp the end caps together by screwing the lower end 192 into the threaded bore 190 of the lower end cap 30. Then a suitable anode connecting part 252 is snapped into the upper end of the anode and the anode and cathode leads are connected. To start the working process, the pump 60 forces the plating solution through the plating cell, as is indicated by the arrows in Figure 2, while current flows through the annular gap g. The plating process continues until the desired thickness of plated metal has been reached.

If Figure 7 is now referred to, the anode 40 which is used in the preferred embodiment of the invention can be seen. A standard platinum-coated titanium anode rod is machined in such a way that it has a selected region of the section 300 which is adapted to the selected surface S which is to be plated. According to one feature of the invention, this surface 10 is cylindrical. The surface or the selected part 300 is therefore also cylindrical and has a length h which is adapted to the length of the surface S to be plated. When the plating process is initiated, the exposed parts of the anode 40 with the exception of the region 300 are composed of

titanium, which is anodized and therefore generates no current flow. The current therefore flows only out of the surface 300, which is adapted to the surface S to be coated. Since the anode 40 is non-consumable in one embodiment of the invention, the gap g remains constant and makes a continuous and uniform flow through the plating cell possible without changes being caused by exhaustion or depletion of the anode.

Figure 8 is a diagrammatic representation of another embodiment of the invention. The solution flow along the path P through the gap from the inlet end F to the outlet end D between the end caps 30 and 32 is controlled in such a way that a rapid and automatic replacement of plating solution takes place in the gap g. In order to achieve this, the cross-sectional area or the boundary of the outlet conduits 64 and 66 is larger than the cross-sectional area or the boundary of the inlet conduit 62; the combined area of the outlet conduits is, however, no greater than twice the cross-sectional area of the inlet conduit. In this way, the solution flow through the plating cell is controlled in such a way that a drop in velocity in the cell as a result of an increase in the cross-sectional areas in the flow process through the cell is prevented. Because of the fact that the outlet cross-section is at least as great as the inlet cross-section, no back pressure occurs and there is no substantial velocity reduction since the outlet cross-section is no greater than about twice the inlet cross-section. This is another feature of the invention which promotes a uniform and continuous flow of plating solutions through the annular gap g.

The parameters which are indicated in Figure 2 and are discussed above, are an example of the present invention. Here the surface 10 has a diameter of 41.2 mm (1.62") and the gap is 15.875 mm (0.625"). In

practice, this gap is between 1.27 and 51 mm (0.050 and 2.0"). The length of the surface S is 38 mm (1.50") and the current is approximately 30 A. 1135 litres (300 gallons) of a nickel sulphamate plating solution are pumped through the gap g per hour. The cross-sectional area A_e of the plenum chamber 150 is approximately equal to the cross-sectional area A_a of the bore of the workpiece, which is bounded by the surface 10; however, it is larger than the cross-sectional area of the gap g and substantially larger than the sum of the cross-sectional areas A_f of the various holes 180, which form the nozzles. This example makes possible a nickel deposition in the desired thickness with a plating cycle of between 2.0 and 6.0 hours. On the other hand, a tank plating of the same surface using chromium to the same thickness, if it were possible at all, would take more than three days.

According to the invention, the replacement rate of the plating solution in the gap g is at least 25 times/min. In general form this is shown by the graph in Figure 9, in which the maximum current density increases with the replacement rate. This relationship defines an operating range which rises to 1.55 A/cm^2 (10 A/in^2) or more as the replacement rate increases to 2500 times/min. Naturally, the current density used in the process is not necessarily the maximum current density since other process parameters determine the precise current density which is desired by the operator concerned for a particular workpiece to be processed. The desired current density can be determined by the size of the gap, the temperature in the gap and the parameters used, which are not part of the present invention.

According to the invention, the ultra-high flow velocity is adjusted so that the plating can be achieved only by

using two separate closures or end caps which limit the plating cell and so that the plating solution is forced through the gap between anode and selected surface to be plated at such a high velocity that high current densities become possible. In practice, the plating solution is a nickel solution and preferably nickel-sulphamate. The temperature in the gap is kept at a value between 43 and 55°C (110 and 130° F).

According to a main feature of the invention, the surface 10 is cylindrical and the circumferential surface 300 of the anode 40 is also cylindrical and limits a non-consumable anode. The plating solution is any of the various plating solutions which are used in selective plating processes without a tank. Chromium is not normally used in this type of process. The solutions normally preferred in selective plating are nickel, lead, copper, iron, tin and zinc. Naturally, noble metals could also be used; the invention is primarily applicable, however, for industrial purposes which do not envisage the use of noble metals. Chromium presents difficulty when used in the present invention insofar as the plating has to be carried out very slowly and the advantages achieved by the rapid flow are not fully achieved in the case of chromium plating. Chromium deposits are brittle and limited in their thickness, which detracts from the usefulness of the present invention. In all cases, chromium would present difficulties if used in the present invention and it is not preferred for this reason. Some features of the invention may, however, entail a certain advantage even for a chromium plating system. Nickel is regarded as the preferred and best metal which can be used in carrying out the present invention.

If the device A is used, the solution flow is limited to the surface to be plated and the anode surface. There

is no necessity for lacquering or any other insulating coating in order to prevent an undesired plating. The workpiece W may have various shapes. As a result of providing the high volumetric flow, there is a constant solution/metal interface at the anode surface 300 and the surface S to be plated. There are no liquid injections of the solution and no other auxiliary inputs into the gap g which could detract from the uniformity of the solution rapidly flowing in the axial direction through the gap. Furthermore, the tendency for gas formation in the solution decreases and there is a high surface pressure between the solution, on the one hand, and the anode surface and the surface S to be plated, on the other, so that an extremely intense liquid/metal interface contact with the flowing solution is produced. The gap g does not require to be precisely monitored provided its cross-section remains essentially the same in order not to interrupt the high surface pressure contact of the liquid solution flowing axially through the gap. The gap should not have any regions which collect the solution or reduce the velocity of the solution during its travel through the gap. Such a reduction in velocity is generally usual in tank plating and results in stagnation and accumulation of weaker plating solution which is in contact with certain parts of the surface to be plated.

According to the invention, the flow direction is directed upwards in the vertical direction in order to coincide with the flow of any gas bubbles which are produced during the plating process. Insofar as it relates to the relationship or the circulation, the term "ultra-high" volume means more than 25 solution replacement processes in the gap g per minute and preferably more than 200 replacement processes per minute. The anode design according to the invention is adapted geometrically to the surface 10 to be plated, in

contrast to the tank plating process, in which the anode is situated far away from the surface to be plated and has no real geometrical relationship with it. The anode surface interacts with the surface S and forms the gap through which the liquid flows at ultra-high velocity.

This is an unusual plating process and quite different from any tank or normal gap plating. As a result of using a lower plenum chamber 150 in the cap 30, the liquid flowing in is uniformly distributed before it flows through the holes 180 at high velocity. This change in velocity in the nozzles ensures that the individual nozzle jets which are generated by holes arranged at a distance from one another in the circumferential direction are driven through the gap in a direction between the surface to be plated and the anode surface. Since each nozzle jet is generated as a vortex or spiral, the liquid velocity increases in the gap because the solution traverses a greater distance on its path from the lower cap 30 to the upper cap 32.

As a result of the use of the cap solution, repeatability is achieved from one workpiece to another. Each workpiece could, of course, have its own specially designed fixing device. For this purpose, said fixing device, together with the pump for the plating solution and the power supply, are portable. The solution traverses a closed system and can be periodically refreshed again after a predetermined period of service. The invention achieves a uniform plating in the entire gap and there are no regions of stagnation, of increased temperature or of low flow rates. This advantage is achieved by the high solvent replacement rates which are limited primarily by the ruggedness and design of the equipment and reach 2500 replacement operations per minute, as is shown graphically in Figure 9. The anode is shaped in such a way that it matches the selected

shape to be plated, it is insoluble in a preferred embodiment, i.e. non-consumable and allows current to flow only from the selected surface, for example from the surface 300 shown in Figures 2 and 7. In this way, a uniform current also flows through the gap from the surface 300 of the anode to the surface S to be plated.



Claims

1. Process for electroplating a selected surface (S) of a workpiece (W), in which an electroplating solution (170) containing metal cations or an electrolyte solution is passed at high velocity through an elongated gap (g) which is limited by an anode (40) and that surface (S) of the workpiece (W) which is to be plated and through which there flows an electric current having a current density of more than 0.3 A/cm^2 (2 A/in^2) transversely from the anode (40) to the workpiece surface (S), characterized in that an anode (40) is used which is not consumed and which has an anodically non-active part (218) and an anodically active surface part (300), which is adapted to that surface (S) of the workpiece (W) which is to be plated, and in that the electroplating solution (170) or the electrolyte solution is passed through the gap (g) at such a high volume replacement rate that the solution in the gap (g) is replaced at least 25 times per minute.

2. Process according to Claim 1, characterized in that the anodically active surface part (300) of the anode (40) which is not consumed is adapted to that surface (S) of the workpiece (W) which is to be plated and in that an external, anodically active coating is removed from the anode at surface regions which do not correspond to the surface (S) to be plated.

3. Process according to Claims 1 or 2, characterized in that titanium is used as base metal for the anode.



4. Process according to Claim 1 or 2, characterized in that platinum is used for the anodic surface part (300).
5. Process according to one of Claims 1 to 4, characterized in that a nickel-plating solution is used as the solution.
6. Process according to one of Claims 1 to 4, characterized in that a nickel sulphamate solution is used as the solution.
7. Process according to one of Claims 1 to 6, characterized in that the temperature of the solution in the gap is maintained in a range from 110° - 130°F.
8. Process according to one of Claims 1 to 7, characterized in that the current density is in the range from 0.3 to 1.6 A/cm² (2-10 A/inch²).
9. Process according to one of Claims 1 to 8, characterized in that the solution replacement takes place in the gap 200 to 1,000 times/minute.
10. Process according to one of Claims 1 to 8, characterized in that the flow rate of the solution in the gap is so great that it is replaced 25 to 2,500 times/minute.
11. Device for electroplating a selected surface (S) of a workpiece (W), having support devices (30, 32) which support the workpiece (W) and the anode (40) in such a way that an elongated gap (g) is formed between anode (40) and that surface of the workpiece (W) which is to be plated, having a pump (60) which forces electroplating solution at high velocity through the gap in the longitudinal direction and having an electric plating current source connected to the workpiece (W)



and to the anode (40) which allows an electric current having a current density of more than 0.3 A/cm^2 (2.0 A/in^2) to flow transversely through the gap (g) from the anode (40) to the workpiece (W), characterized in that the anode (40) is a non-consumable anode which has an anodically active surface part (300) which is adapted to that selected surface (S) of the workpiece (W) which is to be plated, and in that the pump (60) has such a high capacity that the electroplating solution forced through the gap (g) by it is replaced at least 25 times/minute.

12. Device according to Claim 11, characterized in that the anode (40) consists of an anodically non-active base metal and an anodically active coating, the shape and dimensions of which are adapted to that surface (S) of the workpiece (W) which is to be plated.

13. Device according to Claim 11 or 12, characterized in that the coating is platinum.

14. Device according to one of Claims 11 to 13, characterized in that the base metal of the anode is titanium.

15. Device according to one of Claims 11 to 14, characterized in that the gap (g) is connected at one end (12) by a second end cap (32), and in that the two end caps (30 and 32) support the anode (40) and have flow openings (180 or 64, 66) which form one part of the path for the closed solvent circuit.

16. Device according to one of Claims 11 to 15, characterized in that a plenum chamber (150), which is connected to the gap (g) via a plurality of flow openings designed as nozzles (180) and arranged in the



end cap, is arranged in front of the first end cap (30) at the inlet end of the gap (g).

17. Device according to Claim 16, characterized in that the nozzles (180) are designed and arranged in such a way that they conduct the individual streams of the plating solution helically through the gap (g).

18. Device according to one of Claims 11 to 17, characterized in that the nozzles (180) for producing the individual liquid streams in the circumferential direction of an annular gap (g) are arranged at a distance from one another.

19. Device according to one of Claims 11 to 18, characterized in that the second end cap (32) has an inlet opening, a gas collection chamber (220) and a plating solution outlet (D), which are connected to the gap (g), at the outlet end of the gap (g).

20. Device according to Claim 19, characterized in that the plating solution outlet (D) of the second end cap (32) has an admission volume which is at least equal to the throughput volume of the solvent inlet (F) of the first end cap (30) and is not greater than double the throughput volume of the solvent inlet (F) of the first end cap (30).