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ELECTROLYTIC MATERIAL REMOVAL WHEREIN THE CHARGE
IN THE ELECTROLYTE IS PARTIALLY DISSIPATE
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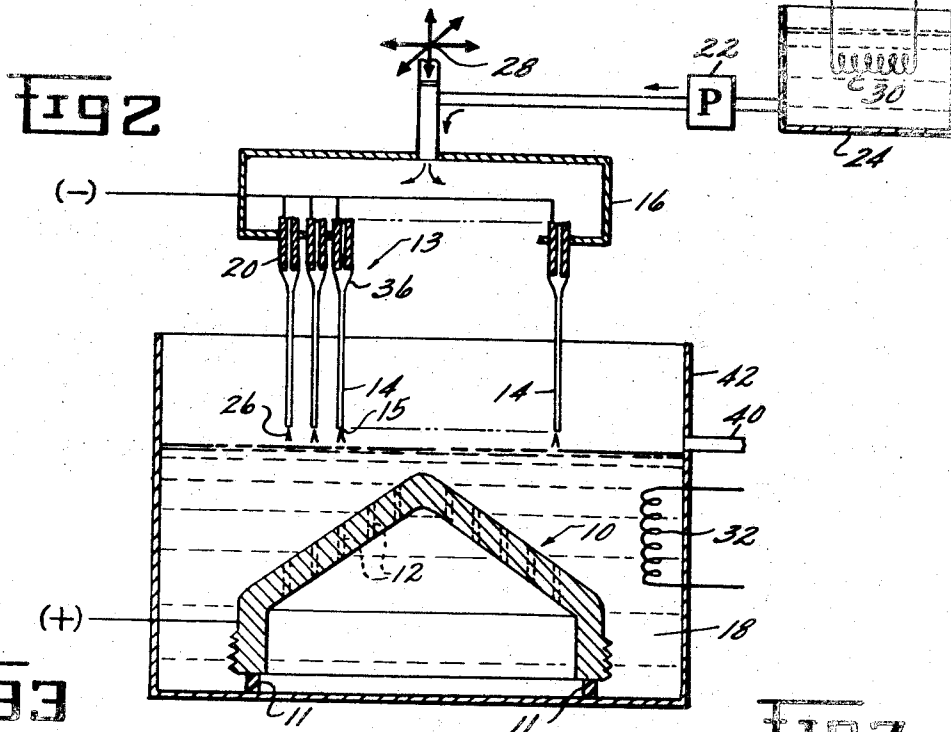
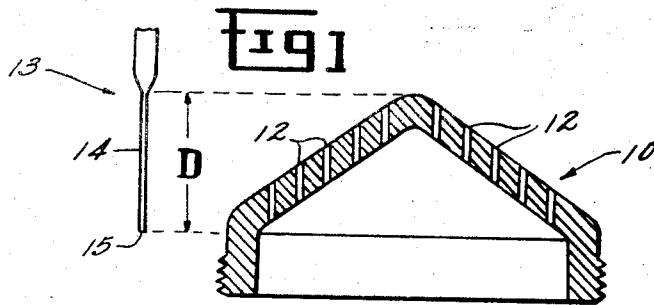


Fig. 3

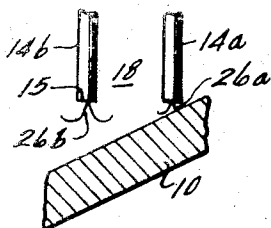


Fig. 5

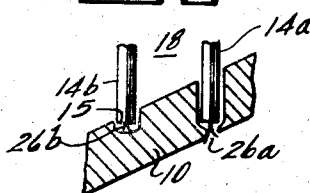


Fig. 4

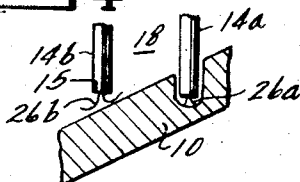


Fig. 6

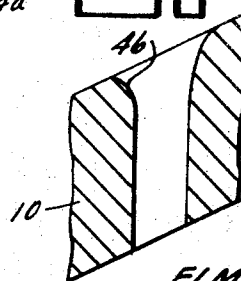
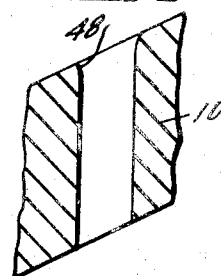


Fig. 7



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ELECTROLYTIC MATERIAL REMOVAL WHEREIN THE CHARGE IN THE ELECTROLYTE IS PARTIALLY DISSIPATE**Elmer Joseph Berger, Cincinnati, and David Clemens Perin, Madeira, Ohio, assignors to General Electric Company, a corporation of New York**

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6 Claims. (Cl. 204—143)

This invention relates to electrolytic material removal and, more particularly, to an improved electrolytic method especially useful in the production of small holes in an electrically conductive article.

In co-pending application Ser. No. 474,833 filed July 26, 1965, and assigned to the assignee of the present invention, a method and apparatus for electrolytic material removal is described. In one embodiment that method directs a stream or jet of charged electrolyte from a nozzle toward a workpiece, the power input of the system being sufficient to place the electrolyte contacting the workpiece in a condition wherein the current-voltage relationship in the electrolyte is in the "Kellogg region" (infra) and is manifested at least as an incipient glow through a well defined glow in the electrolyte.

As used in this specification, like the above identified co-pending application, the term "incipient glow" in the electrolyte refers to the condition in the electrolyte between a cathode and an anode at which the current density is greater than that which produces the quiet evolution of bubbles in direct current electrolysis. It is in the range of the "transition region" reported by Kellogg in the Journal of Electrochemical Society, 1950, 97, 133-142. At the point where an incipient glow appears in the electrolyte, the current decreases with increasing voltage whereas prior to the appearance of an incipient glow in the electrolyte, current increases linearly with increasing voltage. At the point of incipient glow, vapor begins to form at the anode surface and the formation of the characteristic bubbles normally formed in electrolysis at that area ceases. The range from this point of power application through the electrolyte up to the level at which a visual glow can be observed is sometimes designated as the "Kellogg region" and is used herein to refer to the condition in the electrolyte causing at least "incipient glow" in the electrolyte as it applies to electrolytic material removal. Further into this region, current is low and generally constant as voltage is increased.

In one specific form of the method and apparatus of that co-pending application, a tool which can include means to apply a negative charge, at least part of the time, to the electrolyte system is positioned opposite the workpiece across a space or gap. Such gap is small enough to allow the electrolyte stream or jet issuing from the the tool and contacting the workpiece to be placed in a condition causing at least an incipient glow in the electrolyte. Other operating conditions and materials being equal, the gap between the tool, and thus the means to apply the negative charge, and the workpiece will control the size and shape of the cavity resulting from removal of material by this method and apparatus. As one practical method of sensing and controlling this gap, the co-pending application describes a method for decreasing the starting space between the tool and workpiece at a first rate until a sensing means recognizes an increase, to a certain value, in current flow as a function of gap. Then, when the workpiece and tool are substantially at their operating spacing, the feed rate is reduced to feed the workpiece and tool more slowly one toward the other at an operating feed rate for the actual material removal operation based on the materials and conditions used in the method. In this way, the tool nozzle, which guides

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or directs the electrolyte and which is frequently made of glass, is protected from damage. More important, however, the size and shape of the cavity produced is accurately controlled.

Another sensing and control means required in the practice of one specific embodiment in the above identified co-pending application for complete penetration of the workpiece is means to sense first breakthrough of the workpiece and the associated drop in electric current flow because of the smaller contact area and greater resistance. Under such breakthrough conditions, the feed rate is further reduced or in some cases actually stopped in the practice of that embodiment to allow the complete penetration of the workpiece to be accomplished smoothly.

The apparatus required to sense variations in current at several selected times in the specific embodiment of the process discussed above, and as a result to control and vary feed rate as a function of current and gap, employs fairly complex circuitry and a variety of numerous inter-related components. Many of these components are best operated, preset or monitored by an equipment operator for each workpiece.

A principal object of the present invention is to provide an improved method for conducting electrolytic material removal of the type described in the above identified co-pending application but which does not require gap sensing at various times in the method and eliminates the need for variable speed feed mechanisms.

Another object is to provide an improved, efficient and practical method for the concurrent production of multiple small holes in a complex shaped workpiece.

These and other objects and advantages will be more clearly understood from the following detailed description, examples and the drawing all of which are meant to be exemplary of the invention rather than any limitation on the scope of the present invention.

In the drawing:

FIG. 1 is a sectional view of an article processed by the present invention;

FIG. 2 is a partially sectional, partially diagrammatic view of apparatus for the practice of this invention;

FIGS. 3, 4 and 5 are fragmentary, sectional views of several stages of material removal;

FIGS. 6 and 7 are fragmentary, sectional views of a comparison between entry holes as a function of starting gap.

The method of the present invention provides an automatic gap control and hence a means for eliminating complex variable feed means and gap sensing means, for example, as a function of current, at various points in the above described process. This method controls feed rate by providing an electric conducting means, one example of which is an electrolyte bath, surrounding the charged electrolyte stream. Such means dissipates the electric charge from the electrolyte stream between the cathode and the workpiece at gaps or distances at which material removal would be inaccurate or undesirable. This gap, most efficient for material removal, is hereinafter called the equilibrium gap. The size of the equilibrium gap is a function of the amount of electric charge in the electrolyte stream and the ability of the electric charge conducting means, such as an electrolyte bath, to dissipate the electric charge from the charged electrolyte stream. Across the equilibrium gap current is allowed to flow toward the workpiece to remove material at about the same linear rate at which the cathode and workpiece are moved one toward the other.

The electrical conducting characteristics of the electrolyte stream and of the electric conducting means, such as the electrolyte bath, can be made constant by fixing such variables as applied voltage, temperatures, pressures, size

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of electrolyte stream, etc. Therefore the equilibrium gap between the cathode and workpiece across which material removal begins need not be sensed or otherwise controlled. Thus a constant feed rate can be used for a single tool or a plurality of tools from which charged electrolyte is directed. Furthermore, because an electrical conductor such as the electrolyte bath surrounds the workpiece surface, added resistance to current flow is eliminated when a hole is first made through a workpiece. Hence no change in feed rate is required for such operation.

The improved electrolytic method of this invention for removing material from an electrically conductive workpiece includes the steps of directing a stream of electrically charged electrolyte from a cathode toward the workpiece across an equilibrium gap while at the same time applying between the cathode and the workpiece an electrical potential of at least 300 volts and passing an electrical current sufficient to produce in the electrolyte stream contacting the workpiece a condition causing at least an incipient glow in the electrolyte as described in the above identified co-pending application. Concurrently, the electrolyte stream is contacted with an electric charge conducting means, such as an electrolyte bath, which will dissipate a sufficient amount of charge to inhibit electrolytic material removal of the workpiece at gaps greater than the equilibrium gap. This inhibition persists until an equilibrium gap is reached if there is relative movement between the cathode and the workpiece.

The above identified co-pending application describes in detail the unusual benefit of maintaining the electrolyte, which passes between the cathode and contacts the workpiece, a condition causing at least an incipient glow in the electrolyte and the wide variety of materials which can be processed. It has been found that a potential of at least about 300 volts, more particularly in the range of 300-1200 volts and preferably 400-800 volts is desired when producing small diameter cavities or holes such as of about 0.05" or less as a maximum width dimension. In particular, that co-pending application describes the significantly improved rate of material removal which can be obtained by maintaining the electrolyte contacting the workpiece a condition causing at least an incipient glow in the electrolyte as well as conditions causing a well defined, clearly visible glow in the electrolyte. However, the power input must be held at a level less than that which produces a workpiece-enveloping vapor film which increases electrical resistance between the cathode and the workpiece sufficient to terminate removal of material from the workpiece.

The present invention will be more full understood with reference to the drawing and the following examples as typical embodiments of the invention. Although the drawings are shown to include a plurality of streams of charged electrolyte directed toward a workpiece, it should be understood that the present invention can be used with a single stream as well. The present invention, however, is particularly significant in the concurrent production of a plurality of cavities or holes in a complex shaped workpiece because of the automatic gap control provided by the electric conducting means such as the electrolyte bath. Thus a plurality of electrolyte directing means or nozzles from each of which is directed a charged electrolyte stream can be located at about the same or a variety of levels or positions with respect to the workpiece without affecting the subsequent production of the cavities or holes in the workpiece or the quality and entrance angles of such holes or cavities. Because the electrolyte stream and the electric conducting means such as the electrolyte together control operating gap, the need for accurate mechanical gapping is eliminated.

The present invention can be used to produce a variety of holes or cavities in a variety of articles. Such articles include tubes, bars, plates and other members such as the fluid spray head shown generally at 10 in FIG. 1. For

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simplicity in the drawing, the perforations or holes 12 through spray head 10 are shown to lie in the same cross sectional plane. It will be understood, however, that the present method can be used to place holes at any point in an article in the same or a variety of cross sectional planes. As will be described in connection with the electrolyte manifold 16 in FIG. 2, the nozzles 14 from which are directed the charged electrolyte stream 26 can protrude in random orientation from the face of such manifold in order to locate the holes wherever desired in the workpiece.

Referring to FIG. 2, the workpiece 10, supported by an electrical insulating means 11, is immersed in an electrical conducting means in the form of an electrolyte bath 18 at least to the extent that the bath will cover the portion of the workpiece surface into which or through which holes or cavities, shown by dotted lines, are to be placed. The electrolyte bath 18 will dissipate, at least a portion of the charge from electrolyte stream 26 directed toward the workpiece from open tip 15 of nozzle 14 to tool 13. Each of the plurality of tools and their nozzles protruding from the manifold 16 includes, in this embodiment, a cathode 20 from which the electrolyte stream gets its charge although in some instances it may be desirable to use a common cathode.

Workpiece 10, and from it electrolyte bath 18, is made to be anodic with respect to cathode 20 and hence anodic with respect to the electrolyte stream 26 directed from tip 15 of nozzle 14. In FIG. 2, manifold 16 is movable at least toward and away from workpiece 10. Preferably it is movable in a three dimensional manner by a conventional motion producing machine such as a press, not shown, but represented schematically by arrows 28. Electrolyte is supplied to manifold 16 for distribution through nozzles 14 by pump 22 from electrolyte supply tank 24.

The temperature of the electrolyte in tank 24 and of the electrolyte bath 18 each can be controlled by a heating or cooling means diagrammatically represented at 30 and 32 respectively. This temperature control is a factor in the adjustment of the relative conductivities of the charged electrolyte issuing from nozzle 14 and the electrolyte bath which acts to dissipate at least a portion of the charge from the electrolyte stream 26 until a desired operating gap has been reached. By maintaining constant operating conditions, the size of the holes or cavities to be produced in workpiece 10 can be made accurately and uniformly. Their size and shape are controlled without mechanically or electrically sensing the gap between the tip 15 of nozzle 14 and the workpiece, which gap relates to the distance between cathode 20 and the workpiece 10.

Cathode 20 for the plurality of nozzles 14 is connected as a cathode to a source of electrical power such as a D.C. rectifier which is capable of supplying at least 300 volts. A broadly useful type would supply a current of from a small amount which will allow material removal from a point at which an incipient glow appears in the electrolyte up to about 4 amps, although up to about 2 amps would be sufficient for most operations. For certain types of operations, it is possible to connect cathodes 20 with an alternating current source of at least 300 volts. Tools 13 are located in manifold 16 in a pattern which relate tips 15 of nozzles 14 to the pattern of holes or cavities desired in the workpiece 10. The capillary portion of nozzle 14 is made sufficiently long, such as D in FIG. 1, to penetrate a desired distance into or through the workpiece.

As was mentioned above, no variation in nozzle feed rate is required as each hole breaks through a workpiece such as to the internal portion of the spray head 10 in the drawing. Therefore, all of the nozzles can be moved at the same time and at the same rate toward the workpiece irrespective of whether or not they are first starting to remove workpiece material or are in an intermediate position within the workpiece, or are completing pene-

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tration of the workpiece. If the nozzles are of the same size and extend the same length from manifold 16 as shown in FIG. 2, the capillary portion of nozzle 14 should be sufficiently long as shown by D in FIG. 1 to allow the cavity or hole initially farthest from the manifold to be completed without having the transition or enlarged area beginning at about 36 to contact the workpiece.

In another arrangement, the enlarged portion of tool 13 in which the cathode has been located in the drawing can be adjusted in length in order to eliminate the need for making excessively long capillary portions. Thus the embodiment shown in FIG. 2 could be modified so that the portions of the tools carrying the cathode could be made progressively longer from the center tools outwardly. Because there is no critically with regard to gap sensing, since the electrolyte stream and the electrolyte bath control gap, the tips 15 of nozzles 14 can be located relatively inaccurately and non-uniformly with regard to the distance between the nozzle tip and the workpiece.

Prior to operation, an electrolyte is selected for the material of the workpiece. Also, the temperature and pressure at which a desired hole will be produced is selected for the electrolyte stream in relation to the temperature of the electrolyte bath 18. A variety of electrolytes used in electrolytic machining and the procedures for selecting operation conditions have been widely described in the literature and in the above identified co-pending application. Two preferred electrolytes for Ni base alloys are a 10 weight percent sulfuric acid aqueous solution and a 14 weight percent hydrochloric acid aqueous solution. Most convenient to use is an electrolyte bath of the same composition as the electrolyte stream. In this way, if desired, the electrolyte can be recirculated such as from an outlet 40 in the enclosure 42 back to electrolyte tank 24, or perhaps through a filter if desired.

With the operating conditions established, including an equilibrium feed rate which is not faster than the rate at which tip 15 of the nozzle 14 will penetrate the workpiece, the variables of feed rate, electrolyte pressure, electrolyte temperature as well as the voltage applied to cathode 20 can be set and controlled automatically by well known components. As the manifold is moved toward workpiece 20, with the electrolyte stream 26 issuing from each nozzle 14 and being charged by cathode 20, the electrolyte stream 26 first contacts electrolyte bath 18 and then tips 15 of nozzles 14 become immersed in bath 18. Because electrolyte bath 18 is an electric conducting means, at least a part of the electric charge is dissipated from the electrolyte stream. However, as shown in FIG. 3, at an equilibrium gap between the workpiece 10 and nozzle 14a sufficient current will flow through the electrolyte stream 26a from cathode 20 to workpiece 10 at voltages of at least 300 volts to place the electrolyte stream in a condition causing at least an incipient glow in the electrolyte. It has been found that at spacing greater than such gap, the electrolyte bath 18 will inhibit any electrolytic material removal. The electrolyte bath is anodic with respect to the cathode electrolyte stream and appears to the stream as a false workpiece. Such a larger gap is shown between nozzle 14b and workpiece 10 in FIG. 3 at which substantially no material removal occurs opposite nozzle 14b even though the electrical potential is 300 volts or greater.

Inaccurate gap control between cathode 20 and workpiece 10 when operating outside the scope of the present invention such as in air can result in the funnel shaped entry 46 to the hole in workpiece 10 as shown in FIG. 6. Because in the practice of this invention there is a sudden change from no material being removed from the workpiece to material removal at an equilibrium rate, the entrance 48 to the cavity or hole produced by the charged electrolyte stream is very accurately dimensioned as shown in FIG. 7. Therefore, as the nozzle 14a in FIG. 4, fed by manifold 16, penetrates further into workpiece 10

at the normal operating feed rate, nozzle 14b can approach the surface of workpiece 10 upon which it is to act without causing the funnel shaped entrance as shown in FIG. 6. With further penetration and actual breakthrough of the charged stream 26a from nozzle 14a as shown in FIG. 5, the feed rate need not be decreased to complete the full penetration of the hole as would be required outside the practice of the present invention. The flow of electrical current through the electrolyte stream at the breakthrough remains the same because of the surrounding electrolyte bath. Consequently the rate of material removal remains the same and nozzle 14b can be fed at the same constant feed rate without concern for nozzle 14a contacting shelf 44. Thus a plurality of holes or cavities can be placed in a complex shaped workpiece without varying feed rate of the nozzles and without mechanical or electrical sensing and controlling of gap other than by the inherent characteristics of the fixed operating conditions and of the electrolytes involved.

In a more specific and typical example of actual production line practice of the method of the present invention, it was desired to produce 12 holes of about 0.02" diameter in a nickel base alloy tube having a nominal composition, by weight, of 0.1% (max.) C; 15% Cr; 3% Cb; 3% Mo; 3% W; 7% Fe; 0.5% Al; 0.6% Ti; 0.006% B; with the balance Ni and incidental impurities, sometimes known as IN 102 nickel base alloy. The tube had a wall thickness of 0.04". Accurately dimensioned holes were placed repeatedly through both walls of the tube over a distance of about 0.19" through the two walls and the central cavity at an applied voltage of 470 volts and a total of 7.1 ampere current for the 12 tubes. In this example, the electrolyte used for the electrolyte stream as well as for the electrolyte bath acting as the electric current dissipating means was an aqueous solution of 10 weight percent sulfuric acid. The temperature of the bath and the temperature of the charged electrolyte was maintained at about 100° F., with an electrolyte pressure of between 40-60 p.s.i. This combination of voltage and current, which produced a condition causing at least an incipient glow in the electrolyte stream, allowed a cutting rate of 0.06" per minute through the tube wall.

It has been found that for the particular application as shown in the above example, by varying the temperature of the electrolyte between 70-200° F. and the applied voltage between 400-600 volts, hole size can be controlled and varied between 0.02-0.03" for the nozzles used. In this example, the nozzle was a drawn glass capillary tube having an inside diameter of 0.015" and a wall thickness of about 0.001".

Although the present invention has been described in connection with specific examples and embodiments as well as specific conditions, it will be recognized by those skilled in the art, particularly the art of electrochemistry and electrolytic processing, the variations and modifications of which this invention is capable. By the appended claims, it is intended to cover all such equivalent variations and modifications.

What is claimed is:

1. An electrolytic method for removing material from an anodic workpiece through the use of a hollow tool having a dielectric wall encasing an electrical cathode, the tool terminating in an electrolyte directing nozzle, comprising the steps of: directing the electrolyte from the cathode through the nozzle in a charged electrolyte stream toward and in contact with the anodic workpiece across an equilibrium gap; concurrently applying an electrical potential of sufficient intensity through the electrolyte stream so that the current passed between the cathode and the workpiece by the potential produces in the electrolyte stream at least an incipient glow wherein the current-voltage relationship in the electrolyte is at least in the "Kellogg region"; while at the same time charged electrolyte stream toward and in contact with the anodic work-

piece across an equilibrium gap; while at the same time applying between the cathode and the workpiece an electrical potential; contacting the stream of charged electrolyte with means to dissipate a sufficient amount of the charge from the electrolyte stream to inhibit electrolytic material removal from the workpiece at gaps greater than the equilibrium gap.

2. An electrolytic method for removing material from an anodic workpiece through the use of a hollow tool having a dielectric wall encasing an electrical cathode, the tool terminating in an electrolyte directing nozzle, comprising the steps of:

immersing in an electrolyte bath that portion of the workpiece surface from which material is to be removed;

positioning the tool and the workpiece one opposite the other;

contacting the cathode with an electrolyte;

directing the electrolyte from a cathode through the nozzle in a charged electrolyte stream toward and in contact with the anodic workpiece across an equilibrium gap;

applying between the cathode and the workpiece an electrical potential; and

moving the cathode and workpiece one toward the other so that the stream of electrically charged electrolyte penetrates the bath into contact with the workpiece across an equilibrium gap while passing electrical current between the cathode and the workpiece through the electrolyte stream in an amount sufficient to produce at least an incipient glow in the electrolyte stream contacting the workpiece wherein the current-voltage relationship in the electrolyte is at least in the "Kellogg region" but less than that amount of current which will produce a workpiece-enveloping vapor film which increases electrical resistance between the cathode and the workpiece sufficient to terminate removal of material from the workpiece.

3. The method of claim 2 in which the rate of moving the cathode and workpiece one toward the other is the same as the linear rate of material removal across the equilibrium gap.

4. The method of claim 2 for producing cavities of up to 0.05" as a maximum width dimension, in which:

the potential applied between the cathode and workpiece is 300-1200 volts with the current flow not exceeding 4 amps.

5. The method of claim 4 for use with an electrically conductive workpiece based on nickel in which:

the potential is maintained within the range of about 400-800 volts with the current flow not exceeding about 2 amps;

the temperature of the electrolyte stream and the electrolyte bath being about 70-200° F.; and

the charged electrolyte stream being directed under a pressure of about 40-60 p.s.i.

6. The method of claim 2 wherein a plurality of electrolyte directing nozzles are used.

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