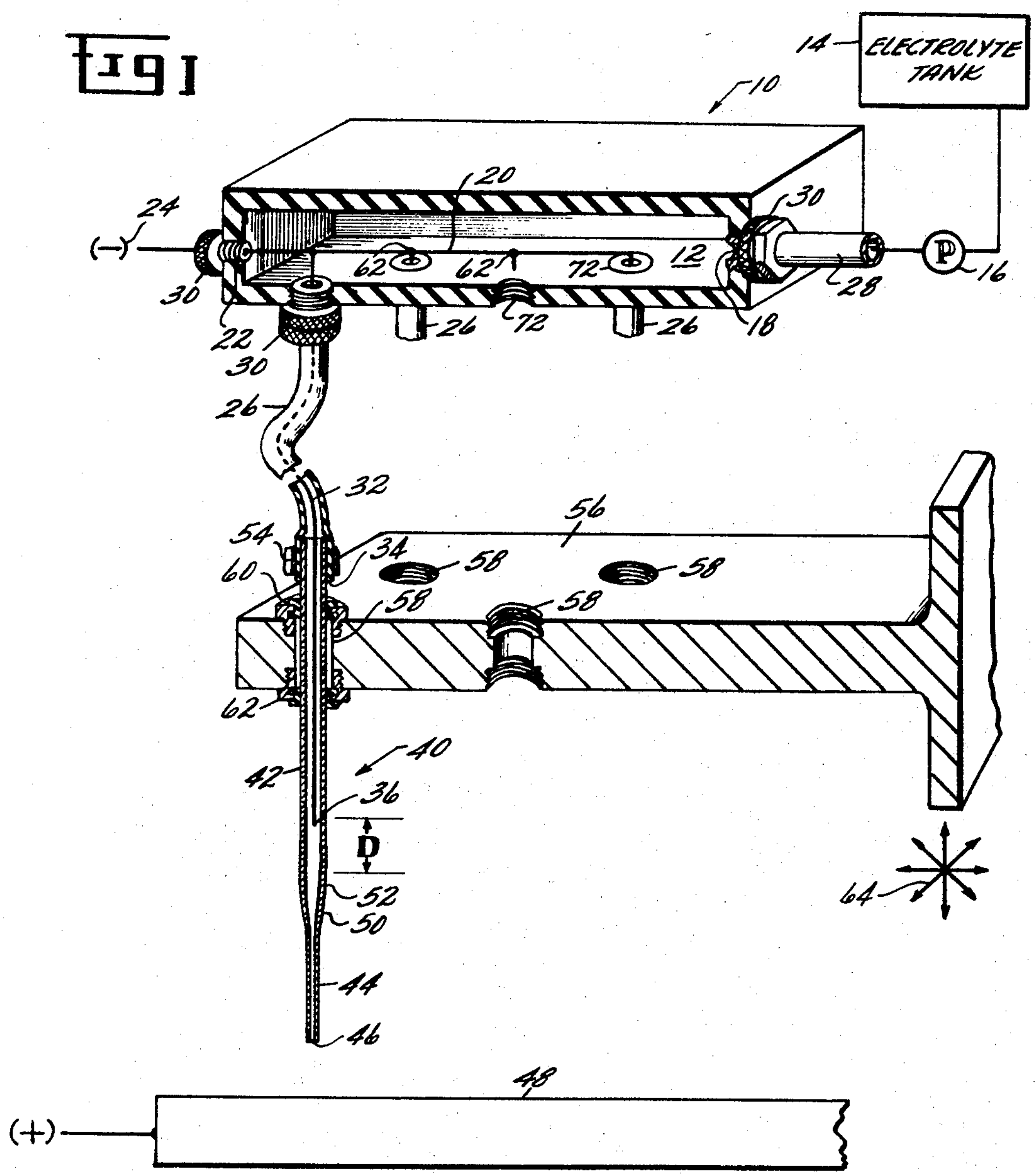
Nov. 5, 1968 J. D. ANDREWS ET AL 3,409,534

ELECTROLYTIC MATERIAL REMOVAL APPARATUS

Filed Dec. 29, 1965 2 Sheets-Sheet 1

Fig 1



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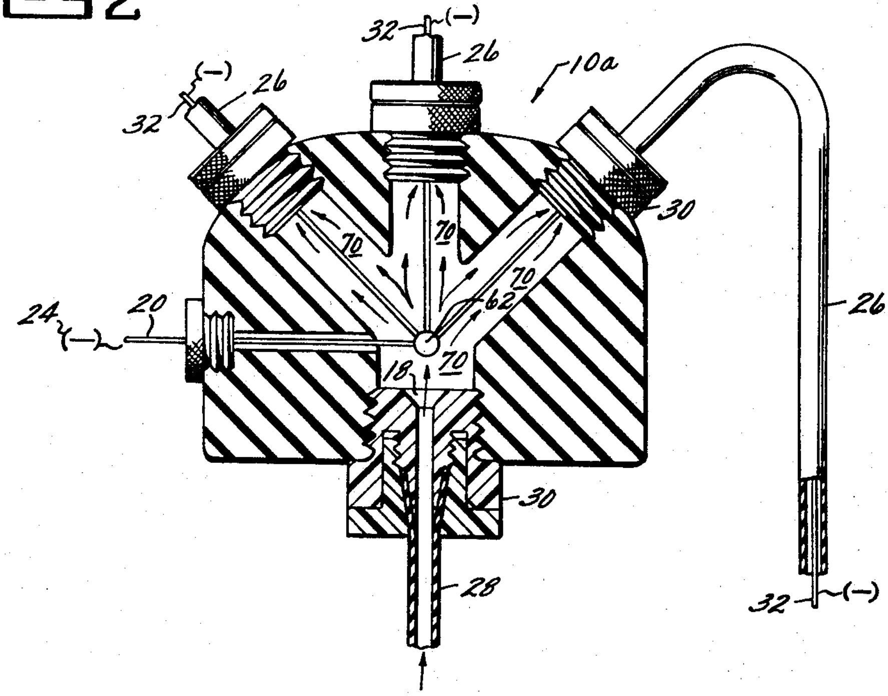
Filed Dec. 29, 1965 2 Sheets-Sheet 2

Fig 2



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1

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ELECTROLYTIC MATERIAL REMOVAL APPARATUS

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ABSTRACT OF THE DISCLOSURE

An improved apparatus for electrolytically producing cavities in a conductive workpiece is described. A cathode is located within a hollow electrolyte directing nozzle in a particular manner so as to provide process control, as well as accurate and repeatable cavities within the workpiece.

The invention described and claimed herein resulted from work done under United States Government contract FA–SS–64–1. The United States Government has an irrevocable, non-exclusive license under this United States patent application to practice and have practiced the invention claimed herein, including the unlimited right to sublicense others to practice and have practiced the invention claimed in this United States patent application for any purposes whatsoever.

This invention relates to the electrolytic removal of material from an electrically conductive workpiece and, more particularly, to apparatus for use in the production of multiple small holes or cavities in a workpiece by such a method.

In general, the method for removing material electrolytically from an electrically conductive workpiece includes placing a cathode-tool and an anode-workpiece one opposite the other while at the same time passing an electric current between the cathode and anode through an electrolyte. The shape and size of the cathode depends upon the shape and size of that portion of the workpiece which is to be removed and the cavity or hole to be produced. This process and its associated apparatus and tooling has been described in detail in the public literature and in the patented art. The known literature is directed principally to the use of relatively large cathodes the shape of which is closely related to the shape to be produced in the workpiece. Such cathodes are positioned across a relatively narrow gap from the workpiece. This method, which is sometimes referred to as electrolytic machining, electrolytic cutting, electrolytic drilling, and the like, has been described to include passing current at relatively low voltages between the cathode and the anode-workpiece.

In co-pending application Ser. No. 474,833, filed July 26, 1965, and assigned to the assignee of the present invention, an improved electrolytic material removal method and apparatus is described. In that method, a stream or jet of charged electrolyte is directed from an electrolyte directing means, such as a nozzle, toward a workpiece with the actual cathode spaced at a relatively greater distance from the workpiece than was previously allowable in other types of electrolytic material removal methods. That invention describes the unusual advantage in maintaining the power input to the charged electrolyte stream between the cathode and the workpiece at a level which produces in that electrolyte stream a condition at least at the threshold of glow discharge. Prior to that invention, the diameter of holes which could be produced electrolytically in an electrically conductive workpiece was limited by the size of a cathode tube through which electrolyte could pass and which could penetrate the workpiece. Generally a practical limitation on the tube outside diameter for production use was no less than about 0.050″. Through the use of the method and apparatus of the above identified co-pending application, a hole could be produced having a diameter of as little as 0.001″ because the actual cathode was not required to penetrate the workpiece.

2

For the production of single holes or single narrow cavities in a workpiece, a single electrolyte nozzle could be readily located opposite a workpiece. Then either the workpiece or the nozzle could be fed one toward the other or could be traversed relatively one to the other to produce a desired shape or cavity. However, in the production of a plurality of holes or cavities located at specific and closely positioned points on a workpiece surface, the co-ordinated movement of the plurality of electrolyte directing nozzles and workpiece presented operational difficulties. This was a particular problem in those situations in which it was desired that the multiple separate cathodes, and hence the electrolyte nozzles, be fed toward the workpiece. Such an embodiment required movement of the means to carry electrolyte to each of the electrolyte directing nozzles from a single source of electrolyte as well as movement of the means to charge each of the electrolyte streams from a single source of electrical power.

A principal object of the present invention is to provide improved apparatus for use in the electrolytic removal of material from an electrically conductive workpiece through a plurality of charged electrolyte streams each at least at the threshold of glow discharge and each directed from nozzles readily movable with respect to the workpiece.

Another object is to provide such apparatus which allows easy replacement of nozzles such as for change in hole size or because of nozzle damage.

A further object is to provide improved apparatus for use in such an electrolytic material removal process in which the cathode is particularly located with respect to the workpiece to provide process control as well as accurate and repeatable hole production.

These and other objects and advantages will be more easily recognized from the following detailed description, examples and from the drawing in which:

FIG. 1 is a partially sectional, partially diagrammatic view of one form of the apparatus of the present invention; and

FIG. 2 is a partially sectional view of another form of the electrolyte manifold in the apparatus of the present invention.

The above objects were achieved according to the present invention by providing improved apparatus in which the electrolyte and an electric conducting means, electrically connected with a source of electrical power, are brought together in an electrolyte chamber of a manifold. Those surfaces of the manifold which are in contact with the electrolyte are a dielectric material. In one practical form, the manifold is made of a dielectric material. The manifold includes means to introduce the electrolyte into the electrolyte chamber. The electrical conducting means in the electrolyte chamber is electrically connected with an electric power source. Communicating with the manifold are a plurality of hollow flexible electrolyte conduits of a dielectric material, such as a plastic. Each conduit, such as a tube, communicates with the electrolyte chamber to allow the electrolyte to pass from the chamber into the conduit. A flexible cathode which is electrically connected with the electric conducting means passes through each conduit and terminates in a cathode tip beyond that end of the conduit remote from the manifold. The apparatus further includes a plurality of hollow electrolyte directing nozzles of a dielectric material comprising a body, a capillary end open at the nozzle tip and a transition section joining the body with the capillary end. The transition section decreases in diameter from the body toward the capillary end. There are means to connect that end of each conduit, remote from the manifold, with its respective electrolyte directing nozzle to allow the electrolyte to flow through each nozzle and toward a workpiece from teh nozzle tip. Thus the cathode tip is located within the body of the nozzle. It has been found that the cathode tip must be located at a point about ¼–¾" from the location at which the transition section joins the body of the nozzle. The apparatus further includes nozzle holding and locating means releasably connected with the body of each nozzle to hold and position the nozzles with respect to the workpiece.

One embodiment of the present invention is shown in the partially sectional, partially diagrammatic FIG. 1. Manifold **10** in this embodiment is made of a dielectric material such as a polymerized methyl methacrylate resin some forms of which are known as Lucite plastic and Plexiglas plastic. Within manifold **10** is an electrolyte chamber **12** into which electrolyte from reservoir **14** is fed by pump **16** through an opening **18**. An electrical conducting means **20**, such as a wire or rod, is connected electrically through a wall such as at **22** of the manifold to a source of electrical power not shown but represented by the negative charge **24**. Because the electrolyte in electrolyte chamber **12** can be electrically charged by electrical conductor **20**, the walls of the manifold **10** in contact with the electrolyte in chamber **12** are covered with a dielectric material in the event the entire body of the manifold **10** is not itself of a dielectric material.

As shown in the embodiment of FIG. 1, each of a plurality of hollow flexible electrolyte conduits **26**, such as of plastic tubing, is connected to manifold **10** so that each communicates with the electrolyte chamber **12** to allow electrolyte to pass from the chamber into each conduit. Conduits **26**, electrolyte supply means such as tube **28**, and electrical conductor **20** through wall **22** can be secured to the manifold by a clamping and sealing means **30**, for example, of a type shown in more detail in FIG. 2.

In electrical connection with electric conductor **20** are a plurality of flexible cathodes such as wires **32** each extending through an electrolyte conduit **26** and extending past end **34** of each conduit **32**, remote from manifold **10**. Each cathode terminates in cathode tip **36**. Each hollow electrolyte directing nozzle, one of which is shown generally at **40**, includes a body **42** and a capillary end **44** open at tip **46** which is directed toward workpiece **48**. Between capillary end **44** and body **42** is a transition section **50** joining the body **42** with the capillary end **44** and decreasing in cross-sectional diameter from the body toward the capillary end. The location **52** at which the transition section joins the body of the nozzle is that at which the transition section starts to decrease in cross-sectional diameter with respect to the cross-sectional diameter of the body.

It has been found that cathode tip **36** must be located within a distance, shown as D in the drawing, of about ¼" to ¾" from location **52** at which the transition section joins the body of the nozzle. If tip **36** is closer to location **52** than about ¼", the flow of electrolyte through capillary end **44** is reduced to a point which causes loss of control of hole size produced in workpiece **48**, the production generally larger than desired holes and significantly reduced life of nozzle tip **46**. If cathode tip **36** is farther than about ¾" from location **52** gases in the electrolyte form into bubbles which results in loss of process control and erratic hole size. This distance is particularly significant with the use of capillary ends having an inside diameter of about 0.03" or less.

The body of each nozzle **40** is releasably secured by clamping means such as **54** to its respective conduit **26** to allow the electrolyte to pass from the conduit into the nozzle and subsequently to workpiece **48**. The body of each nozzle **40** is releasably secured with a nozzle holding and locating means such as metal plate **56** through which holes such as **58** have been produced to receive the body of nozzle **40**. The holes **58** are large enough to allow nozzle **40** to be removed for replacement by release or removal of the clamping means securing the nozzle with the conduit **26** and with means **56**. In order to locate nozzle tip **46**, and indirectly cathode tip **36**, with respect to workpiece **48** or with respect to other of the plurality of nozzles, a locator **60** and a lock means **62** are attached with body **40**. When it is desired to remove nozzle **40** either to replace it with a different size nozzle or because nozzle **40** has become damaged, clamp means **54** and locators and locks **60** and **62**, respectively, can be removed and the nozzle can be replaced without disturbing the means connected with manifold **10** to supply electrolyte to each conduit **26** and without disturbing the electrical connection between the power source **24**, electric conductor **20** and the plurality of cathodes **32**.

As shown in FIG. 1 a plurality of cathode wires **32** are connected with electrical conductor **20** at a plurality of points **62**. However, it will be understood that points **62** can be a common point as well as separate points on conductor **20**. The embodiment of FIG. 2 shows a manifold on which point **62** is a common one for each of the cathodes **32**.

The nozzle holding and locating means **56** of FIG. 1 can be movable such as with standard and well known machines, represented diagrammatically by arrows **64**, in a variety of directions with respect to workpiece **48**. The advantage of providing means **56** and hence nozzles **40** to be movable in a variety of directions with respect to the workpiece while at the same time maintaining manifold **10** in a fixed position has particular significance in the production of the plurality of holes or cavities in workpiece **48**. In addition to the more simple arrangement of components, problems relating to the loosening of connectors, wear and breakdown of insulation and contacts, and the like with regard to manifold **10** are thus eliminated. At the same time easy replacement of nozzles **40** are provided.

In FIG. 2, the manifold is shown in an embodiment generally at **10***a* in which a plurality of channels **70**, functionally equivalent to openings **72** in the manifold **10** of FIG. 1, are directed to a common point. Cathodes **32** are joined with electrical conductor **20** at **62**. Electrolyte from conduit **28** is directed to that point for passage subsequently through each channel **70** to flexible conduit **26** as described above. By using a plurality of manifolds **10***a* of the type shown in FIG. 2 with a single nozzle holding and locating means such as **56** shown in FIG. 1, the arrangement of the plurality of conduits **26** to the electrolyte nozzles **40** can be made more readily accessible.

The following examples will more clearly describe the specific conditions and the specific effects of the positioning of cathode tip **36** in the body **42** of nozzle **40** at a distance between about ¼"–¾" from the start **52** of transition section **50**.

Example 1

A nozzle having a capillary end of 0.014" outside diameter and 0.0125" inside diameter was used in an electrolyic process to produce holes in a tube of a nickel base alloy 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, and sometimes referred to as IN 102 nickel base alloy. The tube had an outside diameter of about 0.2" and a wall thickness of about 0.04". The aim was to produce 0.017" diameter holes.

The electrolyte used was an aqueous solution of 10% H_2SO_4 applied at a pressure of about 40–60 p.s.i. The power applied was at a potential of 500 volts at 300 milliamps.

In this example, the tip **36** of cathode **32** was placed within the range of ¼" to ¾" from the location **52** at which the transition section of the nozzle joins the nozzle body. Holes of 0.017" were consistently produced and nozzle tip **46** was essentially unaffected for as many as about 10,000 holes.

Example 2

The conditions, materials and apparatus of Example 1 were used in this example except that tip **36** of cathode **32** was placed at a distance less than ¼" from location **52.** Holes of about 0.020" diameter were produced rather than 0.017" and the life of nozzle tip **46** was limited to about 100 holes before replacement was required.

Example 3

The conditions, materials and apparatus of Example 1 were used in this example except that tip **36** of cathode **32** was placed at a distance greater than ¾" from location **52.** Holes of erratic size fluctuating between 0.015 and 0.017" were produced along with formation of gas bubbles which affected process control.

Thus through the practice of the present invention including the particular placement of cathode tip **36** within nozzle **40**, unusual repeatability and accuracy in hole production can be achieved in an electrolytic material removal process involving a jet of charged electrolyte.

Although the present invention has been described in connection with particular examples and embodiments, it will be understood by those skilled in the art the variations and modifications of which the invention is capable. It is intended to include in the appended claims all such variations and modifications.

What is claimed is:

1. Improved apparatus for use in the electrolytic removal of material from an electrically conductive workpiece comprising:

a manifold having walls enclosing an electrolyte chamber, the surfaces of the manifold in contact with the electrolyte being dielectric;
means to introduce electrolyte into the chamber;
an electric power source;
electric conducting means in the electrolyte chamber electrically connected with the electric power source;
a hollow flexible electrolyte conduit of a dielectric material communicating with the electrolyte chamber to allow electrolyte to pass from the chamber into the conduit;
a flexible cathode electrically connected with the electric conducting means, the cathode passing through the conduit and terminating in a cathode tip beyond an end of the conduit remote from the manifold;
a hollow electrolyte directing nozzle of a dielectric material comprising a body, a capillary end open at the nozzle tip and a transition section joining the body with the capillary end, the transition section decreasing in diameter from a location on the body toward the capillary end, the nozzle tip directed at the electrically conductive workpiece;
means connecting the conduit with the nozzle to allow electrolyte to flow from the conduit through the nozzle and toward the workpiece from the nozzle tip;
the cathode tip being located within the body of the nozzle about ¼"–¾" from the location at which the transition section joins the body of the nozzle; and
nozzle holding and locating means releasably connected with the body of the nozzle to hold and to position the nozzle with respect to the workpiece.

2. The improved apparatus of claim **1** for use in the electrolytic removal of material from an electrically conductive workpiece, comprising:

a manifold of a dielectric material having walls enclosing an electrolyte chamber;
means to introduce electrolyte under pressure into the chamber;
an electric power source at a potential of at least 300 volts;
electric conducting means in the elestrolyte chamber passing through a wall of the manifold and electrically connected with the electric power source;
a plurality of hollow flexible electrolyte conduits each of a dielectric material and each communicating with the electrolyte chamber to allow electrolyte to pass from the chamber into each conduit;
a flexible cathode for each conduit electrically connected with the electric conducting means, each cathode passing from the electrolyte chamber through the conduit and terminating in a cathode tip beyond an end of the conduit remote from the manifold;
a hollow electrolyte directing nozzle for each cathode of a dielectric material comprising a body, a capillary end open at the nozzle tip and a transition section joining the body with the capillary end, the capillary end having an inside diameter of no greater than about 0.03", the transition section decreasing in diameter from a location on the body toward the capilllary end, the open nozzle tip directed toward the electrically conductive workpiece;
releasable means connecting each conduit with its associated nozzle to allow electrolyte to flow from the conduit through the nozzle and toward the workpiece from the nozzle tip;
the cathode tip being located within the body of the nozzle about ¼"–¾" from the location at which the transition section joins the body of the nozzle; and
movable nozzle holding and locating means releasably connected with the body of the nozzle to hold and to position the nozzle with respect to the workpiece.

3. The improved apparatus of claim **2** for use in the electrolytic removal of material from an electrically conductive workpiece comprising:

a plurality of manifolds of a dielectric material, each having walls enclosing an electrolyte chamber;
means to introduce electrolyte under pressure into each of the electrolyte chambers;
an electric power source at a potential of at least 300 volts;
electric conducting means in each electrolyte chamber passing through a wall of each manifold, each electric conducting means electrically connected with the electric power source;
a plurality of hollow flexible electrolyte conduits each of a dielectric material, each communicating with its respective electrolyte chamber to allow electrolyte to pass from the chamber into each conduit;
a flexible cathode for each conduit electrically connected with the electric conducting means in its respective electrolyte chamber, each cathode passing from its electrolyte chamber through the conduit and terminating in a cathode tip beyond an end of the conduit remote from the manifold;
a hollow electrolyte directing nozzle for each cathode of a dielectric material comprising a body, a capillary end open at the nozzle tip and a transition section joining the body with the capillary end, the capillary end having an inside diameter of no greater than about 0.03", the transition section decreasing in diameter from the body toward the capillary end, the open nozzle tip directed toward the electrically conductive workpiece;
releasable means connecting each conduit with its associated nozzle to allow electrolyte to flow from the conduit through the nozzle and toward the workpiece from the nozzle tip;
the cathode tip being located within the body of the nozzle about ¼"–¾" from the location at which the transition section joins the body of the nozzle; and
movable nozzle holding and locating means releasably connected with the body of the nozzle to hold and to position the nozzle with respect to the workpiece.

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