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Raymond et al.

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[54] **ELECTROPLATING METHOD AND APPARATUS**

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[52] **U.S. Cl.** **204/26;** 204/228; 204/269; 204/272

[51] **Int. Cl.²** **C25D 7/04**

[58] **Field of Search** 204/26, 228, 255, 272, 204/269

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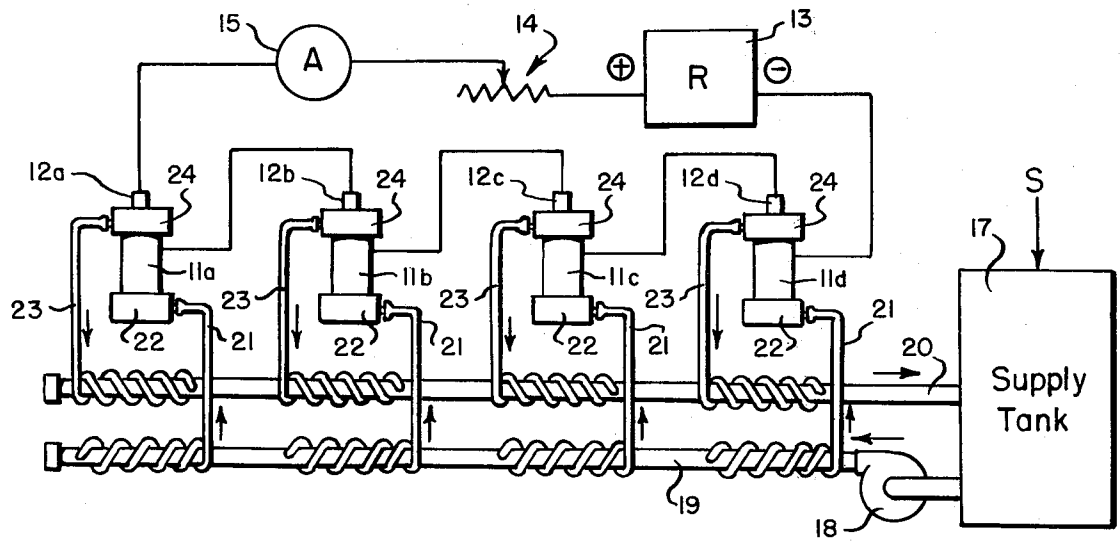
[57] **ABSTRACT**

The interior surfaces of each of a plurality of hollow metal objects are simultaneously electroplated with a uniform layer of electrodeposited metal by positioning an anode centrally within each of the hollow objects and electrically connecting the anodes and the objects being electroplated in series with each other and with a source of an electrolyzing current. An electrically conductive electrolyte solution is continuously supplied to the interior of each of the hollow objects and an equivalent quantity of the solution is continuously withdrawn from each of the objects and returned to the source of supply of the solution. The electrolyte solution is introduced into and is withdrawn from each object through a conduit that provides a path of high electrical resistance to the flow of an electric current through the electrolyte contained in said conduit so that the stray electrolyzing currents flowing from any of the objects through the solution in the conduit are reduced to a value that will not significantly affect the electroplating operation taking place in the other objects being electroplated.

4 Claims, 4 Drawing Figures



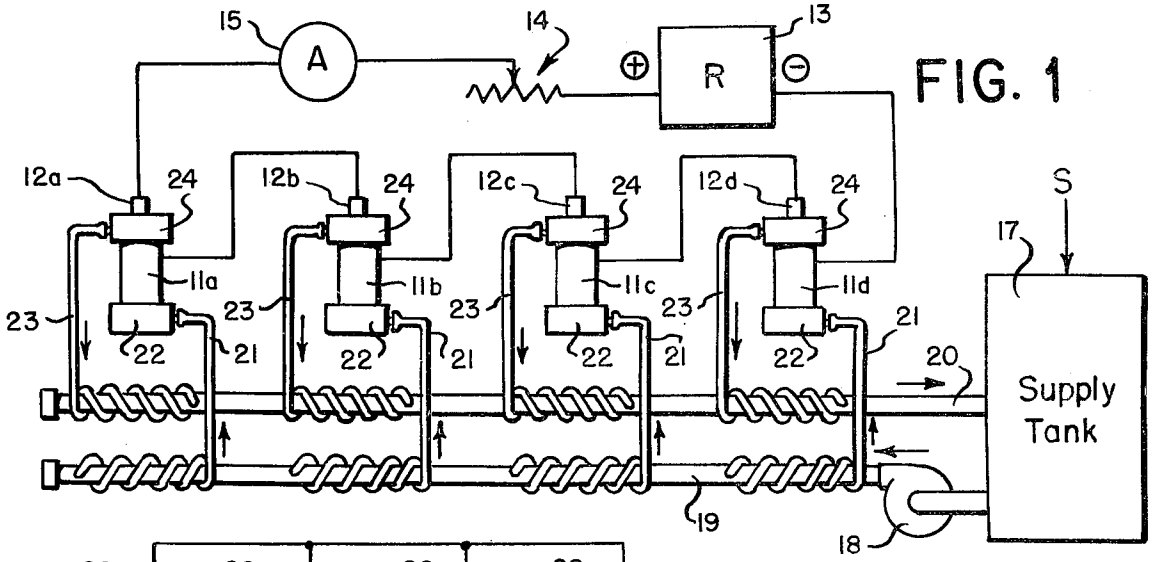


FIG. 1

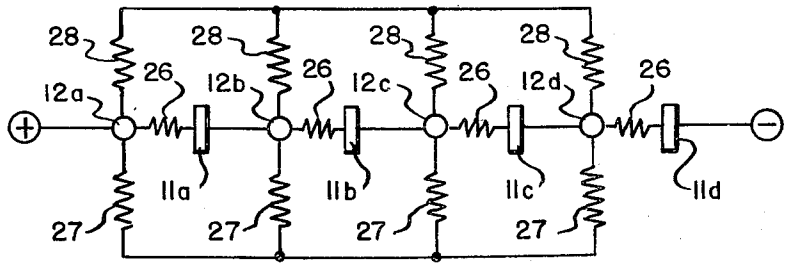


FIG. 2

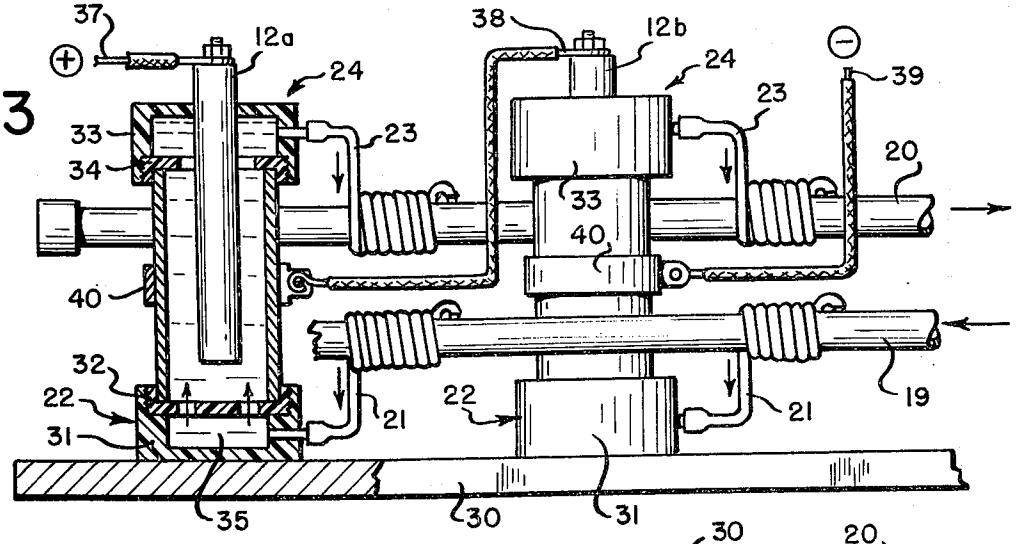


FIG. 3

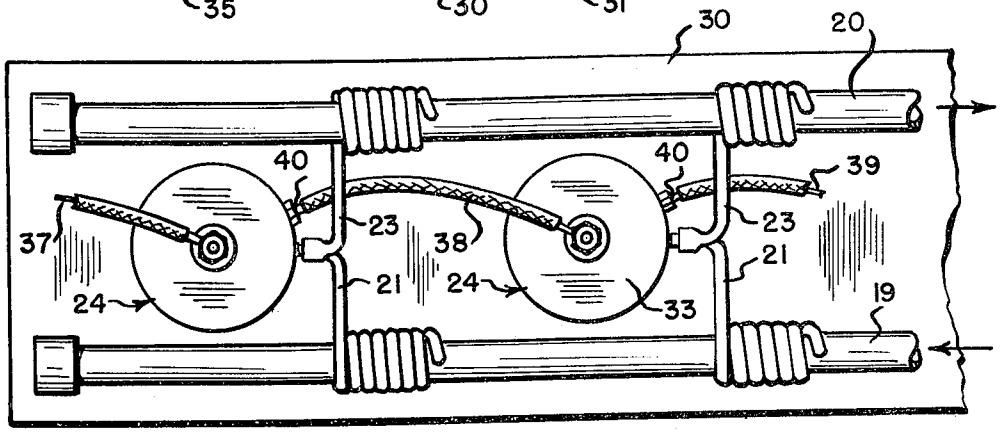


FIG. 4

ELECTROPLATING METHOD AND APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the simultaneous electroplating of the interior surfaces of a plurality of hollow metal objects.

2. Prior Art

It is frequently desirable to provide the interior surface of a hollow metal object with a corrosion resistant and/or wear resistant layer of electrodeposited metal. For example, gun barrels and the cylinder walls of internal combustion engines are frequently chromium plated to provide hard, wear-resistant interior surfaces for these objects. In one method for accomplishing this result, the exterior and all other surfaces of the objects except the interior surfaces to be electroplated, are masked or coated with a non-conductive material so that the object can be totally immersed in an electrolyte solution contained in a conventinal electrolyzing tank and the interior surfaces thereof electroplated in the conventional manner. In a preferred procedure to which the present invention pertains, the hollow metal object is employed as the container itself for the electrolyte solution, the openings of the hollow object being sealed off and electrolyte solution being supplied to and being withdrawn from the interior of the object through suitable conduits connected to a source of supply of the electrolyte solution. An anode is positioned centrally within the hollow object, and an electrolyzing current is passed from the anode through the electrolyte solution within the object to the interior metal surface being electroplated. In this procedure, the hollow metal object, the anode and the electrolyte solution contained in the object comprise, in effect, a self-contained electroplating cell.

If a number of hollow metal objects are to be electroplated it is desirable from the standpoint of both economy and efficienty that all of the objects, or as many of the objects as possible, be electroplated at the same time. Moreover, it is frequently very important that the layer of electrodeposited metal on the interior surfaces of all of the objects being electroplated have the same uniform and reproducible thickness. When a number of hollow metal objects are to be electroplated in accordance with the procedure to which the present invention pertains, it has theretofore been the general practice either to connect the centrally positioned anode within each hollow metal object and the hollow metal object (the cathode) with which the anode is associated directly to their own individual source of electrolyzing current (usually a rectifier), or to connect all of the anodes and all of the metal objects (the cathodes) in parallel to a common source of electrolyzing current. The use of an individual rectifier for each hollow metal object being electroplated is, in most cases, expensive. On the other hand, if all of the anodes and all of the cathodic metal objects are connected in parallel to a single rectifier, it is extremely difficult to control precisely the electrolyzing current flowing through the electrolyte solution in each object and hence to control the thickness of the layer of metal being electrodeposited on the interior surfaces of each object.

In order to obtain an electrodeposited layer of uniform thickness on the interior surfaces of each of the hollow metal objects it is necessary that the same quantity of electrolyzing current be caused to flow through the electrolyte in each object. We have discovered that the most effective way to accomplish this result is to connect the anodes and the hollow objects being electroplated in series with each other and with the source of electrolyzing current so that the same current (theoretically, at least) will flow through all of the objects in the series. However, despite a very substantial improvement in the uniformity of the thickness of the layer of electrodeposited metal, we have found that significant and troublesome variations remain in the thickness of the electrodepoited metal from one metal object to another in the series. Investigation of the problem has disclosed that stray electrical currents flow through the electrically conductive electrolyte solution from one hollow object to the others in the series thereby adversely affecting the electroplating operation taking place in the other objects. After further investigation we have found that these stray electrical currents can be reduced to an acceptably small value by causing the electrolyte solution being supplied to and being withdrawn from each hollow object being electroplated to travel through a relatively long length of small diameter non-conductive plastic tubing. As a result, stray electric currents are reduced to an acceptable minimum, and uniform layers of electrodeposited metal are readily obtained on the interior surfaces of series-connected hollow metal objects.

SUMMARY OF THE INVENTION

In our new procedure for simultaneously electroplating the interior surfaces of each of a plurality of hollow metal objects with a uniform layer of an electrodeposited metal, the metal objects are serially arranged with respect to each other and an anode is positioned centrally within each of the objects. The metal objects and the anodes positioned within each object are then electrically connected in series with each other and with a source of an electrolyzing current. An electrically conductive electrolyte solution from a common source of supply of the solution is continuously supplied to the interior of each of the hollow metal objects being electroplated, and an equivalent quantity of the solution is continuously withdrawn from each of the objects and returned to the common source of supply to the solution. The electrolye solution is introduced into and is withdrawn from each object through a conduit that provides a path of high electrical resistance to the flow of an electric current through the electrolyte solution contained in said conduit so that stray electrolyzing currents flowing from any of the objects through the solution contained in the conduit is reduced to a value that will not significantly affect the electroplating operation taking place in the other objects being electroplated.

By way of example, each of the electrolyte solution supply and discharge conduits comprises a separate length of non-conductive tubing. Each of said lengths of tubing has a cross-sectional area and is of a length such that the resistance to the flow of an electrical current through the electrolyte solution contained in each length of tubing is sufficiently great that the magnitude of stray electrolyzing current flowing from any object in the series through the solution contained in the tubing connected thereto is reduced to a value that will not significantly affect the electroplating operation taking place in other objects in the series.

BRIEF DESCRIPTION OF THE DRAWINGS

The simultaneous electroplating of the interior surfaces of a plurality of metal objects in accordance with the invention will be better understood from the following description thereof in conjunction with the accompanying drawings of which:

FIG. 1 is a schematic view of the overall arrangement of hollow metal objects being electroplated connected in series with the source of electrolyzing current and in parallel with the source of electrolyte solution,

FIG. 2 is a schematic representation of the electrical characteristics of the arrangement shown in FIG. 1,

FIG. 3 is a side view of two hollow metal objects the interior surfaces of which are being electroplated in accordance with the practice of the invention, one of the metal objects being shown in section to illustrate the internal arrangement of the parts, and

FIG. 4 is a plan view of the apparatus shown in FIG. 3.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

As noted, the present invention relates to the simultaneous electroplating of the interior surfaces of each of a plurality of substantially identical hollow metal objects with uniform layer of an electrodeposited metal. It is applicable to the electroplating of any hollow metal object that can be made to serve as the container for the electrolyte solution containing ions of the metal being electrodeposited, including such objects as gun barrels, reactor vessels, food processing equipment and utensils, machine parts and the like. The new procedure and the apparatus for carrying out the procedure will be described in connection with the simultaneous electrodeposition of a uniform layer of metallic chromium on the cylindrical interior surfaces of removable metal liners for the cylinders of an internal combustion engine.

As shown schematically in FIG. 1 of the drawings, four substantially identical cylinder liners **11***a*, 11*b*, 11*c* and **11***d* are arranged serially with respect to each other, and nonconsumable anodes **12***a*, 12*b*, 12*c*, and **12***d* are positioned centrally within each cylinder liner. Power supply means **13** (advantageously, a rectifier R) are provivded for supplying an electrolyzing current to the system, and current control means **14** and current measurement means **15** are also provided for controlling and measuring the amount of electrolyzing current being supplied by the electrolyzing current supply means. Electrical conductor means electrically connect the cylinder liners and the anodes disposed therein in series with each other and with the current supply means so that the positive pole of the source of electrolyzing current is electrically connected to the anode disposed within the first cylinder liner in the series, each cylinder liner except the last liner is electrically connected to the anode disposed within the next succeeding cylinder liner in the series, and the last cylinder liner is electrically connected to the negative pole of the source of the electrolyzing current. That is to say, with reference to FIG. 1 of the drawings, the positive pole of the rectifier R is electrically connected to the anode **12***a* centrally disposed within the first cylinder liner **11***a*, the first cylinder liner **11**a is electrically connected to the anode **12***b* centrally disposed within the second cylinder liner **11***b*, the second cylinder liner **11***b* is electrically connected to the anode **12***c* centrally disposed within the third cylinder liner **11***c*, the third cylinder liner **11**c is electrically connected to the anode **12***d* centrally disposed within the last cylinder line **11***d*, and the last cylinder liner **11***d* is electrically connected to the negative pole of the rectifier.

A supply of electrolyte solution S (for example, an aqueous solution of chromic acid) is contained in a supply tank **17.** A pump **18** delivers the electrolyte solution to the solution supply main **19** from whence it is delivered to the interior of each of the cylinder liners, and excess or overflow electrolyte solution is discharged from each cylinder liner and is returned to the supply tank **17** through the solution discharge main **20.** The electrolyte solution is supplied to each cylinder liner **11***a*, 11*b*, **11***c* and **11**d through individual solution supply conduits **21** each of which communicates at one end with the solution supply main **19** and at the other end with a solution inlet fitting **22** secured to the lower end of each cylinder liner. Similarly, the electrolyte solution is discharged from each cylinder liner through individual solution discharge conduits **23** each of which communicates at one end with the solution discharge main **20** and at its other end with a solution discharge fitting **24** secured to the upper end of each cylinder liner.

When electrolyte solution is being supplied to each of the cylinder liners and when an electrolyzing current is passed through the arrangement of series-connected anodes and cylinder liners, the same amount of current will pass through the electrolyte solution contained in each of the cylinder liners and, theoretically at least, precisely the same amount of metallic chromium will be electrodeposited on the interior surfaces of each of the cylinder liners. As previously mentioned, however, it has been found that stray electrolyzing currents flow through the electrolyte solution from one cylinder liner to another in the series and, as a result, adversely affect the desired uniformity in thickness of the layer of electrodeposited metal in adjoining cylinder liners.

We have found that these troublesome stray currents can be reduced to an acceptable level, if not entirely eliminated, by increasing substantially the electrical resistance to the flow of these currents through the electrolyte solution being supplied to and being discharged from each cylinder liner. That is to say, if each of the conduits through which the electrolyte solution is supplied to and withdrawn from each cylinder liner provides a path of high electrical resistance to the flow of an electrical current through the electrolyte solution contained in the conduit, stray electrolyzing currents flowing from any of the cylinder liners through the solution in the conduit is reduced to a value that will not significantly affect the electroplating operation taking place in the other cylinder liners being electroplated.

In the presently preferred embodiment of the process the required increase in the electrical resistance of the electrolyte solution is obtained by causing the solution being supplied to and withdrawn from the cylinder liners to travel through relatively long lengths of relatively small diameter non-conductive plastic tubing. That is to say, the resistance to the flow of an electric current through an electrolyte solution contained in a length of non-conductive plastic tubing varies directly with the length of the tubing and inversely with the square of the diameter of the tubing. More specifically, the electrical resistance of an electrolyte solution contained in a

given length of plastic tubing 6mm (¼ inch) in diameter is four times as great as the electrical resistance of the same solution contained in the same length of plastic tubing 12mm (½ inch) in diameter, and if the 6mm diameter tubing is twice as long the 12mm diameter tubing the electrical resistance of the electrolyte solution contained in the smaller tubing will be eight times that of the solution contained in the larger tubing. Accordingly, in the embodiment shown in FIG. **1**, the solution supply conduits **21** and solution discharge conduits **23** comprise lengths of non-conductive tubing of sufficiently small diameter and of sufficiently great length to reduce the magnitude of stray electrolyzing current flowing therethrough from one of the cylinder liners to a value that will not significantly affect the electroplating operation taking place in the other cylinder liners in the series.

Other means may be employed to provide the necessary path of high electrical resistance to the flow of an electric current through the electrolyte solution contained in the solution supply and discharge conduits. For example, each conduit may be fitted with two or more valve-like elements which open and close alternately in succession to provide a discontinuous path for the flow of an electric current. Other equivalent measures may also be employed. In the preferred embodiment the lengths of tubing employed as solution supply and discharge conduits are substantially longer than would normally be required to connect the solution supply main **19** to the solution inlet fitting **22** or to connect the solution discharge main **20** to the solution discharge fitting **24** of each of the cylinder liners being electroplated, and preferably at least two or three times as long as actually needed to connect the mains to fittings. Similarly, the tubing employed is of substantially smaller diameter than the tubing that would normally be employed for this purpose, and preferably at least about one half the diameter of such tubing. The tubing itself must be made of an non-conductive material such as polyethylene. The excess length of the small diameter tubing may be conveniently accomodated by wrapping the tubing helically about the solution mains as shown in the drawing.

The effect of causing electrolyte solution to flow through the relatively long lengths of relatively small diameter tubing **21** and **23** on the electrical characteristics of the electroplating system is shown schematically in FIG. **2** of the drawing. The resistance to the flow of electrolyzing current through the electrolyte solution disposed between the anode **12***a* and the cathodic cylinder liner **11**a (and between the anode **12***b* and the cathodic liner **11***b*, etc.) is represented by the resistance symbol **26,** and the resistance to the flow of stray electrolyzing current through the elongated supply conduits **21** and discharge conduits **23** are represented by the resistance symbols **27** and **28,** respectively. In order to reduce the stray currents flowing through the electrolyte solution contained in the conduits **21** and **23** to acceptable levels, the ohmic value of each of the resistance **27** and **28** must be substantially greater (at least several times greater) than that of the resistance **26.**

The required ohmic values of the resistances **27** and **28** may be determined by first determining the maximum variation in the thickness of the layer of electrodeposited metal that can be tolerated, by computing the amperage of the stray currents required to plate or deplate a layer of metal equal in thickness to a layer of the prescribed tolerance, and by computing the minimum ohmic values required to prevent the amperage of the stray currents from exceeding the maximum amperage permitted. The length of the electrolyte supply and discharge conduits required to provide these minimum ohmic values is, of course, a function of the specific resistivity of the electrolyte solution being used and may be determined by routine calculation. Alternatively, the selection of tubing of sufficiently small diameter and of sufficiently great length to meet this requirement may be accomplished by empirical observation. If the layer of electrodeposited metal is of uniform thickness in all of the hollow objects being electroplated, stray currents have been reduced to an acceptable level and the tubing is of the correct size and length. If the layer is not uniform and stray currents are the reason, a smaller diameter tubing or a longer length of tubing must be employed.

In the embodiment shown in FIGS. **3** and **4** of the drawings, the cylinder liners **11**a and **11**b are serially disposed on the support structure **30.** The solution inlet fitting **22** secured to the lower end of each cylinder liner comprises an outer cap member **31** and an inner seal member **32,** and the solution discharge fitting **24** secured to the upper end of each cylinder lining comprises an outer cap member **33** and an inner seal member **34.** The inner seal members **32** and **34** provide a fluid tight seal between the lower and upper ends of the cylinder liner and the outer cap members **31** and **33.** The inner seal member **32** also serves as a solution distribution plate for the electrolyte solution flowing upwardly from the solution inlet chamber **35** into the interior of the cylinder lining. The inner seal members **32** and **34** are formed of a non-conductive plastic material that is inert with respect to the electrolyte solution, for example, polypropylene, and the outer cap members **31** and **33** are advantageously, but not necessarily, formed of a similar material.

Non-consumable anodes **12***a* and **12***b* are centrally disposed within each of the cylinder liners **11***a* and **11***b*, each anode extending downwardly through appropriate openings formed in the outer cap member **33** and the inner seal member **34,** respectively. The anode **12***a* is connected by a heavy gauge conductor **37** to the positive pole of the source of electrolyzing current (not shown), the cylinder liner **11***a* is connected to the anode **12***b* by the heavy gauge conductor **38,** and the cylinder liner **11***b* is connected to the next anode in the series or to the negative pole of the source of electrolyzing current by the heavy gauge conductor **39.** The conductors **38** and **39** are secured to their respective cylinder liners **11***a* and **11***b* by means of metal clamp members **40** which insure a good electrical connection between the cylinder liners and the conductors.

An electrolyte solution supply main **19** and a solution discharge main **20** are connected to a solution supply tank (not shown). Electrolyte solution from the solution supply main **19** is delivered to the solution inlet fitting **22** secured to the lower end of each cylinder liner through a relatively long length of relatively small diameter plastic tubing **21,** and overflow electrolyte solution from the solution discharge fittings **24** secured to the upper end of each cylinder liner is delivered to the solution discharge main **20** through relatively long lengths of relatively small diameter plastic tubing **23,** all in accordance with the practice of the invention.

The following example is illustrative but not limitative of the practice of the invention.

Ten steel liners for the cylinders of an internal combustion engine are provided with solution inlet and solution discharge fittings and are arranged serially on a support bench, a non-consumable anode made of lead is disposed centrally within each cylinder liner, and the ten anodes and cylinder liners are electrically connected together in series with each other and with a source (a rectifier of 1000 amperes capacity) of electrolyzing current, all as shown in FIGS. 1 and 3 of the drawings. An electrolyte solution containing 32 ounces per gallon chromic acid (CrO_3) is contained in a 500 gallon supply tank, the supply tank is connected to solution supply and solution discharge mains made of 1½ inch diameter plastic pipe, and the solution supply and discharge mains are connected respectively to the solution inlet fittings and the solution discharge fittings of the cylinder liners by means of solution supply and solution discharge conduits made of non-conductive plastic tubing, as also shown in the drawings. Electrolyte solution from the supply tank is circulated through all of the cylinder liners, the flow of the solution through each cylinder liner being controlled so that the solution flows over the inner surface of each liner at the rate of 133 ft/minute. An electrolyzing current is passed through the ten series connected anodes and cathodic cylinder liners, the current being 500 amperes at 50 volts (representing a voltage drop of 5 volts per liner). The electroplating operation is carried out in two separate periods or runs as described below.

In the first electroplating run each of the solution supply conduits and solution discharge conduits comprises polypropylene tubing of 1 inch inside diameter and 5 feet in length. At the end of the electroplating run the layers of electrodeposited chromium metal on the interior surface of the cylinder liners are observed to be slightly non-uniform in thickness.

In the second electroplating run each of the solution supply conduits and solution discharge conduits comprises polyethylene tubing of ½ inch inside diameter and 15 feet in length. On completion of the electroplating run the layers of electrodeposited chromium metal on the interior surfaces of the cylinder liners are observed to be of substantially uniform thickness and quality.

We claim:

1. Method for simultaneously electroplating the interiors of each of a plurality of hollow metal which comprises,

positioning an anode centrally within each of the hollow objects being electroplated,

electrically connecting said anodes and the objects being electroplated in series with each other and with a source of an electrolyzing current,

continuously supplying an electrically conductive electrolyte solution from a common source of supply of said solution to the interior of each of the hollow objects being electroplated and continuously withdrawing an equivalent quantity of said selectrolyte solution from each of said objects and returning said solution to said common source of supply,

passing an electrolyzing current through the series of anode and electrolyte-containing objects, and

causing the electrolyte solution being supplied to and being withdrawn from each object being electroplated to travel through solution inlet and solution outlet passageways that provide a path of high electrical resistance to the flow of an electric current through the electrolyte solution contained in said passageways, whereby the magnitude of the electrolyzing current flowing from any of the objects being electroplated through said electrolyte solution is reduced to a value that will not significantly affect the electroplating operation taking place in other objects in the series.

2. The method according to claim 1 in which the solution inlet and solution outlet passageways connected to the objects being electroplated each comprises a separate length of non-conductive tubing, each of said lengths of tubing having a cross-sectional area and being of a length such that the resistance to the flow of an electrical current through the electrolyte solution contained in each length of tubing is sufficiently great that the magnitude of stray electrolyzing current flowing from any of said objects through the solution contained in said tubing is reduced to a value that will not significantly affect the electroplating operation taking place in other objects in the series.

3. The method according to claim 1 in which the required minimum ohmic value of the resistance to the flow of an electric current through the electrolyte solution contained in each passageway is determined by first determining the maximum variation in the thickness of the layer of electrodeposited metal that can be tolerated, by determining the amperage of stray currents required to plate or deplate a layer of metal equal in thickness to a layer of the prescribed tolerance, and by determining the minimum ohmic value required to prevent the amperage of the stray currents from exceeding the maximum amperage permitted.

4. Apparatus for simultaneously electroplating the interior surfaces of each of a plurality of hollow metal objects with a uniform layer of an electrodeposited metal which comprises:

a plurality of serially disposed substantially identical hollow metal objects to be electroplated, a non-consumable anode centrally disposed within each of the hollow metal objects in the series, power supply means for supplying an electrolyzing current, and electrical conductor means electrically connecting the hollow metal objects and the anodes disposed therein in series with each other and with the electrolyzing current power supply means,

a vessel adapted to contain a supply of electrolyte solution, an electrolyte solution supply conduit connected to the electrolyte solution supply vessel and to each of the hollow metal objects for supplying electrolyte solution to the interior of each of said hollow metal objects, and an electrolyte solution discharge conduit connected to each of the hollow metal objects and to the electrolyte solution supply vessel for withdrawing electrolyte solution from each of said objects and returning said solution to said supply vessel,

the electrolyte solution supply conduit and discharge conduit connected to each hollow metal object comprising a length of tubing of electrically insulating material, said tubing having a cross-sectional area and having sufficient length such as to cause the resistance to the flow of an electric current through the elctrolyte solution contained in each of said lengths of tubing to be sufficiently great to reduce the magnitude of the electrolyzing current flowing therethrough from any of the objects being electroplated to a value that will not significantly affect the electroplating operation taking place in other objects in the series.

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