Oct. 20, 1970 W. E. COOKE ET AL 3,535,222

APPARATUS FOR CONTINUOUS ELECTROLYTIC TREATMENT

Original Filed Feb. 4, 1964 5 Sheets-Sheet 1

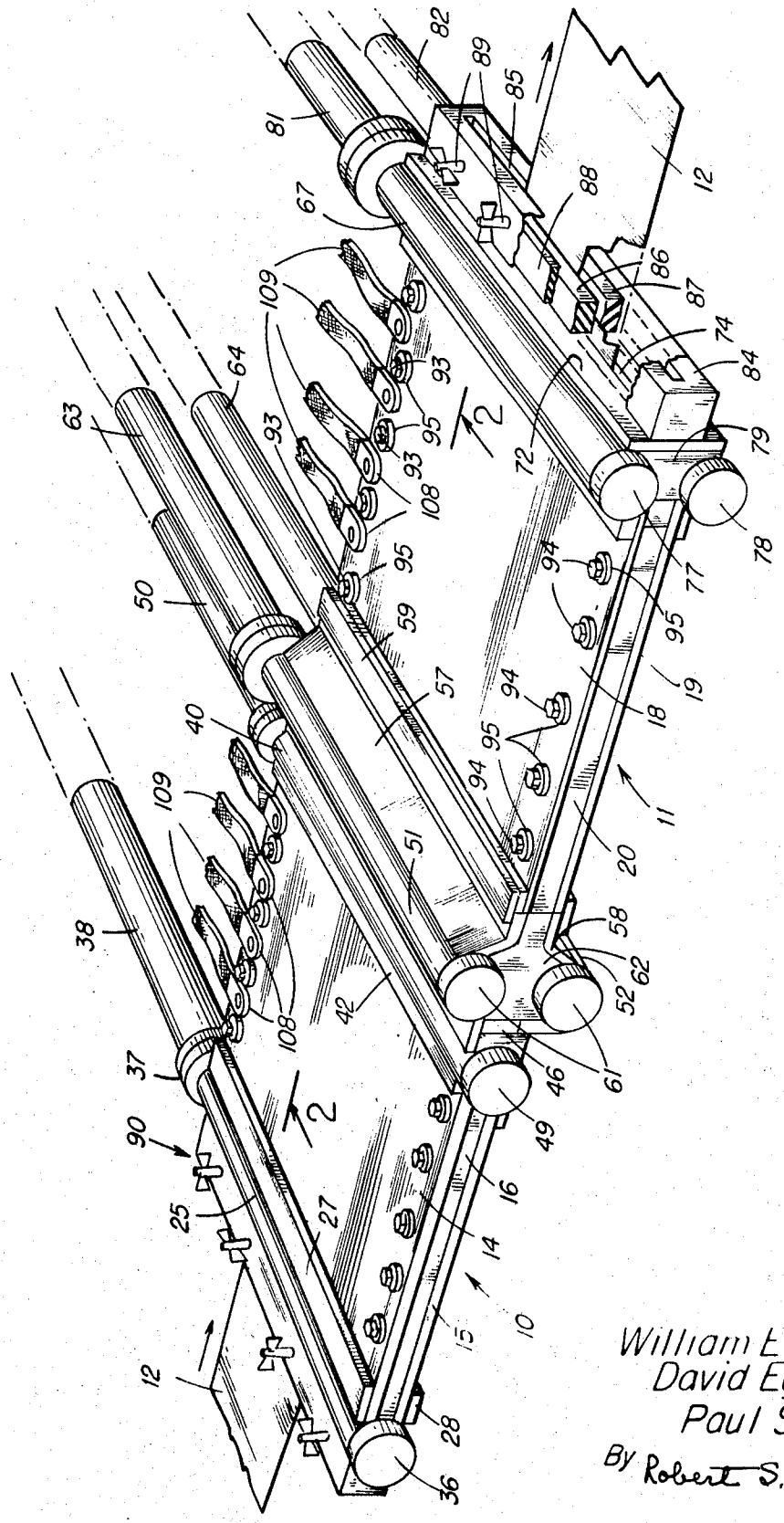


FIG. 1

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APPARATUS FOR CONTINUOUS ELECTROLYTIC TREATMENT

Original Filed Feb. 4, 1964 5 Sheets-Sheet 2

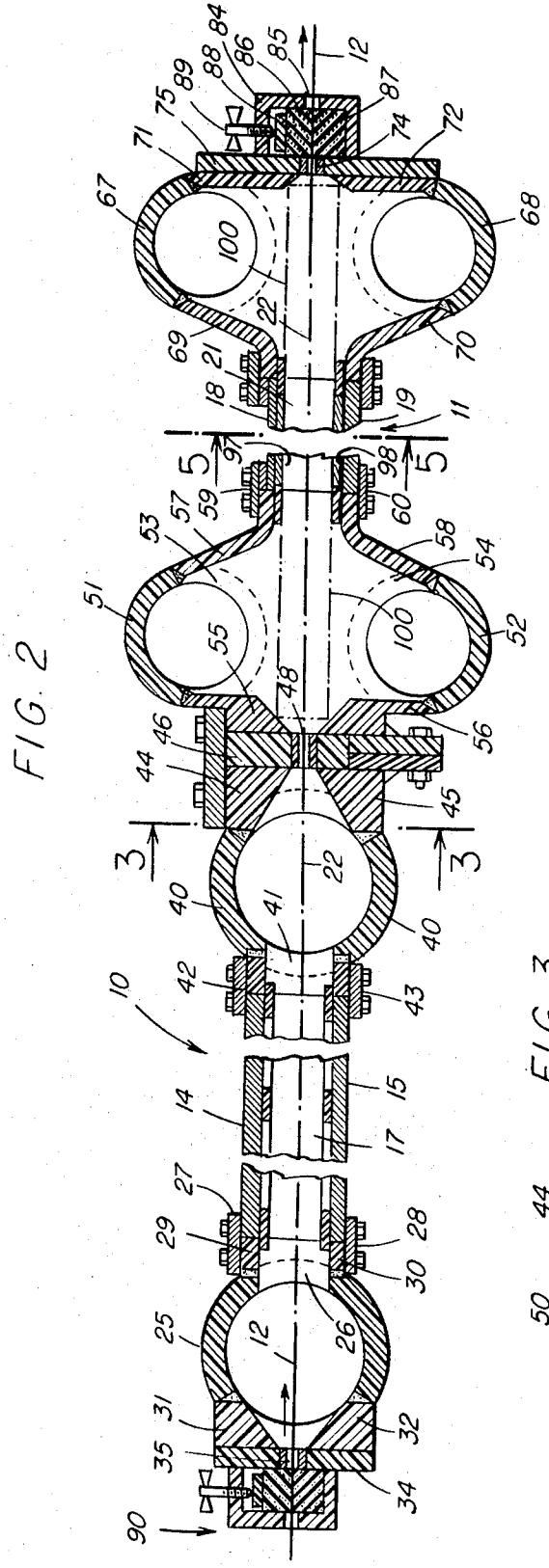


FIG. 2

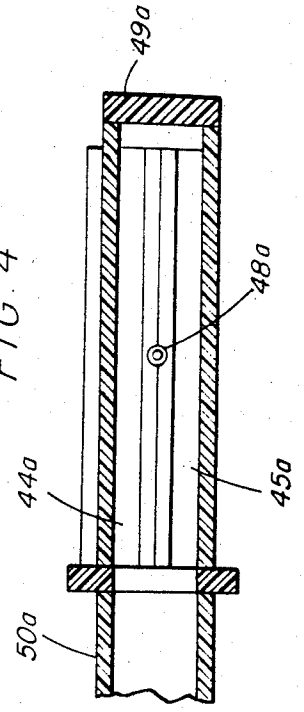


FIG. 4

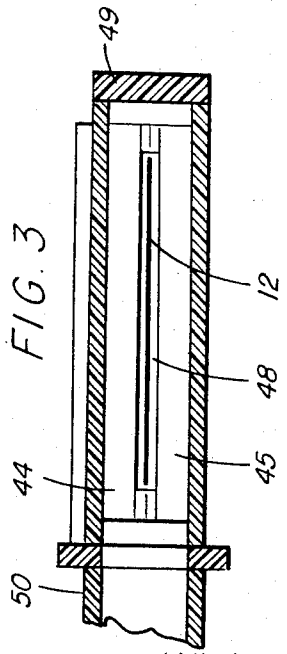


FIG. 3

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APPARATUS FOR CONTINUOUS ELECTROLYTIC TREATMENT

Original Filed Feb. 4, 1964 3 Sheets-Sheet 3

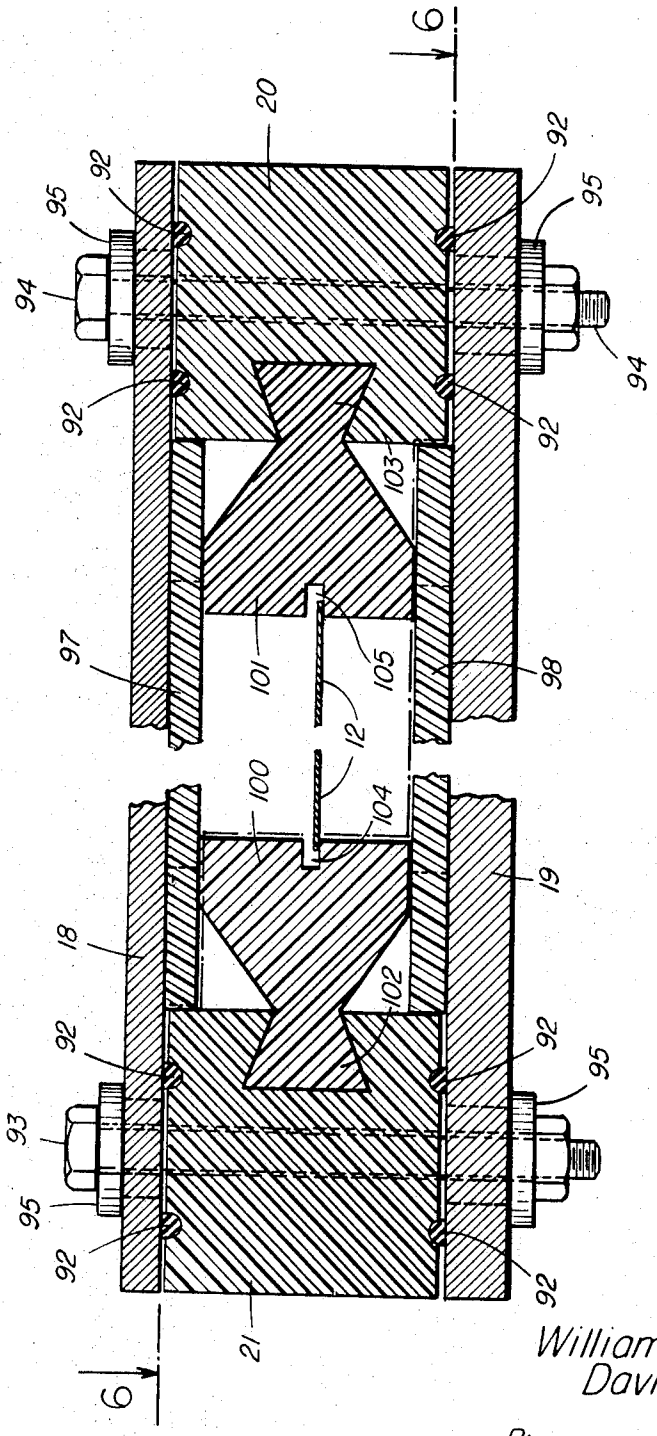


FIG. 5

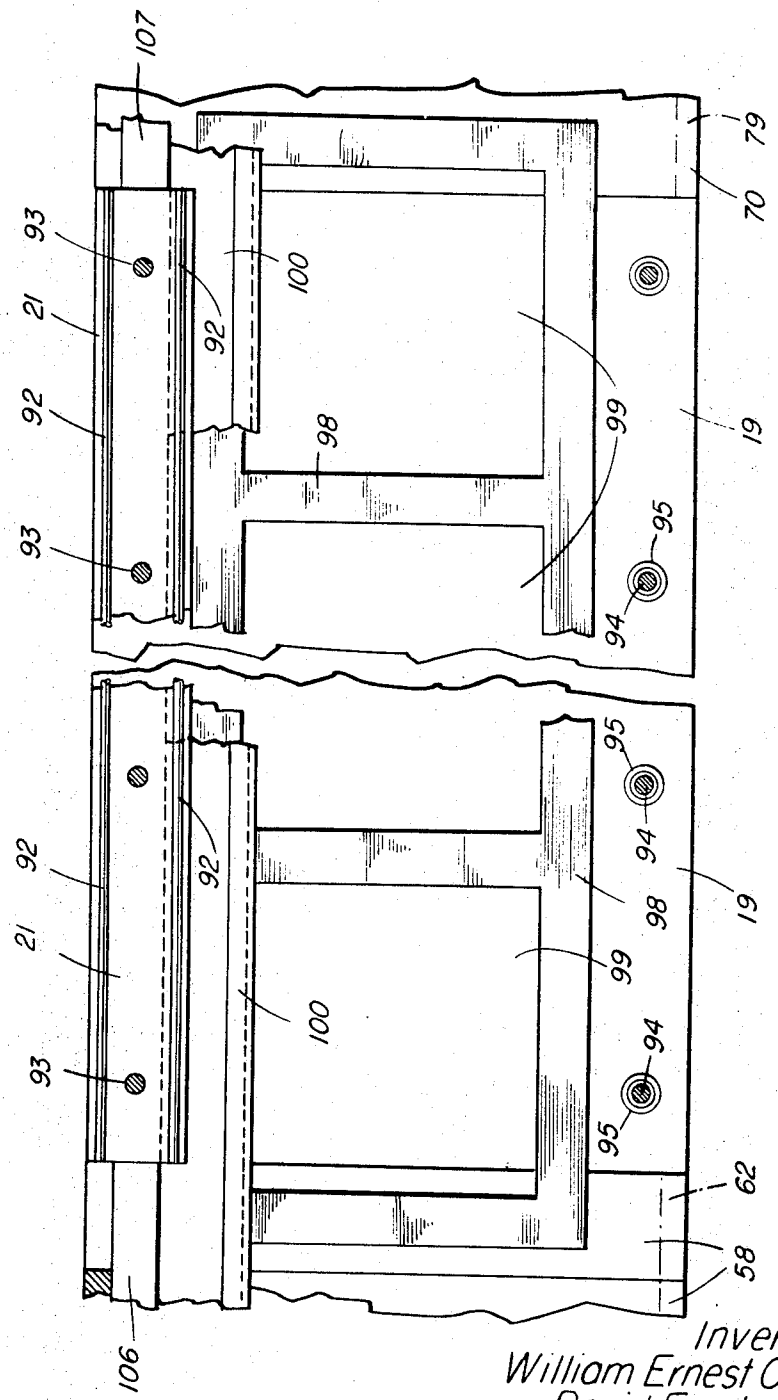
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APPARATUS FOR CONTINUOUS ELECTROLYTIC TREATMENT

Original Filed Feb. 4, 1964 5 Sheets-Sheet 4

FIG. 6



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APPARATUS FOR CONTINUOUS ELECTROLYTIC TREATMENT

Original Filed Feb. 4, 1964 5 Sheets-Sheet 5

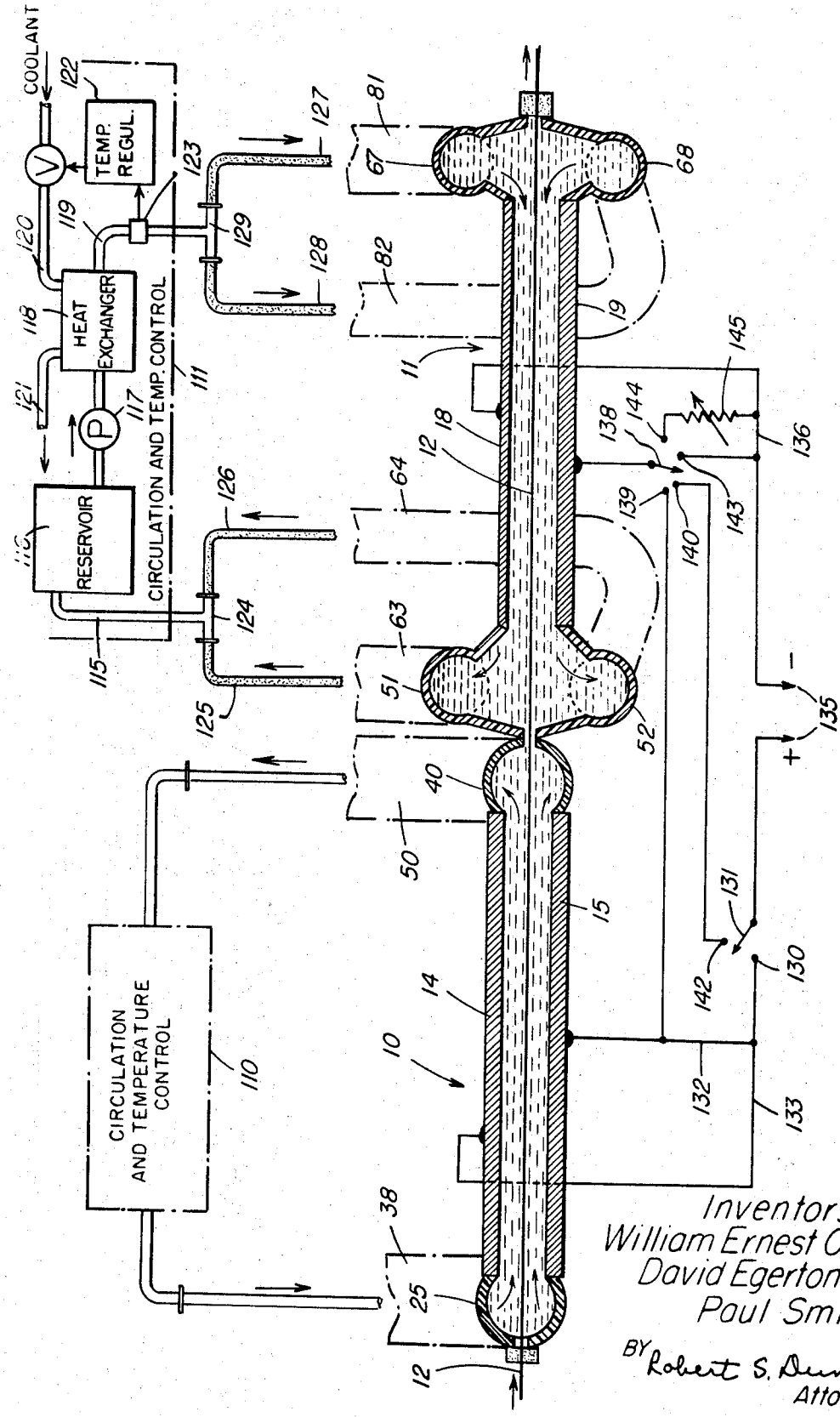


FIG. 7

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3,535,222

APPARATUS FOR CONTINUOUS ELECTROLYTIC TREATMENT

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Original application Feb. 4, 1964, Ser. No. 342,450, now Patent No. 3,359,189, dated Dec. 19, 1967. Divided and this application Nov. 14, 1967, Ser. No. 682,749

Int. Cl. B01k 3/00; C23b 5/68

U.S. Cl. 204—207 5 Claims

ABSTRACT OF THE DISCLOSURE

Apparatus for continuous anodizing includes an integrated assembly of elongated horizontal cleaning and anodizing tanks each with liquid entrance and exit conduits at opposite ends to effectuate high speed circulation of liquid in turbulent manner along the surfaces of the passing strip. Side spacer means and upper and lower spacer grids provide for guiding the strip in centered relation between the upper and lower walls of each section, which may constitute electrodes. The strip enters and leaves through compressible end seals, while means preferably individual to the tanks are provided for circulating the electrolyte and controlling its temperature, the system including insulated piping in the connections to the tank inlet and outlet parts to prevent significant electric current loss. A switching arrangement provides a selectable variety of connections for choice of cleaning and anodizing actions. The selectable connections include electrical circuit means extending to the electrodes, for providing different electrolytic treatment, e.g. differential anodizing, of the opposite surfaces of the strip.

This application is a division of our copending application Ser. No. 342,450, filed Feb. 4, 1964 now Pat. No. 3,359,189.

BACKGROUND OF THE INVENTION

This invention relates to the production of anodic coatings or films on aluminum, the term aluminum being employed to include aluminum base alloys which, like pure aluminum, are susceptible of being anodized to produce porous type oxide films. More particularly, the invention is directed to apparatus for continuous anodizing of extended aluminum articles, meaning sheet, strip, wire, rod or the like, being articles that are greatly elongated and may therefore be caused to traverse continuously one or more baths wherein anodizing or other treatment is performed. In a further sense, the present improvements are concerned with apparatus for continuous electrolytic treatment of elongated aluminum members, including both anodic and other operations, a particular aim being to afford improved apparatus for performing successive treatments on the passing member, up to very rapid rates of travel of the latter.

The invention is thus especially designed to achieve relatively high speed operation, whereby anodic films of desirable character are applied to elongated aluminum articles, without difficulties of imperfections in the film, overheating of the metal, poor efficiency and uncertainty

in control, such as have attended at least a number of prior efforts to achieve rapid anodic treatment, or more particularly, a continuous anodizing operation which is economically satisfactory. A special object is the improvement of apparatus for applying relatively thick, porous type anodic coatings, i.e. of a thickness of 0.1 mil and notably upwards thereof, so as to achieve such coatings in a rapid, continuous manner that is believed to have been unattainable in prior practice.

A further object of the invention is to provide apparatus adapted for achievement of results as outlined above, which by adjustment or modification of its structure may be readily adapted for a variety of types of treatment, e.g. as to sheet in strip form, or as to wire or the like, or with respect to the nature of the coating, a special feature being adaptability of the equipment to the production of anodic coating on both sides or only one side, of strip material (e.g. sheet). Another object is to provide, in continuous anodizing systems or methods, for simultaneous treatment of opposite sides of a strip in a different way, i.e. to create anodic coatings having different characteristics of thickness, porosity or the like, such operation being conveniently herein described as differential anodizing.

SUMMARY OF THE INVENTION

For the above objects of rapid, continuous production of relatively thick anodic coatings, the operation of the invention preferably comprises advancing the aluminum article lengthwise through, and in effect, in submergence in aqueous electrolyte, e.g. as contained in or confined by an appropriate elongated vessel, while maintaining such electrolyte, over all exposed surfaces of the article, in continuous turbulent flow lengthwise of the path of travel of such article and while passing electric current from the article into and through the electrolyte at relatively high density, i.e. at least about 100 amperes per square foot of exposed surface, and more specifically at densities of about 300 amperes per square foot and upwards. Thus in the case of continuous aluminum sheet or equivalent article, the aqueous liquid is arranged in two bodies respectively in contact with opposite sides of the sheet, and in continuous flow along such sides, being brought from and returned to appropriate pumping and temperature-controlling instrumentalities whereby there is continuous recirculation. In all instances the entire exposed area of the aluminum article (e.g. both faces of the moving sheet) is kept in contact with the turbulently flowing liquid at all times, as by the above arrangement of submergence, such flow being in a direction longitudinal of the path of the work surface and the turbulence being substantially uniform across the surface.

A chief critical factor is that the flow is turbulent as distinguished from the kind usually called streamlined or laminar, whether such turbulence is attained simply by selection of appropriately high velocity for the liquid as it travels from one end to the other of the tank traversed by the aluminum strip or like article, or whether it is aided by baffles or other supplemental means of a kind conventional for promoting turbulence. It has been found that in the absence of the defined conditions, excessive dissolution or burning of the oxide films occurs as the current density is raised or the electrolyte concentration increased in efforts to achieve desirably thick films at rates of speed of the strip which would otherwise

be high enough to make continuous anodizing economical. Indeed it now appears that it has been essentially impossible to attain such coatings in accordance with prior proposals for achieving continuous treatment by using high current densities; for any given strip speed and electrolyte concentration a limit has been found (usually corresponding to a relatively thin film) beyond which increase of the coulombic charge affords no further increase of film thickness whatever. In contrast, with the above-defined condition of turbulent electrolyte flow along the surfaces where anodic films are being formed, and with moderate electrolyte concentration, a plot of film thickness against current density slopes upward to very useful values.

The reasons for the effectiveness of turbulent electrolyte flow in obviating or inhibiting dissolution of the oxide coating are not fully understood. Although it is now believed that one function of turbulence is in aid of heat removal at the coating surface, it is also now considered that the chief source of heat in high-current anodizing is at the base rather than the surface of the oxide coating as it forms. The operation, moreover, does not seem to be critical with respect to the temperature of the circulating liquid, over a wide range; satisfactory results can usually be expected by keeping each body of electrolyte (e.g. as traversing the surfaces being anodized) at any point in the range, for example from room temperature (say, 20° C.) upwards. In any event, and regardless of theory, use of the apparatus has been found effective in continuously producing anodic coatings as stated, e.g. even of the order of one mil thick, or in the range up to 10 mils.

Likewise in furtherance of one or more of the objects stated above, and for other ends as may become apparent, apparatus pursuant to the invention comprises tank structure having provision for continuous traversal of the elongated article through the electrolyte in tank, preferably in a horizontal direction and very preferably through the ends of the tank below the electrolyte surface, e.g. through end seals. Electrode structure is provided, advantageously above and below the passing article, or at least in certain portions of the tank, whereby current flow follows a path from one electrode through the liquid to the article and from the article through the liquid to the other electrode. Where differential or one-side anodizing is required, means are included for isolating the portions of the liquid on opposite sides of the strip from each other, a special feature of the apparatus being the inclusion of separating elements removably associated with the side wall parts of the tank. In accordance with the invention, it has been found highly desirable to maintain the same electrolyte liquid on both sides of the strip, with the advantage of avoiding non-uniform results such as differences in the character of anodic film adjacent the edges, which might be caused by seepage or intermixing of electrolyte at the latter regions. With identity of electrolytes such problems are avoided.

The system further includes means for directing a continuing and rapid flow of electrolyte along the surface of the article, e.g. in a direction parallel to its direction of travel, whether concurrent or counter-current with such flow. Such longitudinal flow along a strip is markedly superior to flow in a transverse direction, i.e. in affording distinctly more uniform film properties across the width of the strip. The tank is arranged, preferably by disposition and dimensioning of electrodes above and below the path of the strip or other article, so that flowing electrolyte is relatively confined, preferably in most cases to a rather shallow region along each surface, while as explained above the process contemplates that the liquid flow should be of turbulent character, as distinguished from laminar flow. While baffle means or the like may sometimes assist such turbulence, it will be appreciated that the latter can in many cases be achieved by appropriate selection of the flow rate, in accordance with known principles.

A greatly preferred embodiment of the apparatus includes a tank of double character, involving in effect two endwise abutted tank chambers having a closely restricted but not necessarily sealed passage between them for the moving article. Similar provision for electrolyte flow is achieved in each of these sections, preferably with electrolyte from separate sources moving from end distributing pipes to like receiving pipes at the partition between the tank sections, i.e. respectively from the opposite ends of the set of tank sections, so that one flow is concurrent and the other countercurrent respecting the strip travel. It has been discovered that the system and operation may involve supply of electrolyte from a common source to separate regions of the tank system, e.g. upper and lower portions of the anodizing section, without short-circuiting, providing the piping that conducts the electrolyte to the inlet and outlet ends is of sufficient length and is suitably insulated electrically, so that long current paths are provided and thus electric current flow is negligible through the liquid in the piping.

In an especially advantageous form of the invention, the first tank section is circumstanced to provide cathodic cleaning of the passing article, while the second section is utilized for the anodizing operation, which may, as indicated, be of two-side or one-side character as desired. Indeed a further feature is the adaptability of the described system to, or its combination with, appropriate switching or other circuit-shifting means whereby it can be employed for a variety of types of treatment and of current supply, including the novel operation of continuous differential anodizing, the latter being achieved, for example, by separate control of voltage or current characteristics with respect to opposite sides of a sheet under treatment.

BRIEF DESCRIPTION OF THE DRAWINGS

Further features of the apparatus of the invention are set forth in the following description and in the accompanying drawings, wherein:

FIG. 1 is a perspective view of one embodiment of cell structure according to the invention, shown in simplified structure form and somewhat shortened in proportions, for clarity of illustration;

FIG. 2 is a longitudinal, fragmented, vertical section as if on line **2—2** of FIG. 1, somewhat enlarged relative to the latter;

FIG. 3 is a simplified vertical section on line **3—3** of FIG 2;

FIG. 4 is a section similar to FIG. 3, showing a modified form of aperture between the cleaning and anodizing cells;

FIG. 5 is a vertical cross-section of one of the cell compartments of FIGS. 1 and 2, somewhat further enlarged, and taken on line **5—5** of FIG. 2;

FIG. 6 is a fragmentary horizontal view of one of the cell compartments, taken as if in section on line **6—6** of FIG. 5, i.e. at various levels as therein indicated, and with the strip under treatment omitted; and

FIG. 7 is a diagrammatic view of the apparatus, with the cells shown as if in longitudinal vertical section, including associated electrical and electrolyte-circulating arrangements.

DETAILED DESCRIPTION

As shown in FIG. 1, the illustrated form of apparatus embodies a cathodic cleaning cell compartment **10** and an anodizing cell compartment **11** through which the work continuously advances, e.g. a continuous sheet of aluminum **12**, shown as entering the apparatus at the lefthand end and progressing through compartments **10** and **11** to move outward at the righthand end. With reference also to FIGS. 2, 3, 5 and 6, the cell **10** consists essentially of an upper plate **14** and a lower plate **15**,

respectively constituting electrodes and arranged in parallel coextensive relation and separated by insulating side walls **16, 17**. Similarly the anodizing compartment **11** is enclosed by upper and lower electrode plates **18, 19** separated by side walls **20, 21**. In all respects here material the two compartments are similarly constructed, i.e. as to the central regions where electrolytic action occurs, so that illustration and description of one may be taken to characterterize the other as well. In the example of apparatus shown, electrode plates **14, 15** and **19** are made of lead and the plate **18** of stainless steel, so that the latter may be thinner, as indicated, but this difference does not affect the principles of construction of the equipment. It will also be appreciated that mechanical details, as of fastening means for various parts, reinforcing structure for some or all of the electrode plates, mounting structure, extended electrical contact means over the surfaces of the electrodes, and the like, are omitted from the drawings for clarity, being unnecessary for understanding of the invention.

As will be seen, the strip **12** is advanced longitudinally through the compartments **10** and **11** in succession, passing in a horizontal plane midway between the electrode plates **14, 15**, and **18, 19**, the cell compartments being filled with liquid (aqueous) electrolyte so that both surfaces of the strip are in submerged contact with the liquid, and the electrodes, parallel to the strip, are at least approximately coextensive in area (or of greater area) with respect to the opposite surfaces of the strip in each compartment. The path of the strip **12** is thus indicated by the dot-and-dash line **22** in FIG. 2. It will be understood that suitable means, not shown, may be provided for advancing the strip or other elongated article under treatment, as by winding it on a take-up reel beyond the righthand end of FIGS. 1 and 2, or indeed beyond further treating equipment such as for washing and drying, the strip thus being unwound from a suitable pay-off reel to the left of the apparatus as shown, such take-up and pay-off equipment being of conventional character and therefore not illustrated.

Means are provided for circulating electrolyte continuously along both sides of the strip in each of the compartments. Thus, for example (FIGS. 1 and 2), a length of pipe **25** of insulating material is cut away along one side at **26**, so as to open sidewise into the entering end of the compartment **10**, being attached thereto with suitable connecting members as generally indicated at **27, 28** for the respective electrode plates **14** and **15**, such connecting structure including transverse parts or strips of insulating material **29, 30** cemented to the edges of the pipe opening. Likewise a pair of insulating members **31, 32** are cemented or otherwise fastened to the edges of a similar opening along the other side of the pipe section **25**, providing a tapering entrance for the sheet **12**, and faced by an end plate **34** which has a horizontal slot **35** through which the sheet enters. Thus the described structure affords a liquid distributing head or chamber at the entrance end of the cell compartment **10**, extending across the latter, and appropriately closed at one end as by a plug **36**. At the other end, this compartment, by appropriate flange connection **37**, communicates with a further pipe **38**, likewise preferably of insulating material. At the strip exit end of the cell compartment **10** a similar distributing chamber is afforded by a like pipe section **40** extending across the apparatus, cut away at one side **41** and connected to the plates **14, 15** of the cell by similar means **42, 43**. Along the other side of the pipe section **40**, appropriate insulating members **44, 45** provide a tapering exit for the strip, where it passes into a central aperture plate **46** having a long horizontal slot **48** through which the strip passes. The distributing chamber is appropriately closed at one lateral end as by parts including the plug **49** and shown in FIG. 1, and at the other end communicates with a connecting pipe **50**.

With respect to the cell compartment **11**, where means for isolating or partitioning upper and lower regions, by the strip, may be provided if desired, electrolyte distributing means are afforded both above and below the path of strip travel at each end. Thus a pair of pipe sections **51, 52** of insulating material are arranged at the entering end of the compartment, one above and one below the locality of the strip under treatment, and respectively cut away along their lower and upper sides at **53, 54**. Insulating members **55, 56**, extending across the apparatus and cemented or otherwise secured to one edge of the open regions of the pipe members **51, 52** provide a tapering communication to the central slot **48**. Likewise, appropriate plate-like structures **57, 58**, secured to the other edges of the pipe segments **51, 52** afford a flaring seal between the pipe segments and the entrance ends of the electrode plates **18, 19**, being secured by appropriate fastening means as indicated at **59, 60**. At one lateral end, the pipe segments **51, 52** and other parts of the double distributing chamber are closed as by the plugs **61** and associated wall structure **62** generally indicated in FIG. 1. At the other end, these pipes **51, 52** open into connecting pipes **63, 64**. Hence a suitable compartment or chamber is thus afforded at the end of the cell **11**, having in effect two portions extending across the cell and respectively connected for electrolyte circulation with the pipes **63, 64**. At the remote end of the anodizing compartment **11**, a like double distributing chamber is afforded, with the pipe segments **67, 68** of insulating material, cut away respectively along lower and upper sides and joined to the electrode plates **18, 19** by insulating plate-like structures **69, 70** whereby the space of the cell communicates in upwardly and downwardly flaring relation with the end chamber. Similar parts **71, 72** secured along the other edges of the pipe segments **67, 68** afford a flaring wall for the opposite crosswise extending side of the end chamber, where the strip exits through a slot **74** in an end plate **75**. As in the other similar structures, one lateral end of the pipe segments and the distributing chamber is closed by plugs **77, 78** and wall structure **79**, while the opposite ends of the pipe segments **67, 68** communicate with connecting pipes **81, 82**.

Provision is also made for inhibiting or preventing escape of electrolyte from the end slots **35, 74** where the strip enters and leaves. For instance, one appropriate sealing arrangement for this apparatus is shown at the righthand end of FIGS. 1 and 2 and comprises a box **84** extending across the apparatus, being attached to the end plate **75**. The box **84** has a horizontal exit slot **85** at its outer side, in registration with the slot **74**, and contains two elongated bodies of sponge rubber **86, 87** arranged to have long plane surfaces respectively in contact with upper and lower surfaces of the strip **12**, which thus passes between the sponge rubber bodies. The pressure plate **88**, of suitable insulating material, extends across the uppermost compressible body **86** and is engaged by turn screws **89** threaded in appropriate means, such as the uper wall of the box, whereby the sealing assembly of the sponge rubber bodies may be vertically compressed for the necessary sealing engagement with the strip. An identical end seal is provided at the strip entrance of the apparatus, generally designated **90**, and need not be further described in detail.

As shown in the drawings, especially FIGS. 5 and 6, the side wall members **20, 21** of the anodizing compartment **11** are sealed to the upper and lower electrode plates **18, 19** by longitudinal rods or strips of resilient material such as rubber or neoprene **92**, partly resting in corresponding recesses or channels in the upper and lower faces of the side blocks. Suitable means are provided for securing electrode plates and side blocks or walls **20, 21** together, as for example the bolts **93, 94** which may be insulated from the electrodes by flanged bushings **95** of appropriate insulating material. Slotted sheets of plastic material **97, 98** are arranged respectively at the lower face of the upper electrode **18** and at the upper face of the lower electrode **19**, being appropriately secured to such faces,

for avoidance of contact of the strip **12** with the electrode faces should severe deflection of the strip occur as it traverses the cell compartment. As shown in FIG. 6 these sheets, there exemplified by the sheet **98**, have a series or array of very large openings or slots **99** over by far the major part of their horizontal area, so that there is relatively little obstruction to the full contact of the corresponding electrode plate with the electrolyte. For clarity, the structure shown in FIG. 6 is somewhat shortened in the direction crosswise of the strip path, it being understood that the width of the apparatus is in any event designed to accommodate the dimensions of sheet or strip to be treated. The structure and parts just described with respect to the anodizing compartment **11** are also conveniently embodied in the cathodic cleaning compartment **10**, i.e. for securing the plates to the side walls and for preventing contact between sheet and plate, and need not be separately shown and explained.

The cell compartments may also include means, in the nature of side rails or guides for loosely engaging the longitudinal edges of the sheet under treatment, especially for isolating upper and lower portions of the anodizing compartment, although also, if desired, for restricting vertical or transverse movement of the strip in traveling through each compartment. Thus as shown in FIGS. 5 and 6, and also indicated in FIG. 2, a pair of such side rails **100**, **101** each consisting of an elongated block or member are disposed longitudinally of the anodizing compartment at the lateral sides of its interior. These members **100**, **101** are slidably dovtailed into the respective side wall members **21**, **20** at **102**, **103**, i.e. so that on disassembling the equipment the side rails can be fitted into the side elements, or removed therefrom as desired. As shown, they are conveniently shaped to have plane surfaces facing the central region of the compartment, and may also be appropriately tapered in a lateral direction to the dovetailed region of each. In the centrally facing surface of each there is a groove, as indicated at **104**, **105** shaped to engage the passing strip with some looseness, i.e. so that there is substantial separation between the upper and lower zones but little or no frictional bearing on the strip.

These side rails may, if desired, conveniently extend into the liquid distributing compartments, especially compartments **51–52** and **67–68** of the anodizing cell, being backed up laterally by appropriate blocks as indicated at **106**, **107** in FIG. 6, whereby the isolation of the two cell compartments extends into the end regions. Such disposition of the side rails is indicated by dot-and-dash lines outlining the rail **100** in FIG. 2. Similar side rail structure may be provided for the cleaning cell compartment, although a separate illustration of such arrangement is omitted as being duplication of the showing in FIGS. 5 and 6.

As will be appreciated, a pair of removable side rails (or two pairs of same if desired for both compartments) should be provided for each width of sheet to be treated in the apparatus, the pair of rails being such as to accommodate the strip with a slight overlap, say one-eighth inch, at each side whereby the sheet or strip traverses the grooves **104**, **105**. For example, a groove one-eighth inch wide (i.e. in the vertical dimension as seen in FIG. 5) and one-fourth inch deep is suitable for accommodating a strip penetrating such groove by one-eighth inch, and having a thickness from that of foil up to a little less than one-eighth inch. In similar fashion the slots **35**, **48** and **74** (FIG. 2) in the end and center plates of the assembly may, for example, have a width (vertical dimension) of one-eighth inch to accommodate like thicknesses of strip, these slots being conveniently faced, i.e. over the surfaces facing the strip, with sheeting of suitable plastic material having low friction properties.

Although the apparatus shown is designed for handling strip material, whether foil or thicker strip, herein sometimes generically defined as sheet, it may equally be adapted for other shapes of continuous elongated articles, such as wire or rod. Thus whereas FIG. 3 schematically illustrates the slot configuration **48** at the central barrier for sheet **12**, FIG. 4 shows an alternative arrangement of similar parts designated **44***a*, **45***a*, **49***a* and **50***a* where the central barrier opening is a small cylindrical hole **48***a* to accommodate wire or rod. It will be understood that slots at other localities of the apparatus are then similarly shaped and arranged, and that other structures may be provided such such as with a plurality of such holes to take a number of wire at once, or there may be openings of yet further shape for specific configurations of the passing article.

The materials of construction of the apparatus are appropriately selected for locality and service, with suitable properties of electrical insulation, strength and resistance to acid electrolyte, to the extent necessary. Thus, for example, the pipe segments **25**, **40**, **51**, **52**, **67** and **68**, and likewise associated members and center and end plates constituting the liquid distributing assemblies are made of strong insulating composition, as likewise the side walls or seals **16**, **17**, **20** and **21** and indeed other enclosure parts including side closures, end seal box **84** and similar structure of end seal **90**, the removable side rails such as shown at **100**, **101**, and plugs for the pipe segments as at **36**, **49**, **61** and **77**, **78**. Appropriate materials for these elements are fiber filled resin bodies of acid resistant nature, e.g. asbestos filled or textile filled resins, the former being particularly suitable for pipes and heavy structures required to have considerable strength. Pipe, plate, and other forms of such material are readily available, for shaping and assembly into structures of the sort shown. In general the arrangement is such as to effectively insulate the electrode plates **14**, **15**, **18** and **19** and to avoid exposure of other metallic surfaces to the electrolyte in or around either compartment. As will be appreciated, means are also provided for electrical contact with the electrodes, such being here simply illustrated as the several lugs **108** and heavy braided conductors **109** in FIG. 1, further parts secured to the electrode plates being used if necessary (not shown) for greater area of electrical contact.

Although the dimensions and proportions of the cell may vary widely to suit requirements of use, it is ordinarily desirable to have the electrode plates closely spaced so that the electrolyte filled cell region above and below the strip or the like is relatively narrow in a vertical direction. In one example of apparatus according to the invention, the electrode plates are all 60 inches long in the direction of strip travel and have a width to provide an internal cell space, i.e. inside the members **20**, **21**, or **16**, **17**, of about 21 inches. Hence the electrolytically functioning regions of the two cell compartments are each about 5 feet long and can accommodate strip up to about 20 inches wide. In the described embodiment, the side members **16**, **17**, **20** and **21** are approximately 2 inches square in cross-section, whereby there is about one inch of space above and below the sheet in each compartment. As will now be seen, the strip **12** continuously travels through the assembly, entering the seal **90**, crossing the first distributing chamber **25**, traversing the cleaning cell compartment **10** and the liquid distributing chamber **40**, after which the strip traverses the central slot **48**, crosses the double distributing chamber **51–52**, passes along centrally of the anodizing compartment **11** and after leaves via the end seal in the box **84**. Liquid electrolyte is circulated continuously through both compartments, both above and below the strip, e.g. in a condition of turbulent flow as explained above. In general in most cases, the direction of flow may be either countercurrent or concurrent to the actual direction of strip advance, although for some purposes countercurrent liquid flow is presently preferred for the anodizing cell.

Referring to FIG. 7, where the parts are shown in diagrammatic fashion and the initial portions of connecting

pipes for the liquid distributing chambers, as at **38**, **50**, **63**, **64**, **82** and **81** are indicated in dot-and-dash lines (with certain of these depicted in distorted form, for illustration purposes), suitable circulation and temperature control means generally designated **110** and **111** are provided respectively for the electrolyte flows in the compartments **10**, **11**. These may be of any appropriate nature and combination of components designed to advance the electrolyte continuously and control its temperature as with the aid of suitable cooling, and may be conveniently identical with each other. One set of such components is shown for the system **111** in FIG. 7, with the understanding that the system **110** may be the same, except that its heat exchange capacity, for cathodic cleaning, can be less than for the anodizing section. Thus by an appropriate pipe **115** connected with the pipes **63**, **64**, liquid leaving the upper and lower zones of the anodizing compartment **11** is received in a suitable reservoir **116** and from the latter advanced by a pump **117** through a heat exchanger **118** to return to the other end of the cell via pipe **119**, i.e. to the inlet distribution chamber **67–68**. The heat exchanger may be of conventional tubular design, arranged for cooling of the electrolyte by flow of water or other coolant through inlet and outlet pipes **120**, **121**, and may be controlled by a suitable temperature regulator, e.g. a commercially available recording temperature controller **122**, having a temperature sensitive element **123** in the electrolyte pipe **119** and operating a suitable motorized valve in the coolant flow line **120**. Thus the function of the described equipment in the circulation system **111** is to advance and control the temperature of the electrolyte, e.g. by removing heat from it so as to maintain a substantially constant temperature therein. The pump **117** appropriately propels the electrolyte at a sufficient rate to achieve the desired turbulent flow above and below the strip.

A particular feature, indeed adaptable to other combinations of electrolyte circulation with other or greater numbers of cell compartments or regions, is the arrangement of piping connections between the distribution heads or chambers and the circulating means. Thus each of the pipes **62**, **64** extends through continuations thereof (of the same diameter) **125** and **126** respectively, joining a T connection **124** to the pipe **115**. It is found that by selecting piping of suitable length and diameter from the upper and lower parts of the distribution chamber **51**, **52**, there can be complete avoidance of appreciable electric current flow or leakage between these two chambers even though the electrodes **18**, **19** may be operated at different electrical potentials or indeed at opposite electrical polarity. A similar arrangement is provided for the pipes **82**, **81**, i.e. by extensions of such pipes as shown at **128**, **127** to a single T connection **129** for the outlet pipe **119** of the circulation means. In other words, where the operations on the upper and lower surfaces of the strip **12** traversing the compartment **11** are such as to differ electrically or otherwise to require electrical isolation of the electrolytes, the supply of electrolyte to both zones may come from a common system, by utilization of the described arrangement of piping, i.e. the pipes of insulating material. As will now be appreciated, the length of the connecting pipes between the distribution chambers and the T joints **124**, **129** are readily determinable from the diameter of the pipe, the specific conductance of the electrolyte and the maximum voltage difference between the upper and lower electrodes **18**, **19**. Where the pipes had a 3 inch inside diameter, the electrolyte was a 15% solution of sulfuric acid and the voltage between the electrodes was about 30 volts, it was found that pipe lengths of 8 feet in each leg were sufficient to reduce leakage current through the electrolyte to a negligible value. As will be seen, the electrolyte is advanced countercurrently to the strip in the anodizing chamber **11** and concurrently with the strip in the second chamber **10**, leaving the compartments at the center of the apparatus through the dual chamber **51–52** and the single chamber **40** respectively.

As indicated above, the flow through the compartments **10**, **11**, most especially through the anodizing compartment **11**, is turbulent in nature. This can be achieved by sufficient rapidity of flow under the circumstances of the flow path, including its cross-section between the adjacent electrode and the strip, the rate being thus selected so that the liquid travels in turbulent, rather than laminar fashion in accordance with established principles of liquid flow in a conduit filled thereby. As stated, this feature of maintaining turbulence in the electrolyte as it passes the strip, whether by selection of appropriately high velocity or with the aid of baffles or other supplemental means (not shown) is found important for effective results in high speed, continuous anodizing to achieve porous-type anodic coatings, especially of thicker character, at high current densities, e.g. upwards of 100 amperes per square foot of exposed strip surface. In general, although conventional auxiliary means may be used, turbulence is satisfactorily achieved by a sufficiently rapid rate of flow. By providing such turbulence throughout its extent across the strip, efficient heat removal is easily attained to permit maintenance of desired temperature values, with sufficient volume of electrolyte per unit time as to have no more than an insignificant temperature rise (e.g. one or two degrees) between the localities of liquid inlet and discharge of the cell compartment.

As will be understood, ascertainment of suitable conditions, for instance a sufficiently high rate of flow, to provide turbulence is generally a matter of calculation under known principles, as by determination of flow rate of the aqueous electrolyte, for the given cross-sectional shape and size of path, which will yield a Reynolds number in the range of turbulent flow. Thus conventionally such numbers larger than about 2500 signify a condition of turbulence, it being understood that for best results in the present process, the flow conditions should be characterized by a substantially higher Reynolds number than the minimum. For example, a liquid flow affording a number of 20,000 is satisfactorily efficient for anodizing operation at a current density of 600 amperes per square foot, and conditions of even greater turbulence, e.g. represented by Reynolds numbers as high as 100,000, can well be used, as for very high current densities. Moreover, in many cases, determination of a suitable flow rate for achieving turbulence and for maintaining a desired temperature in the passing liquid without more than a few degrees of rise can be made by simple preliminary tests and observations.

FIG. 7 also illustrates one system of electrical connections for the apparatus, including switching means (which may be replaced by other, equivalent shiftable connection devices if desired) whereby a variety of different types of operation may be selectably achieved. Thus the electrodes **14**, **15** of the cleaning compartment **10** are connected together and to one contact **130** of a switch **131** by conductors **132** and **133**, the switch arm **131** being in turn connected to the positive terminal of a current source **135**, i.e. a D.C. source. One electrode, for instance, the upper electrode **18** of the anodizing cell **11**, is connected via a conductor **136** to the other terminal of the D.C. source **135**. The other electrode, e.g. the lower electrode **19** of the cell **11** is connected to a switch **138** having four contacts of which the first, **139**, is connected to the electrodes **14**, **15** of the cleaning cell and thus in effect to the positive terminal of the source **135** when the switch **131** is closed to its contact **130**. A second contact **140** of the switch **138** is connected to a second contact **142** of the switch **131**. A third contact **143** of the switch **138** is connected to the conductor **136**, i.e. thus to the negative terminal of the current source. Finally, a fourth contact **144** of the switch **138** is connected through a resistor **145** to the conductor **136** and via the latter, to the negative source terminal.

With the stated switching arrangement, or equivalent means, the system is flexibly adapted to a variety of types of treatment. For example, if switch **131** is closed to contact **130** and switch **138** is closed to contact **143** the operation of continuously cleaning and continuously anodizing both sides of the strip may be performed. Electrodes **14** and **15** are both connected to the positive terminal of the source, while both electrodes **18** and **19** are connected to the negative terminal, current thereby flowing from the first-named electrodes through the electrolyte bodies in the compartment **10** to the strip, for cathodically cleaning both surfaces, such current then passing through the strip and traveling into and through the electrolyte bodies (with the strip as anode) in compartment **11**, to the electrodes **18**, **19**, thence returning to the negative terminal. If switch **138** is turned to its contact **144** instead of contact **143**, again two-side cleaning and anodizing is effected (switch **131** remaining as before), but the operation is of differential character in the compartment **11**. The resistance **145** reduces the current flow in the lower half of the cell, so that for example a thinner coating is applied on the lower surface than on the supper surface. Conveniently, the resistor **145** may be adjustable and may assume any suitable character (for instance, an electrolytic resistor comprising a column of sulfuric acid solution with movable lead electrodes), its function being a voltage dropping device and being indeed attainable in a variety of ways. In fact, if the cell system is appropriately designed the necessary voltage drop for differential anodizing can be achieved by corresponding differences in spacing of the electrodes from the strip.

If it is only necessary or desirable to apply the anodic film to one side of the strip, certain other connections are used. One such arrangement is to maintain switch **131** connected to its contact **130**, while shifting switch **138** to contact **140**. In th is scheme, cathodic cleaning is effected on both sides of the strip, while only the upper electrode **18** is energized in the anodizing compartment, current thereby traversing only the upper body of the electrolyte in the latter and building a suitable film on only the upper surface. In such case, as indeed in all cases of one-side anodizing and likewise differential anodizing, the side rails are appropriately installed, at least the side rails **100**, **101** of the anodizing compartment. Another and particularly satisfactory arrangement is to connect the switch arm **138** to its contact **139**, while switch arm **131** remains in contact with its point **130**. Here not only the electrodes **14** and **15** of the cleaning compartment **10** but also the lower electrode **19** of the anodizing compartment **11** are connected to the positive terminal of the source, so that some of the anodizing current between the strip and electrode **18** has traveled along the strip from the compartment **10** while the remainder has traversed the lower body of electrolyte in compartment **11** and entered the lower face of the strip. In this way a relatively higher current density may be achieved or less heating of the strip by current flow, than in the first-mentioned arangement for one-side treatment.

A still further set of connections for one-side operation is achieved by setting switch arm **131** on its contact **142** and switch arm **138** on contact **140**. In this case there is no cathodic cleaning and the D.C. source is directly connected to the electrodes **19** and **18** with the former positive and the latter negative. Anodizing current then simply flows from the electrode **19** through the lower body of electrolyte to the strip and from the strip to the upper body through the electrode **18**, building up the film on the upper surface of the strip. It may incidentally be noted that the apparatus is adapted for alternating current operation without cathodic cleaning, as by connecting one terminal of such source to the electrodes **14**, **15** and the other terminal to the electrodes **18**, **19**, or alternatively to single electrodes on only one side of the strip for one-side A.C. treatment. Graphite electrodes are preferably used, rather than lead, for A.C. operation.

Even though the central slot **48** and the grooves in the side rails or guides, such as grooves **104**, **105** have a slightly or somewhat loose fit with the passing article, sufficient isolation of electrolyte bodies, both electrically and otherwise is ordinarily achievable so that the desired variety of operations can be attained. Indeed electrolytes at different flow rates, with different temperatures maintained in them, can be utilized as between the cathodic cleaning and anodizing compartments. Moreover, with the side rails in use there is insufficient electrical leakage in the anodizing compartment to adversely affect one-side anodizing treatment or differential treatment.

In general, it is greatly preferred to utilize liquids of the same composition in the upper and lower parts of the anodizing chamber even where these parts are isolated. In such fashion, slight seepage of the electrolyte around the edges does not then afford any undesirable modification of the film on one side or the other adjacent such edges of the passing sheet. With other forms of apparatus, it is conceivable that the process, used for anodizing one side alone, may employ other aqueous liquids than an anodizing electrolyte for the body adjacent one surface of the strip, in situations where no current is to flow through liquid to the strip at such locality. However, it is greatly preferred to use a liquid electrolyte, e.g. of the same composition, even under such circumstances. It may also be noted that the center plate **46** need be no more than of moderate thickness, say one inch, and particularly that the arrangement of the distribution chambers **40** and **51–52** is such as to afford a turbulent state of the electrolyte essentially up to the entrance and exit of the slot **48**. Under such circumstances, where a high electrical current may be traveling through the strip, heating effects are effectively minimized at this locality.

In anodizing operations with apparatus of the character shown, the speed of strip travel is generally governed by the thickness of anodic film desired, having regard to the length of the anodizing path and the applied current density. For many purposes, speeds of the order of 1 to 20 linear feet per minute are suitable, in cells, such as cell compartment **11**, from 1 to 5 feet long and with current densities at the surface or surfaces under treatment, in the range of 100 amperes per square foot and above, more usually upward of 250 amperes per square foot, and indeed preferably of the order of 500 to 1000 amperes per square foot. Thus, for instance, anodic films on sheet, up to and including 1.0 mil in thickness on the sheet surfaces have been produced with high efficiency using an aqueous electrolyte of 15% sulfuric acid maintained at approximately 65° C. in the bodies on both sides of the strip, with current densities of 250 to 1000 amperes per square foot and at convenient rates of strip travel. In such case the electrolyte flow rate was about 5 linear feet per second, achieving abundant turbulence, uniformly across the strip. Thus in an anodizing tank five feet long, at a current density of 650 amperes per square foot, 1.0 mil films are produced with a strip speed of 5 linear feet per minute and films of 0.2 mil thickness at a correspondingly faster speed of 25 feet per minute, very thin films (of the order of 0.01 mil) being at tainable at high strip speed, e.g. 250 to 750 feet per minute.

The electrolyte to be employed, especially in the anodizing compartment, is selected in accordance with required operation, it being found that exceptionally satisfactory results are obtained with sulfuric acid electrolytes, i.e., aqueous solutions of sulfuric acid. In general electrolyte concentrations below 2% sulfuric acid are too low, and develop excessive heat by their resistance to current travel. Concentrations above 50% generally appear to have too much dissolving power on the oxide film, for attainment of thick coatings. A more useful acid concentration is 5% or preferably 10% or more, present practice of the

invention being to employ 15% acid electrolytes. Ordinarily it appears unnecessary to use concentrations above 40%. In general, of course, rapidity of action is enhanced at higher concentrations but these involve greater limitations on the film thickness and tend to require very short times for anodizing and correspondingly very high and sometimes impractical current densities. References herein to acid or other concentrations in solution will, of course, be understood to mean percentages by weight.

In the cathodic cleaning compartment **10**, the electrolyte may be such as suitable for this purpose. Quite conveniently sulfuric acid is effective here, and indeed acid solutions of concentrations similar to those preferred for the anodizing cell. If there is substantial difference in composition of electrolyte between the compartments **10** and **11**, greater care may be required to avoid mixing at the vicinity of the connecting orifice, as for example by inclusion of a short rinsing section of tank (not shown) with orifices at its ends. Where the two electrolytes are of the same composition, as is now preferred, there is of course no problem at all about mixing. Indeed the electrolyte temperatures maintained in the two compartments can be different if desired, and likewise the treatment times, as by constructing the compartments to have different lengths. The cathodic cleaning action is found to be very effective in the illustrated apparatus, being both electrochemical and chemical. Hydrogen is usually evolved from the surface of the metal in this compartment, and such evolution, combined with the chemical action of the electrolyte, cleans the surfaces of extraneous foreign matter such as dirt and grease.

Although sulfuric acid electrolytes are described above for the procedure of the invention, other electrolytes appropriate for anodizing operations may be employed in some cases, e.g. acid electrolytes of generally equivalent function. Thus examples of suitable electrolytes for the anodic treatments here described are sulfuric acid, chromic acid, di- and tri-basic organic acids, or their equivalents, either separately or in suitable combination, all as will be readily understood by persons familiar with the art of anodic treatment of aluminum to produce porous-type oxide films. It will be understood that if the apparatus is used for treatments, e.g. in the compartment **11**, of different nature than the described production of porous oxide films, as for example to effectuate electrolytic brightening, electrolytic polishing or other film operations where the metal is connected as anode, appropriate electrolyte compositions are employed, in accordance with known principles of the art relating to such treatments.

In practice, the temperature maintained in the electrolytes may be selected generally in accordance with known principles, a presently understood advantage of the turbulent flow conditions being that satisfactory heat removal is achieved despite the present belief that outer portions of the oxide film under formation may tend to impede heat transfer from the base of the film, and despite the large heating effect of high current densities. Thus in the anodizing compartment, temperatures within a wide range, even up to about 100° C., may be selected although it is distinctly less practical to attempt maintenance of values below 20° C. The range of 40° C. and upwards seems presently quite feasible. Similar temperatures appear useful in the cathodic cleaning operation, i.e. for the electrolyte, and indeed it may be convenient to utilize acid solution at the same selected temperature; in the latter event, it is conceived that a single circulating and temperature control system for electrolyte in all parts of the apparatus could sometimes be used as explained above. Alternatively, rather higher temperatures may be preferred for the cathodic cleaning. Thus, for instance, with a 15% sulfuric acid electrolyte kept at approximately 80° C., and current densities of 1000 amperes per square foot of sheet surface area, remarkably complete cathodic cleaning has been attained in a tank 5 feet long (as shown) with strip speeds up to 750 feet per minute. The contact time was thus only 0.4 second, while by comparison, utilizing the same electrolyte at the same temperature but without any applied current, comparable surface conditions could be attained in at least about one minute of exposure.

As will now be appreciated, current densities, notably for the anodizing operation, may vary over a large range, e.g. from 100 to 4000 amperes per square foot of surface being anodized. The invention is particularly significant at values of 300 amperes per square foot and notably above, for achieving rapid anodizing action without sacrifice of film thickness and character. Indeed values of current density of 600 amperes per square foot and upwards, e.g. to 1500 amperes, represent a special range of departure from anything heretofore deemed practical. Above 4000 amperes per square foot (and to some extent above 2000), it appears that with ordinary mechanical arrangements for circulating electrolyte the desired heat removal tends to become unduly difficult.

The operation of differential anodizing, readily achieved with apparatus of the sort shown whereby different electrical conditions, e.g. different current densities, are provided respecting opposite surfaces of the strip **12** in the compartment **11** (with switch **138** on its contact **144**), has distinct advantages. For example, it enables the production of sheet or other articles having quite different anodic film thicknesses on opposite surfaces. Such products are conceived to be useful, for instance, in architectural or other building applications where a high measure of corrosion resistance is desired on one side of the sheet, with a relatively thick coating, while a lower degree of resistance is satisfactory on the other side. Presently for this purpose, the reverse side of the sheet is simply left bare, lacking any significant enhancement of its corrosion resistance. Thus this new product affords economic benefits over conventional two-side anodizing, i.e. in the saving of some current and other costs necessary for treating one of the sides, and also affords distinct improvement in respect to durability as contrasted with articles having only bare metal on such side.

Although a variety of specific conditions for various anodizing treatments have been set forth hereinabove, a further specific example may be given, as for the operation of the apparatus to apply like coatings on both surfaces of a continuing strip **12** of aluminum. In such operation, the electrolyte in both of the cell compartments **10** and **11** was a 15% sulfuric acid solution, and the temperature control was exercised to keep the turbulently traveling acid solution at about 65° C. in each compartment, there being a rise of not more than about 1° or 2° C. between the compartment ends in any case. Each of the systems **110** and **111** provided a total flow rate of about 300 U.S. gallons per minute, i.e. approximately 150 gallons per minute along each surface of the strip in the cleaning tank **10** and likewise in the anodizing tank **11**. With the cross-section of the flow passage adjacent each surface of the strip having dimensions of about 1 inch by 20 inches, such electrolyte flow was attained at a linear flow rate of 2.5 feet per second. With a current density of 650 amperes per square foot, i.e. at the exposed upper and lower surfaces of the strip **12** in the anodizing compartment **11** (the switches **131** and **138** being set at their contacts **130** and **143** respectively), highly satisfactory porous-type anodic coatings were achieved. Each of the tanks was 5 feet long and strip speeds of 5 feet per minute yielded films of 1.0 mil thickness, while at 25 feet per minute a thickness of 0.2 mil was readily attained. According to tests, as above, linear electrolyte flow velocities of about 2.5 feet per second or more appear completely adequate and afford preferred efficiency, but in a more general sense, liquid velocities of about one foot per second and above can be considered useful.

In the treatment of wire, for instance as mentioned above relative to FIG. 4, very good results have been realized, yielding good electrical insulation characteristics

of the anodic coating and high scrape abrasion resistance, at speeds of wire travel up to 200 feet per minute.

The efficiency of the process, for instance in operation under presently preferred conditions as exemplified above, seems unusually high. The coulombic input found necessary (in pilot plant operation) to produce an oxide film of 1 mil thickness, utilizing the described process is about 39,000 coulombs per square foot, this representing about 90% coulomb efficiency in contrast to about 70% efficiency (54,000 coulombs per square foot) in a number of prior operations for production of comparable films.

As indicated, the apparatus in some generic aspects is applicable to A.C. anodizing operation. Likewise the cleaning treatment in tank **10** may be an A.C. electrolytic cleaning, e.g. using electrolytes known for such purpose; in that event, appropriate electrical connections are employed, including a separate power source for tank **11**, being A.C. for two-side and D.C. for one-side anodizing.

It is to be understood that the invention is not limited to the specific operations, compositions and structures herein described but may be carried out in other ways without departure from its spirit.

What is claimed is:

1. In apparatus for continuous anodic treatment of aluminum strip moved lengthwise through the apparatus and having upper and lower surfaces to be exposed for treatment, in combination, first and second elongated tanks arranged in tandem for traversal respectively in succession by the strip, each tank having side walls and upper and lower enclosure plates respectively constituting electrodes, the first tank being adapted to provide a cathodic cleaning compartment for the strip and the second tank being adapted to provide an anodic treating compartment for the strip moving from the first tank, said second tank having insulating side walls for electrically isolating the upper and lower electrodes thereof, each of the tanks being arranged to be filled with electrolyte for submerging contact of same with the upper and lower surfaces of the strip, means for circulating the electrolyte in turbulent flow over both upper and lower surfaces of the strip, said means including inlet and outlet means at the ends of the tanks for directing said flow in alignment with the path of travel of the strip, means connecting the tanks for liquid-submerged advance of the strip from the first to the second, and electrical circuit means for the apparatus to provide current flow through the electrolyte between the article surface and the electrodes in each tank, said electrical circuit means comprising resistance means, a connection from one terminal of a source of current to the electrodes of the first tank, and connections from the other terminal of said source directly to one electrode of the second tank and through said resistance means to the other electrode of the second tank, for differently electrolytically treating opposite surfaces of the strip.

2. In apparatus for continuous anodic treatment of an elongated aluminum article moved lengthwise through the apparatus and having upper and lower surfaces to be exposed for treatment, in combination, first and second elongated tanks arranged in tandem for traversal respectively in succession by the article, each tank having side walls and upper and lower enclosure plates respectively constituting electrodes, the first tank being adapted to provide a cathodic cleaning compartment for the article and the second tank being adapted to provide an anodic treating compartment for the article moving from the first tank, said second tank having insulating side walls for electrically isolating the upper and lower electrodes thereof, each of the tanks being arranged to be filled with electrolyte for submerging contact of same with the upper and lower surfaces of the article, means for circulating the electrolyte in turbulent flow over both upper and lower surfaces of the article, said means including inlet and outlet means at the ends of the tanks for directing said flow in alignment with the path of travel of the article, means connecting the tanks for direct liquid-submerged advance of the article from the first to the second, including structure providing an orifice for the article shaped to be spaced slightly from the cross-sectional periphery of said article, for free movement of same while restricting electric current path through electrolyte around the article, said electrolyte circulating means including structure at the ends of the tanks adjacent said orifice for maintaining turbulence in the electrolyte around the strip as the latter moves into and away from the orifice, means at the ends of the tanks respectively remote from said tank-connecting means, and having strip-passing orifices respectively at said last-mentioned ends, for inhibiting escape of electrolyte as the strip enters the first tank and leaves the second, and electric current supply means for the electrodes, comprising positive and negative terminals for a source of direct current, means connecting one electrode of the second tank to the negative terminal, a first conductor means connecting the two electrodes of the first tank together, a second conductor means, means connected to the positive terminal and shiftable for effecting connection thereof selectively to said first conductor means and to said second conductor means, resistance means connected to said negative terminal, and means connected to the second electrode of the second tank and shiftable for effecting connection thereof selectively to the electrodes of the first tank, to the said second conductor means, to the negative terminal and to said resistance means, said resistance means, when connected, providing a lesser flow of electric current between the article and said second electrode than between the article and the first electrode, of said second tank.

3. Apparatus as defined in claim **2**, in which the tanks are arranged for treatment of an article consisting of metal strip advanced continuously lengthwise with its surfaces parallel to said electrodes, said second tank including two mutually spaced side rail means extending lengthwise thereof and respectively removably attached to the side walls in abutment therewith, each side rail means having a longitudinal groove along an innermost surface, disposed to receive an edge of the strip under treatment in loose sliding relation, said side rail means being dimensioned and arranged to coact with the said strip for dividing said second tank into upper and lower enclosures mutually partitioned by the strip.

4. In apparatus for continuous anodic treatment of an elongated aluminum article moved lengthwise through the apparatus and having upper and lower surfaces to be exposed for treatment, in combination, first and second electrolyte-holding tanks arranged in tandem for traversal respectively in succession by the article with both of its surfaces in submerged contact with electrolyte in each tank, means connecting the tanks for liquid-submerged advance of the article from the first to the second, said tanks being adapted to serve respectively as cathodic cleaning and anodic treating cells, each of said tanks having upper and lower electrodes respectively arranged for current flow between them and the said surfaces of the article through the electrolyte, and electric current supply means for the electrodes, comprising positive and negative terminals for a source of direct current, means connecting one electrode of the second tank to the negative terminal, a first conductor means connecting the two electrodes of the first tank together, a second conductor means, means connected to the positive terminal and shiftable for effecting connection thereof selectively to said first conductor means and to said second conductor means, resistance means connected to said negative terminal, and means connected to the second electrode of the second tank and shiftable for effecting connection thereof selectively to the electrodes of the first tank, to the said second conductor means, to the negative terminal and to said resistance means, said resistance means, when connected, providing a lesser flow of electric current between the article

and said second electrode than between the article and the first electrode, of said second tank.

5. Apparatus as defined in claim 4, for treatment of an article consisting of aluminum strip, said tanks being arranged for continuous advance of the strip lengthwise through the tanks with its upper and lower surfaces respectively facing the upper and lower electrodes, said second tank including structures removably attached therein and coacting with the strip for partitioning said second tank horizontally by the strip.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,535,222 Dated Oct. 20, 1970

Inventor(s) WILLIAM ERNEST COOKE, DAVID EGERTON BURY and PAUL SMITS

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 4, line 44, "structure" should read --structural--;

Col. 8, line 10, delete "such" (first occurrence)

line 11, "wire" should read --wires--

line 65, after "after" insert --traversing the further double liquid chamber 67-68,--;

Col. 11, line 23, "supper" should be --upper--

line 58, "arangement" should read --arrangement--;

Col. 14, line 3, after "could" insert --only--

SIGNED AND SEALED MAR 2 1971

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

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Commissioner of Patents

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