Feb. 26, 1963 E. R. RAMIREZ ETAL 3,079,308

PROCESS OF ANODIZING

Filed Oct. 7, 1958 2 Sheets-Sheet 1

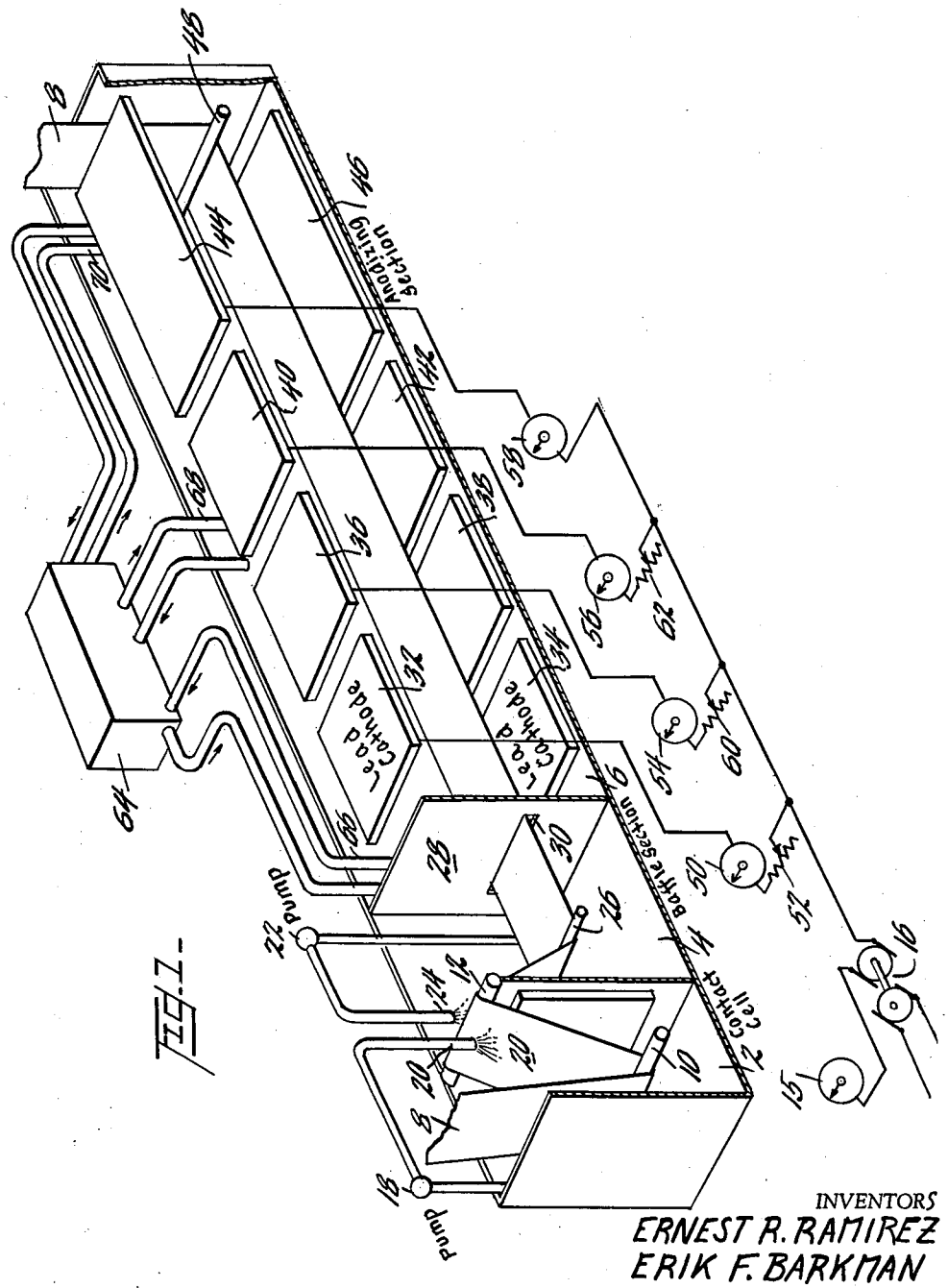


FIG. 1

INVENTORS
ERNEST R. RAMIREZ
ERIK F. BARKMAN

BY Glenn E. Jackson

Their ATTORNEYS

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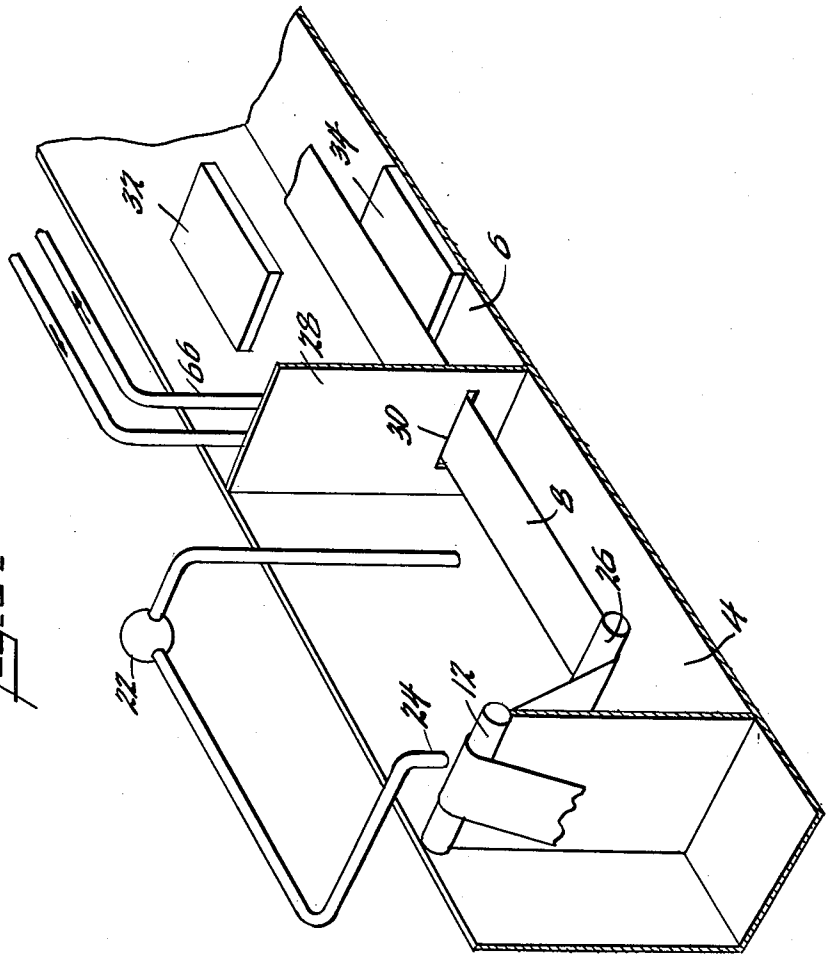


FIG. 2.

INVENTORS
ERNEST R. RAMIREZ
ERIK F. BARKMAN

BY Glenn & Jackson

This ATTORNEYS

United States Patent Office 3,079,308 Patented Feb. 26, 1963

3,079,308

PROCESS OF ANODIZING

Ernest R. Ramirez, Royal Oak, Mich., and Erik F. Barkman, Henrico County, Va., assignors to Reynolds Metals Company, Richmond, Va., a corporation of Delaware

Filed Oct. 7, 1958, Ser. No. 765,844
11 Claims. (Cl. 204—28)

This invention relates to an improved method for anodizing metals in strip form. More particularly, the invention concerns a novel method for the continuous high speed anodizing of aluminum articles such as strip, foil, and wire.

This application is a continuation-in-part of our application Serial No. 688,670, filed October 7, 1957, and now abandoned.

Presently employed methods of anodizing metals such as aluminum, magnesium, or copper, are based primarily upon batch concepts. In the case of anodizing aluminum, for example, the operation is ordinarily carried out employing current densities of the range of 12 to 15 amperes per square foot, for anodizing times varying from 15 to 60 minutes. While the anodic coatings obtainable by this method are adequate in respect to dielectric properties, ability to absorb dyes, and for corrosion protection of the underlying metal, batch methods fail to meet the needs of the times for a rapid, dependable method suitable to mass production techniques. Efforts have been made in the industry to achieve continuous anodizing processes. These attempts have heretofore been unsuccessful, particularly so in the case of aluminum, in that burning or bare spots and nonuniform anodizing were invariably found on coating made by continuous anodizing. This was especially true where high current densities were employed.

Experience has shown that the coating on anodized metals consists of a relatively thin, dense, and dielectrically compact barrier layer of oxide, surmounted by relatively porous outer oxide layer. The effectiveness of the overall coating depends to a considerable extent upon the characteristics of the barrier layer, which in turn are related to the manner in which the barrier layer is formed.

In accodance with this invention, we have found that by close control of anodizing conditions during the first few seconds of the anodizing process, the character of the barrier oxide layer may be established so that this layer will exhibit optimum properties. We have found further, in accordance with this invention, that control of the initial anodizing conditions governing the formation of the barrier layer produces a uniform, dense and electrically-resistive oxide layer which makes it possible to carry on subsequent anodization at greatly increased rates of operation, up to almost any practical desired value. These greatly increased rates necessitate resorting to the use of high speed anodizing lines employing multiple cathodes, with regulation of voltage and/or current density at intervals corresponding to successive cathode sets. It has been further found, in accordance with this invention, that anodizing rates along the entire length of the metal being anodized may be regulated and controlled, with a simultaneous substantial saving in power consumption, by the use of multiple anodizing power sources arranged in parallel, these multiple power sources being supplied from a monocyclic square type of power source.

The various aspects of the present invention will be illustrated with respect to the aanodizing of aluminum strip, foil and wire, but it is to be understood that the principles as developed and disclosed herein are applicable with minor variations to the anodizing of other metals such as magnesium and copper, which are amenable to this treatment.

We have found, in accordance with this invention, that

in order to achieve successful results in subsequent anodizing, the initial formation of the barrier layer of aluminum oxide must take place within a period not exceeding about 60 seconds, preferably from about 2 to 6 seconds. We have found that by employing carefully balanced control of impressed voltage or of current density or both during the first few seconds, for example, the first four seconds that the aluminum enters the anodizing liquid, the barrier layer will be uniformly and completely formed. It requires roughly from 2 to 4 seconds for a good barrier layer to be thus formed. Careful control of the growth of the barrier layer permits proper control of the subsequent growth and uniformity of the oxide layer subsequently applied in the continuous anodizing operation. The barrier layer preferably has a thickness of between about 0.5% and 2% of the thickness of the outer layer.

We have found that formation of the barrier layer in this manner facilitates the subsequent formation of the main body of porous oxide using a gradual build-up of current density which is controlled, in accordance with the invention, by the increased voltage for the several multiple electrode pairs located along the anodizing tank, as will be described below. Immediately following the formation of the initial barrier layer, pore formation takes place through this layer which propagates the formation of additional oxide. Directly between the initial barrier layer and the metal surface, a new barrier layer is formed, the thickness of which depends on the applied voltage and is of the order of 0.5% to 2% of the thickness of the main body of the oxide. In the completed film, the thin dense oxide layer most adjacent to the metal surface becomes the inner layer, and the other part of the oxide becomes the outer layer.

The key factor, from the industrial standpoint, in continuous anodizing, is the ability to employ high and uniform current densities on the aluminum or other metal strip. Unless the aluminum surface is prepared to take on these high current densities, selective anodizing (burning) will take place on the aluminum surface, thereby producing a nonuniform and inferior type of anodic coating. During conventional anodizing in sulfuric acid, at current densities of about 15 to 25 amperes per square foot, the formation of the barrier layer is not intentionally controlled, but is dependent upon the applied voltage used for a particular metal or alloy and upon electrolyte conditions.

For example, upon initially immersing the aluminum strip into the anodizing electrolyte, the dense but thin air-formed oxide film on the metal, which is generally in the range of 10 to 50 Angstrom units thick, must be uniformly and rapidly converted into a comparatively thick barrier layer between about 210 and 280 Angstrom units thick. We have found that it is during this transformation period, which has been found to extend from 2 to 4 seconds in duration, that the anodizing process must be carefully controlled. A gradual and uniform build-up of this compact barrier layer during these initial 4 seconds is essential if high current densities are to be subsequently used to produce high quality anodic coatings. Once the barrier layer is uniformly built up to a suitable thickness, then exceptionally high current densities can be readily and advantageously employed to complete the anodization. Inasmuch as the process of this invention, and especially that phase which comprises anodizing in the main part of the system, employs exceedingly high current densities, it is of highest importance that there be controlled voltage and current conditions during the initial period to insure a rapid and complete build-up of the resistive nonporous barrier layer, to prevent burning at isolated spots on the strip or film. This control is achieved by maintaining relatively close

limits for either or both the voltage and current density in the cell.

Thus, for example, in accordance with this invention, an average current density of about 20 to about 100 amperes per square foot, maintained with an average anodizing voltage of about 14 volts for a period of about 4 to 6 seconds provides the nearly complete formation of the barrier layer so as to facilitate subsequent formation of the porous layer at current densities exceeding 250 amperes per square foot.

In carrying out this initial treatment, in accordance with one mode of operation, we have found that control of the quality and uniformity of the barrier layer entails the use of higher average voltages, in the neighborhood of 14 to 15 volts, as threshold voltages for the barrier layer forming step. At the same time the current density is carefully controlled, by maintaining it at an initial value of about 80 to 600 amperes per sq. ft. when the 14–15 volt average potential is first applied, and then reducing the average current density to about 10 amperes per sq. ft., during period of a few seconds as the barrier layer is formed. Lower voltages unduly prolong the layer formation time, while higher voltages have been found to induce burns, i.e. spots where the electrical resistance of the initially formed barrier layer is nonuniform, with the result that in the subsequent propagation of the oxide growth with a high current density, a white spot may appear on the anodized surface, indicative of varying thickness of the outer layer.

In accordance with our novel method, the anodizing rate is controlled during the first several seconds after initiating the operation, by either voltage control or current control. The operation is performed preferably in a separate anodizing compartment, which may be enclosed, and which will be described more fully below.

The initial anodizing step leading to controlled formation of the barrier layer may be carried out in any suitable anodizing electrolyte of conventional type, such as an aqueous solution of sulfuric acid, oxalic acid, sulfamic acid, or chromic acid, or combinations thereof. When using sulfuric acid, for example, the concentration of the solution may range from 5 to 70 percent in strength, preferably about 30% is used. For the other acids, the concentrations will range between 2% and 10%, for example 5% in the case of oxalic acid. Anodizing bath temperatures may range from about 65° to 80° F. in the case of sulfuric acid, and about 85° F. in the case of oxalic acid.

According to a second, and preferred mode of operation of our novel process, during the first period of not less than about 4 to 6 seconds, when the purpose is primarily to form a barrier layer of oxide, the operation is controlled at an average current density of the order of 20 to 100 amperes per sq. ft., preferably about 50 amperes per sq. ft. Immediately thereafter, the current density may decrease somewhat because of the added resistance of the deposited barrier layer. The impressed voltage is permitted to increase, in order to maintain the aforesaid level of current density, during which time the barrier layer attains somewhat more than half (about 90 to 110 A. units) of its final thickness. The initial barrier layer may be built up completely during this initial step if the time is extended, but the formation may also, and preferably, be completed during the time when the material being anodized first is subjected to the main anodizing operation, and at much higher current densities, up to 500 or 1000 amperes per sq. ft., but preferably not in excess of 1000.

While the formation of the barrier layer of oxide may be carried out as either a batch or continuous operation, the latter will be described here, since it forms a part of the continuous anodizing high speed method which constitutes the present invention. Preferably direct current is employed.

We have found that the barrier layer formation is best carried out by the use of a baffle section which forms a part of the main anodizing tank (see FIG. 1). The name arises from the presence of a baffle wall, described more fully in connection with the explanation of the accompanying drawings, said wall containing a slot to permit passage of the metal strip to the main tank. Said slot also serves to permit flow of current via the eletcrolyte to facilitate control of the anodizing rate in the baffle section. Thus, the design of the baffle section and anodizing conditions in the first cathode section of the main anodizing tank permit close control of the barrier layer formation. The baffle section has no cathodes of its own. Anodizing in this section is controlled by traveling the current through a strip opening and then through relatively lengthy resistance paths. In this way, and by keeping the average voltage below about 14 to 15 volts, the baffle section serves to eliminate possible surges or rapid rises of current which may set in after about the first 2 seconds of anodizing.

Within the baffle section, which may, for example, be one or two feet in length, and accommodate, by appropriate weaving, 4 or 5 feet of strip, the controlled initial anodizing of the first 4 seconds, or of the first 4 to 6 seconds of the anodizing cycle may be performed so as to be coordinated with the anodizing conditions maintained in the main anodizing tank, for example, by controlling the size of the slot opening. There may be provided, if desirable, circulation of the electrolyte within the baffle section, by means, for example, of a pump system, directing a stream of electrolyte against the metal strip, as well as separate means for adjustment of voltage and current density.

Conducting the barrier layer formation step in a separate baffle section in the manner outlined above provides a uniform and continuous barrier layer, a surface which can be subsequently anodized in the continuous anodizing portion of the system at current densities averaging 100 to 400 amperes per sq. ft. Moreover, the speed of passage of the metal strip through both the baffle section and the anodizing section may be increased to from 10 to 100 feet per minute, depending upon the length of the system. By the process of this invention, it has been possible to anodize an aluminum strip completely in as little as 24 seconds, and yet obtain very high quality coatings. It is further possible to anodize successfully aluminum strip of thin gauge, for example, from 0.004" to 0.008". The anodized surfaces of aluminum strip thus treated exhibits D.C. breakdown voltages of 470 to 485 volts.

Prior to being led into the baffle section, the aluminum strip may be subjected to a pretreatment with sulfuric acid at a temperature somewhat higher than the anodizing bath temperature in a contact cell (see FIG. 1). This treatment serves to condition the aluminum or other metal strip and to form a liquid contact between the source of potential and the metal to be anodized. In such a contact cell, for example, there may be circulated by pump means a 30% sulfuric acid solution at a temperature of about 100° to 160° F.

In the main anodizing portion of the system, the objective is to achieve high quality and uniform coatings, by applying the aforesaid outer layer over the initially formed barrier layer. This is accomplished by maintaining a substantially uniform anodizing rate throughout the entire length of the anodizing tank. In accordance with this invention both control and regulation of the anodizing rate along the strip being anodized are achieved by use of a multicathode arrangement, in conjunction with either (*a*) a series of variable voltage power sources, or (*b*) a series of constant current power sources. The latter involves in addition the use of the monocyclic square arrangement as a constant current power source.

For a better understanding of the invention and its

various objects, advantages and details, reference is now made to the present preferred embodiment of the invention which is shown, for purposes of illustration only, in the accompanying drawings.

In the drawings:

FIG. 1 is a perspective view showing a complete continuous high speed anodizing system;

FIG. 2 is a perspective view of the baffle section employed to carry out the formation of the barrier layer.

Referring to FIG. 1, there is a dipicted a complete high speed continuous anodizing system comprising a contact cell **2**, for immersing the metal **8**, such as aluminum strip, in the electrolyte solution, and supplying current thereto, a baffle section **4** in which the formation of the barrier layer is performed, and a long main anodizing tank or section **6**, in which the main anodizing operation is completed. Contact cell **2** is provided with guide rollers **10** and **12** over which metal strip **8** passes and reverses its direction. Current is furnished to the contact cell by means of a lead or graphite anode which is connected through an ammeter **15** to the positive terminal of a power source such as a motor generator set **16**. Pump **18** serves to circulate electrolyte in the contact cell against the metal strip at point **20**, thereby cooling the strip, while pump **22** circulates electrolyte in the baffle section **4** against the metal strip at point **24**. Baffle section **4** is provided with a guide roller **26** around which the metal strip passes immersed in the electrolyte through the opposite wall of the section, which serves as a baffle to separate this portion from the main anodizing section **6**, by means of adjustable slot **30**. If desired, of course, the baffle section could be built as a separate unit with guide means provided for passing the metal strip to the separate main anodizing tank. The main anodizing section **6** comprises a long tank in which the metal strip passes immersed in the anodizing solution, between consecutively placed pairs of cathodes, **32–34**, **36–38**, **40–42**, **44–46**, which may be for example, lead plates, thence over guide roller **48** and out of the system. These cathodes are generally progressively larger in area toward the end of the tank. The cathodes are suspended horizontally above and below the metal strip, as shown in FIG. 2, and the respective pairs or sets are interconnected. The first cathode pair **32–34** is connected through an ammeter **50** and a variable resistor **52** to the negative terminal of the motor generator set **16**. Subsequent cathode pairs **36–38**, **40–42**, **44–46**, etc. are connected in the same manner to the negative terminal of the motor generator set through ammeters **54**, **56**, and **58**, and variable resistors **60** and **62**. The last cathode pair, e.g. **44–46** is connected to the motor generator set through ammeter **56** without a resistor, since at this stage of the operation, the resistance of the oxide coating is sufficiently high to require no outside resistor. Where the monocyclic type power source is to be employed, e.g. to maintain constant current settings through the various cathode pairs by means of variable resistances, the appropriate circuit may be connected across the terminals of the motor generator set.

The temperature of the anodizing solution in the main anodizing tank may be maintained at any desired level by continuous circulating of electrolyte through a cooling apparatus **64** which circulates the solution to and from various portions of anodizing tank, through circulating pipes as indicated generally at **66**, **68**, and **70**.

The functions and operation of the various parts of the system will readily be understood in the light of the previous discussion and of the following observations. The electrolytic contact cell serves to introduce the unusually high current into the metal strip, and entirely eliminates the problem of arcing where the current enters the strip. The strip leaving the contact cell enters the baffle section of the anodizing system where it is the anode and encounters, for example, a 30% sulfuric acid solution at a temperature around 72–75° F. for a period of passage of generally less than 6 seconds. The anodizing operations described herein utilize direct current, but under certain circumstances, alternating current may be employed with equal facility.

The metal strip then passes through the slot portion of the apparatus into the main anodizing section which preferably contains the same electrolyte as the baffle section. The principle involved here is based upon a multi-cathode arrangement with careful control of either the anodizing current or the anodizing voltage being carried out by means of a series of voltage sources connected in parallel, resulting in control of the anodizing rate along the rapidly moving strip. The arrangement is such that the potential during anodizing between the moving metal strip and a given cathode pair is controlled at will and is independent of the voltage relationship existing at any other point in the anodizing tank. This results in ease of control and reduced power input. It is superior, for example, to an arrangement using a single power source and a parallel arrangement of resistors to distribute the current evenly through a series of spaced cathode pairs. The constant hazard of burning the metal being anodized as it enters the anodizing tank is totally eliminated. The method of the present invention uses a parallel series of power sources connected between a common anode and a series of cathode pairs distributed along the anodizing tank, as shown in FIG. 1.

The use of cathode pairs (split cathodes) is preferable to the use of single cathodes spaced along the anodizing tank in that it eliminates formation of burns by providing controlled rise of current density at each cathode point. The use of cathode pairs alone, as known in some processes, will not, however, alone assure satisfactory results unless accompanied by unduly increased voltages or by specific voltage settings for each cathode point, and even this would not be enough to assure good results unless uniformity of current density can be maintained, i.e. a variation not in excess of about 30%, in passing from one section of the strip to the next. Moreover, experience has demonstrated that in the anodizing operation there should be a voltage drop of approximately 1 volt between adjacent cathode pairs.

In accordance with the present invention any variation in current density is kept below 30%, and the voltage drop is held to about 1 volt between adjacent cathode pairs by using circuiting of the monocyclic square type. A dense compact film of oxide of superior dielectric properties is obtained thereby. Using these circuits makes possible maintenance of fine control of the current density and voltage conditions within the desired limits.

The monocyclic square power source may be characterized as an arrangement whereby a constant D.C. or A.C. current can be maintained by conversion of a constant voltage fed into the circuit, as from a motor generator set. The circuit is based upon the principle of a resonant network of reactors and capacitors or capacitor banks connected in a closed circuit. This resonant network provides a constant current which is unaffected by the resistance or impedance of the load. Thus the monocyclic square circuit may be employed to secure constant current settings through the various cathode pairs of an anodizing tank by means of variable resistances. Ordinarily, such resistances could absorb as much as 10–25% of the power input. This power loss is eliminated by the incorporation of the monocyclic square arrangement into the anodizing current supply.

In anodizing, due to the IR drop along the metal strip, there is a diminution of anodic current density as we go from the beginning of the anodizing strip to the end, when a single cathode arrangement is used. This effect can be greatly reduced or even reversed by the employment of multiple cathodes. The number of cathodes needed to maintain the same anodizing potential along the entire

strip, and the length of these cathodes is limited by practical factors, such as the cross-sectional current density in the metal strip, the maximum variation in current density permissible along the strip, and the rate of change of anodizing current density with respect to change in anodizing voltage. The greater the permissible variation in current densities along the strip, expressed in percent, the fewer and longer will be the cathodes used. As mentioned previously, the optimum permissible variation in current density is of the order of 30%.

The effect of changes in the aforementioned optimum anodizing operating conditions is shown in the following Table 1:

TABLE 1

Aver. anodizing current density (amps./sq. ft.)	Aver. potential diff. between adjacent cathode pairs, (volts)	Approx. percent variation in anodizing rate between adjacent cathodes	Character of anodized surface
30	0.4	±5	Good.
45	0.8	±15	Good.
60	1.2	±20	Good.
75	1.6	±25	Some burns.
100	2.0	±30	Serious burns.

Hence, in the case of thin gauge material, permitting the average anodizing current density to rise to 75 amps. per sq. ft., which corresponds to a potential of 1.6 volts, which is greater than the optimum difference of 1 volt, results in burns. This optimum voltage changes with increasing thickness of the material being anodized.

The effect of variation of current density on the quality of the anodic coating is further shown in Table 2, below. This table gives summary data derived from a run using aluminum foil 0.008" thick and ½" wide, in an anodizing tank designed for a maximum fluctuation of current density between adjacent cathodes of 30%. The tank was 48 feet long, and had a total cathode length of 45 feet. Strip speed was 30 ft. per minute. The cross-sectional current density was 55,000 amperes per sq. in., the area of aluminum strip in the anodizing tank was 3.8 sq. ft. Lead strips 2" in width were used as cathodes, and placed at a distance of 5" above and below the metal strip. Nine pairs of cathodes of varying length were employed, the arrangement of which, and corresponding current densities, were as follows:

Position of Cathode	Length of Cathode, ft.	Amperes Passed	Average Current Density for Each Strip Section, amps. per sq. ft.	Average Sectional Anodizing Voltage, Volts D.C.
1st (entry of strip)	2	5	30	18.8
2nd	3	8	32	19.1
3rd	4	11	33	19.3
4th	5	19	46	20.2
5th	5	21	50	20.3
6th	5	23	55	20.4
7th	6	31	62	20.6
8th	7	43	74	21.0
9th (exit of strip)	8	59	88	21.4
	45	220	Aver. 58	

In Table 2, the first column refers to sectional variations in anodizing rates within the area covered by a pair of cathodes. The second column refers to percentage variation in current density on the strip between adjacent pairs of cathodes, the first three percentages being maintained within the optimum limit of about 30%. The fourth column shows effect on the anodic coating:

TABLE 2

Sectional Variation in Anodizing Rates	Percent Variation in Current Density	Voltage Drop Per Cathode at 50,000 Amps./sq. in.	Quality of Anodic Coating
55–50 amp./sq. ft.	∓5	0.2	Uniform.
70–50 amp./sq. ft.	∓15	1.0	Uniform.
120–50 amp./sq. ft.	∓30	2.2	Some Burns.
200–50 amp./sq. ft.	∓40	3.3	Frequent Burning.

As mentioned previously, the mode of operation in the baffle section where the barrier layer of oxide is first formed may involve either constant voltage or constant current control. In the case of constant current control, the current is controlled by means of the monocyclic square type of circuit described above. In either case, controlled anodizing during the first 4 to 6 seconds of the cycle is relied upon to produce the desired barrier layer. This layer provides a surface which can subsequently be anodized at high current densities between about 100 and 1000 amperes per sq. ft., but preferably between about 100 and 400 amperes per sq. ft.

By the use of the novel anodizing process of this invention, strip speeds of as much as 75 to 100 feet per minute may be attained.

The method of pretreatment and anodizing may be illustrated by the following examples, but the invention is not to be regarded as limited thereto.

EXAMPLE 1.—CONSTANT VOLTAGE CONTROL

Anodizing tank	22 feet long.
Electrolyte employed	30% sulfuric acid.
Anodizing temperature	72° F.
Anodizing time	.9 minute.
Baffle section	1½ feet long.
Time of the aluminum strip in baffle section	4 seconds and voltage control was applied (14 volts).
Density in aluminum strip	90,000 amps./in.².
Gauge and width of aluminum strip	.008, ½ inch.
Speed of strip	25 feet/minute.
Dielectric properties of anodized surface	470 volts D.C. breakdown.
Average anodizing rate in tank	220 amps./ft.².

The anodizing tank has ten cathode pairs. The current drawn by each cathode pair as well as their respective lengths is given in Table 3.

TABLE 3

Conditions Prevailing in 22 Foot Anodizing Tank [1]

Cathode Pair	Cathode Length (feet)	Average Current Density in Strip Adjacent to Each Cathode Pair, amps./ft.²	Average Sectional Anodizing Voltage, Volts D.C.
1st	1	41	19.6
2nd	1	111	21.6
3rd	1	156	22.0
4th	2	164	22.3
5th	2	178	22.4
6th	2	197	22.5
7th	2	215	22.6
8th	2	245	22.7
9th	3	330	22.8
10th	3	350	23.0

[1] Voltage in the baffle section is maintained at 14 volts.

EXAMPLE 2.—CONSTANT CURRENT CONTROL

Anodizing tank ---------- 7 feet long.
Electrolyte employed ----- 30% sulfuric acid.
Anodizing temperature --- 76° F.
Anodizing time ---------- .4 minute.
Baffle section ---------- 1½ feet long.
Time of the aluminum strip in baffle section -------- 6 seconds applying constant current control (30 amps./ft.²).
Density in aluminum strip-
Gauge and width of aluminum strip ---------- 30,000 amps./in.².
Speed of strip ---------- .008, 2 inches.
Dielectric properties of anodizing surface ---------- 15 feet/minute.
Average anodizing rate in tank ---------- 485 volts D.C. breakdown. 250 amps./ft.².

The 7 foot anodizing tank has 4 cathode pairs. Table 4 shows the conditions prevailing during this test.

TABLE 4

Conditions Prevailing in 7 Foot Anodizing Tank [1]

Cathode Pair	Cathode Length, feet	Input Voltage Total	Average Current Density in Aluminum Strip Adjacent to Cathode Pair	Average Sectional Anodizing Voltage, Volts D.C.
1st	1	42	134	21.7
2nd	1	44	255	22.6
3rd	1	45	294	22.8
4th	2	48	330	23.0

[1] Current density maintained in baffle section is 30 amps./ft.².

EXAMPLE 3.—PREFERRED METHOD

Two typical runs made in an apparatus comprising a tank 18 feet long having a 2 foot baffle section, and a 16 foot anodizing section connected therewith by a slot opening, are described. The electrolyte was 30% sulfuric acid maintained at temperature of 67°–70° F. Aluminum strip of 0.02 inch gauge and 2.25 inches wide was run through the apparatus at a speed of 28.5 feet per minute. Direct current was employed. The strip was first prepared by subjecting it to a cleaning with a detergent solution, followed by a water rinse, then followed by a hot bright dip bath containing a mixture of nitric and phosphoric acids, followed by another water rinse. Thence the strip was passed into a contact cell containing 30% sulfuric acid at a temperature of 140° F., employing the aluminum strip itself as the cathode and a pair of lead sheets as the anodes. Thence the aluminum strip was passed, after first cooling by means of acid sprays as shown in FIG. 1, into the baffle section. In the baffle section the average current density range was 50 to 80 amperes per square foot, and the average voltage was 13 to 15 volts. The time of exposure was about 4 seconds. The strip then was passed into the main anodizing tank equipped with 11 successively placed pairs of spaced and interconnected lead cathode plates, each pair being about 6 inches wide, the length increasing progressively as follows: 11, 11, 12, 13, 14, 14, 15, 16, 19, 24, and 31 inches, respectively. Conditions prevailing at the first and last pairs of cathode for each run were as follows:

FIRST CATHODE PAIR

	Run 1	Run 2
Current density (amps./sq. ft.)	about 189	about 282
Strip voltage drop (volts/ft.)	0.28	0.44

LAST CATHODE PAIR

Current density (amps./sq./ft.)	217	310
Strip voltage drop (volts/ft.)	0.060	0.090

After emerging from the main anodizing section the strip was rinsed with water and steam sealed in accordance with conventional procedures. The resulting coating is uniform in apperance, free from voids and defects and burns. Film thickness range is about 0.20 to 0.30 mil. The anodized strip is capable of being dyed with organic dyes to attractive shades.

While we have illustrated and described present preferred embodiments of the invention, it will be recognized that the invention may be otherwise variously embodied and practiced within the scope of the following claims.

We claim:

1. In the art of anodizing aluminum, the method comprising the steps of:

(*a*) forming a uniform, dense and electrically-resistive oxide layer on the surface of an aluminum article by

immersing said article in an acidic dissolving electrolyte,

applying an electric current to the aluminum as anode at an average anodizing current density not in excess of 100 amperes per sq. ft., employing an initial current density in the range of 20 to 600 amperes per sq. ft. and controlling the anodizing rate to prevent burning,

completing the formation of said resistive layer during a period not exceeding about 60 seconds; and

(*b*) continuing the anodizing of said article at increased anodizing current density to form the main body of the final anodized layer thereon, the thickness of said main body being at least about 50 times that of said resistive layer, by

passing an electric current through an acidic dissolving electrolyte, between a cathode immersed therein and said article as anode, at an average anodizing current density much higher than 100 amperes per sq. ft.

2. In the art of anodizing aluminum, the method comprising the steps of:

(*a*) forming a uniform, dense and electrically-resistive oxide layer on the surface of an aluminum article by

immersing said article in an acidic dissolving electrolyte,

applying an electric current to the aluminum as anode at an average anodizing current density not in excess of 100 amperes per sq. ft., employing an initial current density in the range of 20 to 600 amperes per sq. ft. and controlling the anodizing rate to prevent burning,

completing the formation of said resistive layer during a period not exceeding about 60 seconds; and

(*b*) continuing the anodizing of said article at increased anodizing current density to form the main body of the final anodized layer thereon, the thickness of said main body being about 50 to about 200 times that of said resistive layer, by

passing an electric current through an acidic dissolving electrolyte, between a cathode immersed therein and said article as anode, at an average anodizing current density much higher than 100 amperes per sq. ft.,

progressively increasing the anodizing current density to a value above 250 amperes per sq. ft.

3. In the art of anodizing aluminum, the method comprising the steps of:

(*a*) forming a uniform, dense and electrically-resistive oxide layer on the surface of an aluminum article by

immersing said article in an acidic dissolving electrolyte comprising aqueous sulfuric acid solution,

applying an electric current to the aluminum as anode at an average current density of about 50 amperes per sq. ft., while controlling the anodizing rate to prevent burning,

completing the formation of said resistive layer to a thickness of at least about 90 to 110 Angstrom units during a period not exceeding 60 seconds; and

(*b*) continuing the anodizing of the article in said electrolyte at an average anodizing current density much higher than 100 amperes per sq. ft. to form the main body of the final anodized layer thereon, the thickness of said main body being at least about 50 times that of said resistive layer.

4. In the art of anodizing aluminum, the method comprising the steps of:

(*a*) forming a uniform, dense and electrically-resistive oxide layer on the surface of an aluminum article by

immersing said article in an acidic dissolving electrolyte comprising aqueous sulfuric acid solution,

applying an electric current to the aluminum as anode at an average current density in the range of 20 to 100 amperes per sq. ft. and an average anodizing voltage of about 14 volts, while controlling the anodizing rate to prevent burning,

completing the formation of said resistive layer during a period not exceeding 60 seconds; and

(*b*) continuing the anodizing of said article at increased anodizing current density to form the main body of the final anodized layer thereon, the thickness of said main body being at least about 50 times that of said resistive layer, by

passing an electric current through an acidic dissolving electrolyte comprising aqueous sulfuric acid solution, between a cathode immersed therein and said article as anode, at an average anodizing current density much higher than 100 amperes per sq. ft.,

progressively increasing the anodizing current density to a value above 250 amperes per sq. ft.

5. In the art of continuously anodizing aluminum in strip form, the method comprising the steps of:

(*a*) forming a uniform, dense and electrically-resistive oxide layer on the surface of aluminum strip by

feeding said strip through an acidic dissolving electrolyte and applying an electric current to the strip as anode at an average anodizing current density not in excess of 100 amperes per sq. ft., employing an initial current density in the range of 20 to 600 amperes per sq. ft. and controlling the anodizing rate to prevent burning,

completing the formation of said resistive layer during a period not exceeding 60 seconds; then

(*b*) continuing the anodizing of said strip at increased anodizing current density to form the main body of the final anodized layer thereon, the thickness of said main body being at least about 50 times that of said resistive layer, by

advancing the strip through an acidic dissolving electrolyte and between successive pairs of split cathodes therein,

passing an electric current through said electrolyte, between said cathodes and the strip as anode, at an average anodizing current density much higher than 100 amperes per sq. ft. and with variations in current density along the strip between adjacent pairs of cathodes limited to about 30%.

6. In the art of continuously anodizing aluminum in strip form, the method comprising the steps of:

(*a*) forming a uniform, dense and electrically-resistive layer on the surface of aluminum strip by

feeding said strip through a pretreatment portion of an acidic dissolving electrolyte,

applying an electric current to the aluminum as anode and to the electrolyte as cathode, at an average anodizing current density not in excess of 100 amperes per sq. ft., employing an initial current density in the range of 20 to 600 amperes per sq. ft. and controlling the anodizing rate to prevent burning,

completing the formation of said resistive layer during an initial period not exceeding 60 seconds, then

(*b*) continuing the anodizing of said strip at increased anodizing current density to form the main body of the final anodized layer thereon, the thickness of said main body being at least about 50 times that of said resistive layer, by

advancing the strip into a main portion of the electrolyte and between successive pairs of split cathodes therein,

passing an electric current through the electrolyte, between said cathodes and the strip as anode, at an average anodizing current density much higher than 100 amperes per sq. ft.; and

(*c*) limiting the flow of current via the electrolyte between the respective portions thereof to control the anodizing rate of the strip in the pretreatment portion of the electrolyte.

7. In the art of anodizing aluminum, the method comprising the steps of:

(*a*) forming a uniform, dense and electrically-resistive oxide layer on the surface of an aluminum article by

immersing said article in an acidic dissolving electrolyte,

applying an electric current to the aluminum as anode at an average anodizing current density not in excses of 100 amperes per sq. ft., employing an initial current density in the range of 80 to 600 amperes per sq. ft. when 14–15 volt average potential is first applied, and controlling the anodizing rate to prevent burning,

completing the formation of said resistive layer during a period not exceeding about 60 seconds; and

(*b*) continuing the anodizing of said article at increased anodizing current density to form the main body of the final anodized layer thereon, the thickness of said main body being at least about 50 times that of said resistive layer, by

passing an electric current through an acidic dissolving electrolyte, between a cathode immersed therein and said article as anode, at an average anodizing current density much higher than 100 amperes per sq. ft.

8. In the art of continuously anodizing aluminum in strip form, the method comprising the steps of:

(*a*) forming a uniform, dense and electrically-resistive oxide layer on the surface of aluminum strip by

feeding said strip through a pretreatment portion of an acidic dissolving electrolyte comprising aqueous sulfuric acid solution and applying an electric current to the strip as anode at an average anodizing current density not in excess of 100 amperes per sq. ft., employing an initial current density in the range of 80 to 600 amperes per sq. ft. when 14–15 volt average potential is first applied and controlling the anodizing rate to prevent burning,

completing the formation of said resistive layer during a period not exceeding about 6 seconds; then

(*b*) continuing the anodizing of said strip at increased anodizing current density to form the main body of the final anodized layer, the thickness of said main body being at least about 50 times that of said resistive layer, by

advancing the strip into a main portion of the electrolyte and between successive pairs of split cathodes therein,

passing an electric current through the electrolyte, between said cathodes and the strip as anode, at an average anodizing current density much higher than 100 amperes per sq. ft.

9. In the art of continuously anodizing aluminum in strip form, the method comprising the steps of:

(*a*) forming a uniform, dense and electrically-resistive oxide layer on the surface of an aluminum strip by

feeding said strip through a pretreatment portion of an acidic dissolving electrolyte comprising aqueous sulfuric acid solution and applying an electric current to the strip as anode, at an average current density in the range of 20 to 100 amperes per sq. ft. and an average anodizing voltage of about 14 volts, while controlling the anodizing rate to prevent burning,

completing the formation of said resistive layer during a period not exceeding about 6 seconds; then

(*b*) continuing the anodizing of said strip at increased anodizing current density to form the main body of the final anodized layer thereon, the thickness of said main body being at least about 50 times that of said resistive layer, by

advancing the strip into a main portion of the electrolyte and between successive pairs of split cathodes therein,

passing an electric current through the electrolyte, between said cathodes and the strip as anode, at an average anodizing current density much higher than 100 amperes per sq. ft. and with variations in current density along the strip between adjacent pairs of cathodes limited to about 30%.

progressively increasing the anodizing current density to above 250 amperes per sq. ft.

10. In the art of continuously anodizing aluminum in strip form, the method comprising the steps of:

(*a*) forming a uniform, dense and electrically-resistive oxide layer on the surface of aluminum strip by

feeding said strip through a pretreatment portion of an acidic dissolving electrolyte comprising aqueous sulfuric acid solution and applying an electric current to the strip as anode, at an average anodizing current density of about 50 amperes per sq. ft. and an average anodizing voltage of about 14 volts, while controlling the anodizing rate to prevent burning,

completing the formation of said resistive layer during a period not exceeding about 6 seconds; then

(*b*) continuing the anodizing of said strip at increased anodizing current density to form the main body of the final anodized layer thereon, the thickness of said main body being at least about 50 times that of said resistive layer, by

advancing the strip into a main portion of the electrolyte and between successive pairs of split cathodes therein,

passing an electric current through said electrolyte, between said cathodes and the strip as anode, at an average anodizing current density much higher than 100 amperes per sq. ft., the variation in voltage between adjacent pairs of cathodes not exceeding about 1 volt and corresponding variations in current density along the strip being limited to about 30%.

progressively increasing the anodizing current density to a value in the range from 250 to about 1000 amperes per sq. ft.

11. In the art of continuously anodizing aluminum in strip form, the method comprising the steps of:

(*a*) forming a uniform, dense and electrically-resistive oxide layer on the surface of aluminum strip by

feeding said strip through a pretreatment portion of an acidic dissolving electrolyte and applying an electric current to the strip as anode, at an average anodizing current density in the range of 20 to 100 amperes per sq. ft. and an average anodizing voltage of about 14 volts, while controlling the anodizing rate to prevent burning,

completing the formation of said resistive layer during a period not exceeding about 6 seconds; then

(*b*) continuing the anodizing of said strip at increased anodizing current density to form the main body of the final anodized layer thereon, the thickness of said main body being at least about 50 times that of said resistive layer, by

advancing the strip into a main portion of the electrolyte,

passing an electric current through said electrolyte, between a cathode immersed therein and the strip as anode, at an average anodizing current density much higher than 100 amperes per sq. ft.; and

(*c*) limiting the flow of current via the electrolyte between the respective portions thereof to control the anodizing rate of the strip in the pretreatment portion of the electrolyte.

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