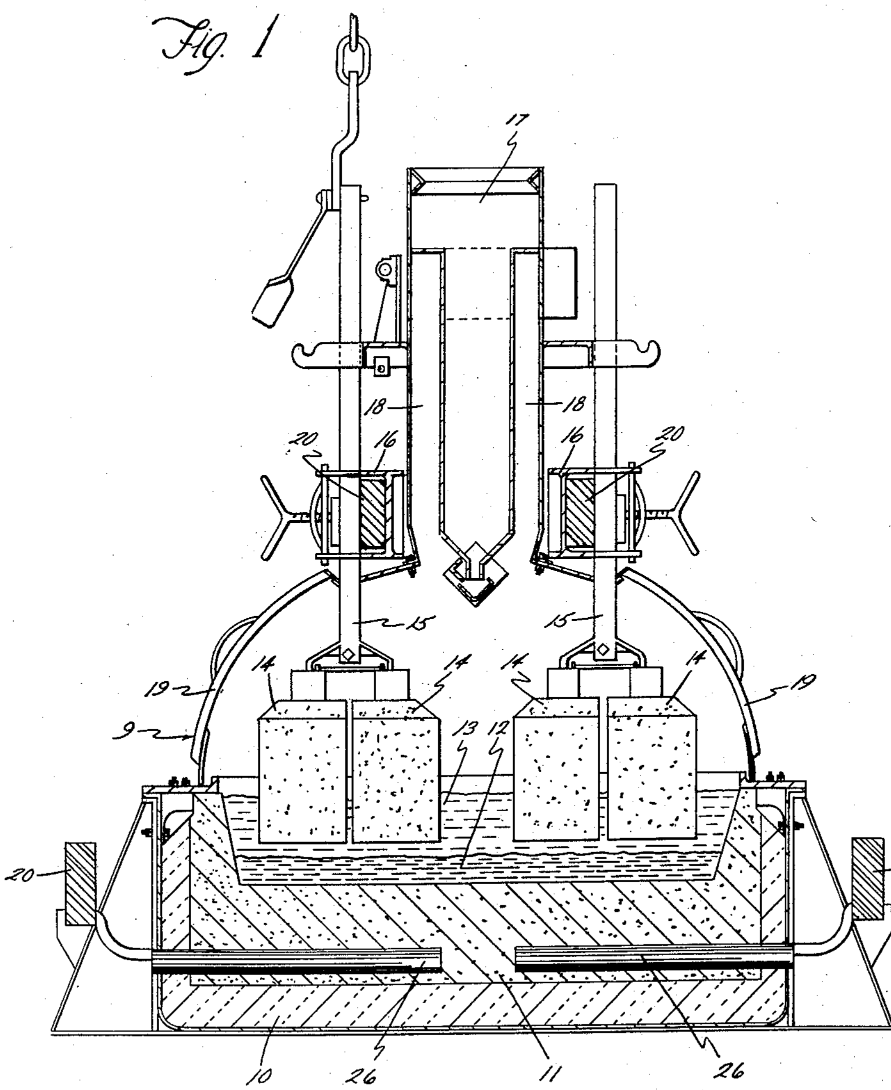
March 29, 1960 R. J. COOPER 2,930,746

CONTROL OF REDUCTION POT LINES

Filed Jan. 10, 1957 4 Sheets-Sheet 1

Fig. 1



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CONTROL OF REDUCTION POT LINES

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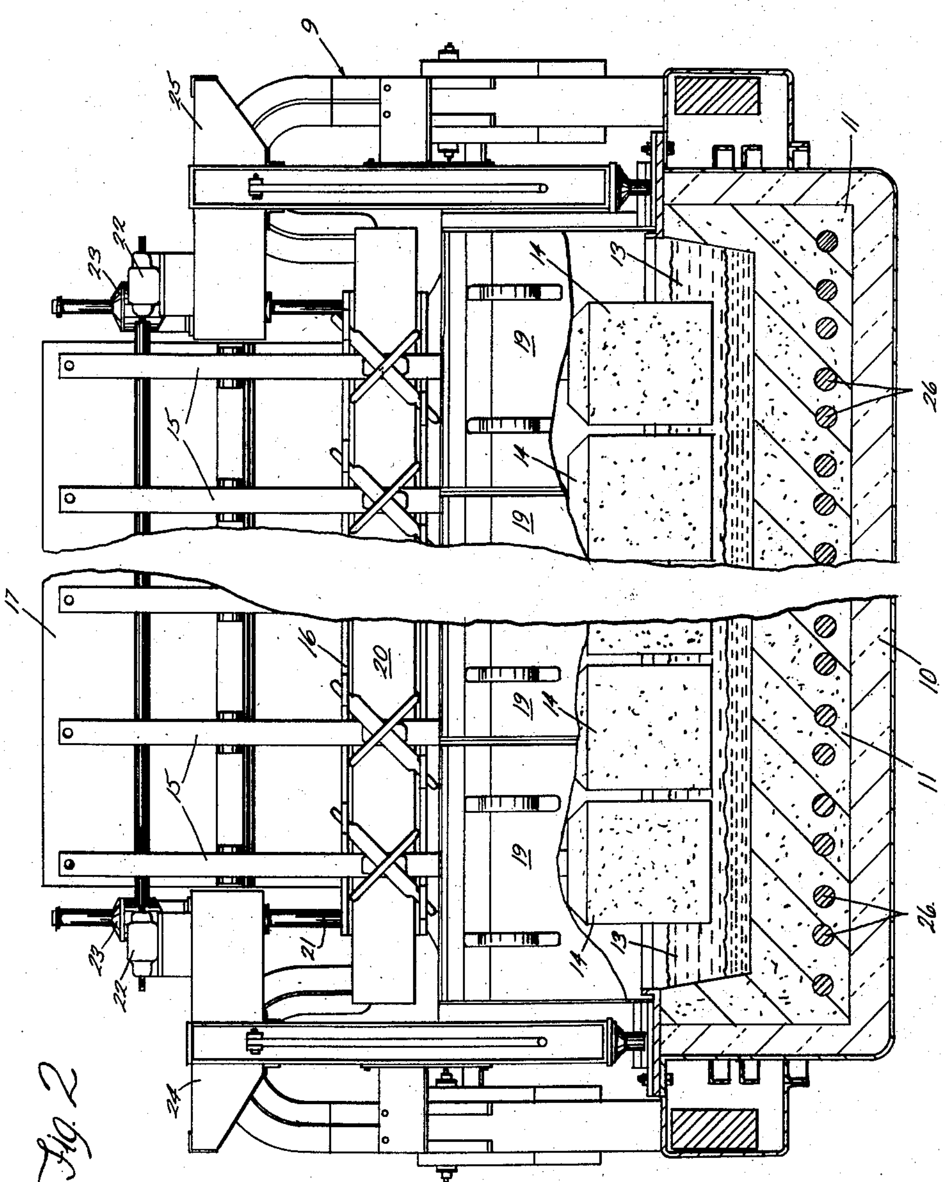

Fig. 2

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CONTROL OF REDUCTION POT LINES

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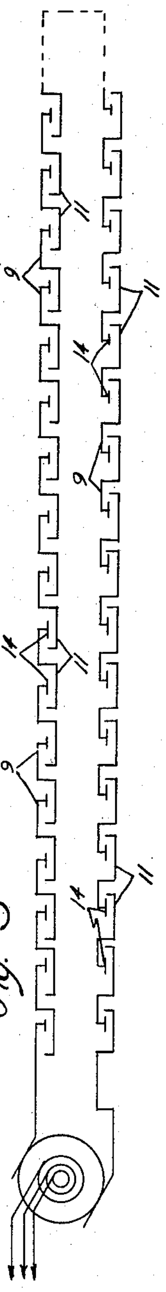

Fig. 3

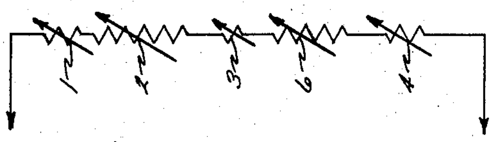

Fig. 7

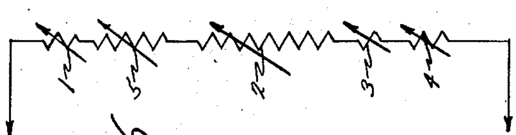

Fig. 6

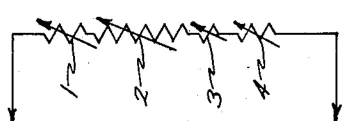

Fig. 5

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CONTROL OF REDUCTION POT LINES

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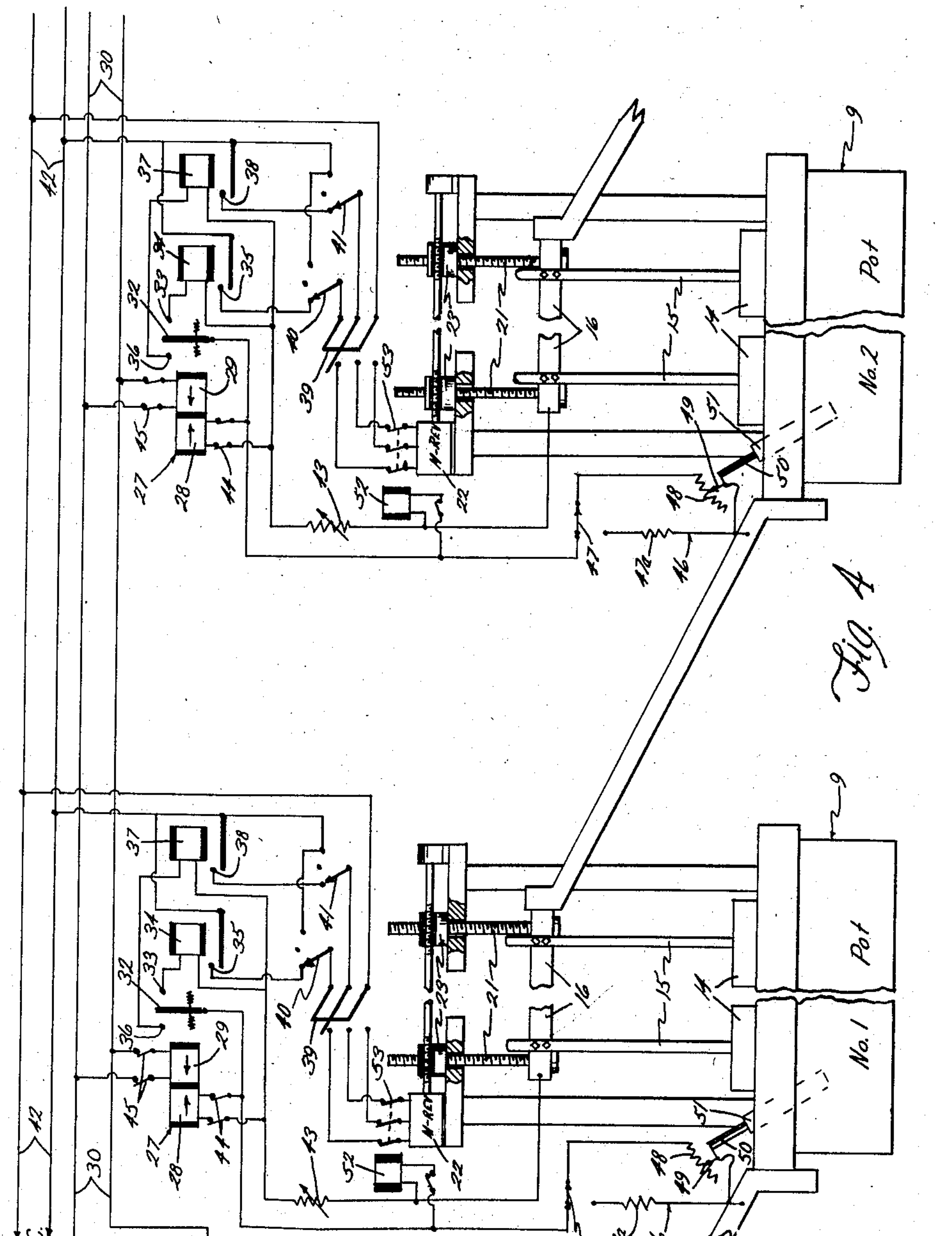

Fig. 4

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United States Patent Office 2,930,746
Patented Mar. 29, 1960

2,930,746

CONTROL OF REDUCTION POT LINES

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Application January 10, 1957, Serial No. 633,436
3 Claims. (Cl. 204—225)

My invention relates to the reduction of aluminum oxide to aluminum by the process of dissolving the aluminum oxide in molten cryolite and passing electric current through the solution.

In the well known pot lines which are commonly used for this purpose, it is the practice to provide a multiplicity of cells or pots which are substantially alike, each consisting of a base unit which is well insulated, a carbon shell forming a pan within the base and having in its bottom a grid of metallic conductors. This shell, which is the cathode of the cell, provides a shallow pan in which molten cryolite, molten aluminum and a crust formation on top of the cryolite are held. In normal operation an anode or a plurality of anodes are suspended from above the cell to extend into the molten cryolite. Current flows from the anode through the molten cryolite in which aluminum oxide is dissolved and decomposes the aluminum oxide. The oxygen thus released combines with the carbon and gradually eats away the carbon anode. The aluminum metal, being slightly heavier than the cryolite alumina solution, sinks to the bottom and forms what is usually termed a pad of molten metal that increases in depth as the operation proceeds until it is necessary to draw off or tap the pot to reduce the depth of the molten aluminum.

The size of the individual cell or pot is quite large and the amount of current passing through a series of pots may be of the order of sixty thousand to one hundred thousand amperes. Decomposition potential in the individual cell is comparatively low, also the electrical resistance in the cell is considerable so that a major portion of the potential drop across a cell is due to electrical resistance of the electrodes, the cryolite bath and the electrode connections. It appears to be substantially universal in the industry to use about five volt potential drop across each pot or cell, thus in a 140 pot line, the total voltage drop across the several pots in series would be 700 volts and the current supply would vary between some sixty thousand amperes and one hundred thousand amperes, depending upon the size of the cells. Since the over all efficiency of the pot line is really measured by the amount of aluminum deposited per unit of power used, it is obvious that efficient operation of each pot is essential. According to Faraday's law, 1,000 amperes will deposit .74 lb. of aluminum per hour at 100% current efficiency. However, many things enter into the operation to affect the current efficiency. Current efficiency in the pots is related directly to bath temperature. It is necessary to maintain the temperature of the bath at about 960 degrees C. Much of the electrical resistance in the cell creates heat which operates to maintain this bath temperature. The cell is so insulated as to maintain the temperature as close as possible to the desired 960 degrees C.

In any event theoretically the amount of aluminum made per unit time in a cell is proportional to the current passing through that cell. A cell of a given size will operate efficiently on a current flow of a given

amount so long as the conditions which affect its resistance to the current flow remain most favorable. There must be adequate alumina in the cryolite bath. There must also not be too much alumina added or it will not dissolve and will settle through the molten aluminum pad. The carbon anode must be maintained at the proper distance from the molten aluminum to produce the desired heat and to decompose the alumina. All these things are difficult to maintain. However, bath temperature and current flow are both highly responsive to changing resistance across the electrode space. It is the purpose of my invention to provide a control means operating automatically to maintain the current flow through the bath at the optimum level by responding to conditions that affect the over all resistance of the cell to current flow.

A discussion of those things, apart from fixed resistances, that affect the current flow across a cell and their effect on all of the cells in a pot line will, it is believed, facilitate understanding of my control system and how it operates to correct the things that interfere with the reduction process.

The overall efficiency of the reduction process is measured fundamentally in terms of units of aluminum recovered per unit of power consumed and units of electrodes used up. There is an optimum temperature at which the cryolite bath should remain for best reduction. This is stated in an article by Reese in Industrial and Engineering Chemistry, vol. 47, No. 10, p. 2069, as about 960 degrees C. Others give the desired temperature of the bath as 970 degrees C. The heat to maintain this temperature is obtained by the current flow through the bath from the carbon anodes to the molten aluminum pad and the carbon lining of the cell or pot. The pots are so insulated that with normal voltage crop across the pot and normal current flow for the pot, the heat generated is sufficient to maintain this temperature. Any deviation from the normal affects the temperature.

The amount of alumina in solution in the cryolite at any time affects the resistance of the bath and consequently the temperature. Normally the bath should contain about 4% but it may vary between 2.5% and 6% without serious adverse effects. If less than 2.5% dissolved alumina is present in the bath, however, the resistance of the bath may climb rather rapidly. The cause of this climb in resistance has not been fully explained. However, it appears to be accompanied by an increased thickness of gas film beneath the anode, or at least a high increase in the resistance at the anode-to-bath junction. The molten bath has a limited capacity to take alumina into solution so feeding excess amounts of alumina into the bath may result in excess alumina settling through the molten cryolite bath and the molten aluminum beneath the cryolite upon the carbon lining because the alumina is heavier than either the molten cryolite or the molten aluminum. These unreduced particles of alumina are poor conductors of electricity and tend to increase the overall resistance of the pot. Also since the resistance increase is below the already reduced molten metal, the amount of alumina decomposed in the cryolite bath may be lessened because of lack of adequate potential across the bath even though the overall voltage across the pot may be higher than normal.

A pot line electrically resembles a multiplicity of variable resistances in series with a substantially fixed voltage applied across them. Since they are in series the current flow is the same in all of them. When one pot has any change in resistance it affects the amount of current flow in all the pots. It also affects the voltage drop across the other pots. This in turn may lower the power available for reduction in the several pots below the optimum and result in serious loss of metal production. The desired condition of course, is optimum current flow through the line with each pot having enough voltage drop across it to take care of the fixed resistances and leave proper voltage available to decompose alumina and to force current through the resistance of the cryolite-alumina solution.

The voltage necessary to decompose the alumina is some times referred to as the counter-voltage of the pot line. It is of the order of 1.65 to 1.75 volts per cell or pot. This voltage does not apparently vary so long as adequate alumina is in the bath regardless of the total voltage existing across a cell or pot. However, the voltage across a pot may rise exceptionally high in response to an excess of gas beneath the anodes in a cell. This condition may result from too little alumina in the molten cryolite bath or other causes. This so called anode effect may be accompanied by a luminous appearance around the anodes caused by current arcing through the gas film between the anode and the bath. In such a case the pot is said to be on light. Working in more alumina into the bath is one aid to getting rid of the anode effect. This can be done by breaking in the crust that forms on top of the bath and thus getting the alumina in the crust into the bath. Other practices include raking the metal in the aluminum pot below the anodes vigorously to cause temporary short circuits from the anode to the aluminum. This cools the gases and disturbs them so they escape more readily. Lowering of the anodes closer to the molten aluminum pad is also used to stop the anode effect.

Reference has been made previously to the bad effects of excessive alumina settling through the bath onto the carbon lining. The settled alumina tends to collect around the sides of the lining first and then gradually spreads across the lining beneath the molten metal. The result is to gradually concentrate the flow of current on the relative free surface of the carbon lining. Increased heating takes place in the bath due to the increased over all resistance across the pot. It is well known that at temperatures slightly above 1,000 degrees C. the molten metal tends to recombine with the released oxygen in the bath. This of course, cuts down the production of metal. To stop the accumulation of alumina on the bottom of the pot it is a practice to reduce or cut off the feed of new ore and to bring the anodes closer to the molten metal. These adjustments do keep the temperature down and do aid in converting alumina in the bath to metal. More important, the reduction in resistance in the sick pot accomplished by bringing the anodes closer to the molten metal is to reduce the over all resistance of the pot line so that other pots will get additional current and not be cooled down.

The temperature of a pot is quite critical. If the temperature is too low the alumina does not go into solution readily and thus tends to pass through the bath to produce muck deposits beneath the molten metal. If the temperature is too high, the metal tends to reconvert by combining with the oxygen in the bath. Cooling of the bath also produces harder crusts of cryolite at the top of the bath and makes it more difficult to get alumina into the bath.

It is believed that I have made clear in the foregoing discussion the reflection of the defects in pot operation in three things: the voltage across an individual pot, the line current through all pots and the temperature of the individual pots. It is the purpose of my invention to provide a control system which utilizes changes of voltage drop across pots, changes in line current and changes in pot temperature to vary the anode-cathode spacing and thereby maintain greater uniformity in pot temperature and line current.

Another purpose of the invention is to provide a control system which is operably connected to the anode raising and lowering mechanism of each individual pot and which is actuated by line current variation to effect adjustment of anode cathode spacing of all spots and actuated by voltage variation across individual pots to effect adjustment of anode cathode spacing of such pots.

Other objects and advantages of my invention will appear from the following description and the accompanying drawings illustrating a preferred form of the invention. It should be understood, however, that the drawings and description are illustrative only and are not intended to limit the invention except insofar as it is limited by the claims.

In the drawings:

Figure 1 is a cross sectional view through a typical pot of an aluminum reduction pot line;

Figure 2 is a view of the pot taken at right angles to Figure 1 with the lower part of the pot in section and the upper part of the pot in side view;

Figure 3 is a diagrammatic view illustrating the series circuit arrangement of pots in an aluminum reduction pot line;

Figure 4 is another diagrammatic view illustrating the control system of my invention on a plurality of pots;

Figures 5, 6 and 7 are diagrammatic views illustrating the electrical characteristics of a pot under three conditions.

In a line that has, for example, 100 pots with a voltage of 500 volts across all of the pots in series and with a current of 50,000 amperes, the individual pot resistance would be .0001 ohm. Each pot theoretically would have a 5 volt drop across it and 50,000 amperes flowing through it. If we assume that one pot in the pot line gets too little alumina, it heats up suddenly and "goes on light."

When a pot is on light, a voltage drop across it of the order of 30 volts may be found to exist. The overall voltage rises slightly, if the line voltage regulators are untouched, to about 508 volts. This means that other pots will have an average of about 4.83 volts drop across each and the current through all pots will be cut down to 48,300 amperes. Obviously the pot "on light" is too hot and its efficiency is down. The current loss is about 3.4%.

Now assume a pot line of 140 pots with a desired load of 60,000 amperes and 700 volts across all of the pots in series. To get the 60,000 amperes the total resistance across the 140 pots would be .0116 ohm or .0000833 ohm per pot. The voltage drop across each pot should be about 4.989 volts. If due to either alumina shortage or deposit of undissolved alumina beneath the molten metal or other causes, the line resistance increases by as little as .0013 ohm to .0129 ohm and the voltage regulators are not touched, line voltage will rise to about 710 volts, making an average voltage of 5.065 volts across a single pot. The line current will decrease from 60,000 amperes to 55,000 amperes. The voltage change is so slight as to be difficult to detect on the meters commonly used to indicate pot voltage. However, the 5,000 ampere drop in the line is an 8.3% loss.

In the case of the pot "on light" the high voltage across it is easily detected. In the other case given, the reduction in line current flow is readily detected.

The third factor of pot temperature may cause great losses in metal production. For example, if the temperature of a pot goes up with current holding steady, then the voltage across this pot should be reduced to avoid the losses in reconversion, etc., that result from too high pot temperature. If the pot temperature is running too low we known that certain problems arise. For example, the ability of the bath to dissolve alumina is reduced. According to my invention, therefore, control means are provided whereby a rise in temperature of a pot can effect a drop in voltage across the pot and a drop in temperature of a pot can effect a rise in voltage across the pot. In all carbon pots the resistance of the carbon of the pot is lowered by heating the carbon, because the resistance of the carbon to the passage of current decreases with an increase in temperature of the carbon. The temperature range in which a pot must operate is so slight that in the overall pot structure, this characteristic of the carbon is not critical. Also the metal leads to the pots have a positive temperature coefficient of resistance which tends to offset the carbon characteristic. I do provide means responsive to the pot temperature as a third control element as will be described later.

As illustrated in Figures 1 and 2, an individual pot **9** in a pot line is made up of a bed **10** of heat insulating material. On this bed is a pan **11** of carbon which forms the cathode of the pot **9**. The pan **11** holds a molten metal pad **12** which is formed of the metal reduced from the alumina. Over the pad **12** is the electrolyte or bath **13** which is molten cryolite with certain additives and dissolved alumina. A crust (not shown) forms on the bath **13** and acts as an insulator to keep heat in the bath. The pot **9** has one or more anodes **14** of carbon suspended by bars **15** from overhead frames **16**. A hopper **17** is used to supply alumina to the bath and is usually manually controlled. Ducts **18** are provided for drawing off gases evolved during the reduction process. Manually removable covers **19** are provided over the pot. These covers are insulated at their edges to prevent current flow. Electrical connections to the anodes **14** are by means of bus bars **20** clamped against the bars **15** in any suitable manner that permits individual adjustment of anodes **14**. The overhead frames **16** that carry the bars **15** and bus bars **20** are suspended for vertical adjustment. In the drawings I show the means of suspension as two shafts **21**, which as illustrated best by Figures 2 and 4 are raised and lowered by motors **22** and rotating screw heads **23** through which threaded portions of the shafts **21** extend. The motors **22** and screw heads **23** are carried on end frames **24** and **25**. Electrical connection to the cathode pan **11** is by rods **26** embedded in the pan **11** and bus bars **20**. It will be understood that the bus bars **20** extend from the anode supporting frames **16** of one pot to the cathode pan **11** of the next pot in line since all pots are in series across the power line as illustrated in Figure 3.

The foregoing description will, it is believed, make the general construction of a pot line for reduction of aluminum sufficiently clear for the purposes of my invention. It is evident, of course, that a typical pot line may use the pre-baked anodes of the Hall process or the anodes that are baked in place according to the Soderberg process. Without further detailed explanation of the well known features of an aluminum reduction pot line, the application of my invention thereto will now be described. I might point out that the shaft **21**, screw heads **23**, and motors **22**, generally are not used for the purpose of adjusting the anodes up and down. They do, however, work well for my purpose. Any equivalent devices may be used for raising and lowering the anodes.

As illustrated best in Figure 4 of the drawings, my invention is embodied in a control system that employs, for each pot, a differential relay **27** having one coil **28** connected across the pot between the bus bar connection to the cathode **11** and the bus bar connection to the anode **14**. This coil **28** therefore is responsive to fluctuations in the voltage drop from the anodes **14** to the cathode connected end of the bus bar **20** for the pot. The other coil **29** of the relay **27** is connected across a voltage source indicated at **30**. The voltage across the coil **29** is varied by a rheostat **31** in response to changes in the amount of current flowing through the pots in series. The rheostat **31** is controlled directly by an ammeter which measures the current flowing through the pots. An example of an instrument which can be used for my purpose is a recording ammeter such as that sold by Leeds & Northrup Company as a "Micromax Recorder" Model S, 4000 series, and described by this company in its direction book std. 1235. For the purposes of this invention any ammeter is satisfactory which will adjust the rheostat **31** in response to changes in current flow through the pot line to increase the voltage across the coil **29** when the current flow through the pot line increases and to decrease the voltage across the coil **29** when the current flow through the pot line decreases.

The relay **27** has its armature **32** biased to neutral position. When the coil **28** exerts more pull than coil **29**, the armature **32** closes its front contact **33** and this energizes another relay **34**, which closes a point at **35** in the energizing circuit for the motor **22**. These motors **22** are all reversible motors and the point **35** is in the circuit which causes the motor **22** to rotate in such a direction as to move the shafts **21** down and lower the anodes **14** toward the cathode **11** of the pot.

When the coil **29** exerts more pull than the coil **28**, the armature **32** closes its back contact **36**. This energizes a relay **37** which closes a point at **38** in the energizing circuit for the motor **22**. The point **38** is in the motor circuit which causes the motor **22** to rotate in the direction that moves the shafts **21** and anodes **14** up away from the cathode **11**. When the current through the pot line is high and the voltage is normal or low on any pot **9**, the anodes **14** of that pot will be raised by energizing its motor **22** through the point **38**. However, if, on any pot in the line the voltage is already high, this will offset the effect of high current and, for this pot, the motor **22** either will not be energized or will be energized for a shorter period so it will not raise its anodes **14** as much as the other motors **22** will raise their anodes **14**.

It will be noted that a main switch **39** is provided in the circuit for each motor **22** so it may be made ineffective. Also the motor lead to the contact point **35** has a switch **40** therein and this switch can be shifted to shunt out the contact point **35** and to connect the motor **22** directly to a source of current **42** to operate the motor in a direction to lower the anodes **14**. Likewise the motor lead to the contact point **38** has a switch **41** therein by which the contact point **38** may be shunted out and the motor **22** connected directly to the current source **42** to operate the motor **22** in a direction to raise the anodes **14**.

In the leads to the coil **28**, I provide a manually variable resistance **43** which can be used to vary the voltage impressed on the coil **28** for any given voltage drop across a pot. For example, it may be desirable to permit a pot to operate "on light" temporarily. By increasing the resistance at **43** sufficiently the effect of the high "on light" voltage cross the pot on the coil **28** can be made to equal the effect of normal pot voltage on this coil. The differential relay can be cut entirely out of operation by manually operable switches **44** and **45**.

In order to utilize the temperature of each individual pot **9** as a factor in its control, a pot temperature responsive device or thermostat **46** is positioned in the bath **13** of each pot as indicated in Figure 4. This device is normally connected in series with the coil **28** of the differential relay **27**. However, a shunting switch **47** is connected around the device **46** so that it may be taken out of circuit whenever the influence of pot temperature is not desired upon the coil **28**.

The device **46**, according to the discussion hereinbefore given, should tend to reduce the voltage across the pot **9** in which it is located as the temperature of the pot goes up because increased voltage across a pot tends to force more current through the pot and thus create more heat in the pot. In order to have the effect desired, the device **46** must reduce the overall resistance in series with the coil **28** as the pot **9** heats up from a minimum desirable operating temperature. In other words, the device **46** must show a negative temperature coefficient of resistance effect in the circuit of the coil **28**. A carbon resistor would have this effect and further has the characteristic of being able to withstand immersion in the bath of the pot. Sensitivity of the carbon, however, is low for this purpose. It must be remembered that permissible temperature variations at the working range of a pot are slight in comparison with the temperature at which the pot must be maintained. A bath temperature of 960 degrees C. to 970 degrees C. is desirable, but a rise of the bath temperature to 990 degrees C. causes a significant drop in current efficiency. I provide a resistance unit **48** as part of the device **46** with a movable contactor **49** actuated by a temperature responsive element **50** which is extended into the bath **13** in a carbon case **51**. The temperature responsive element is indicated as a bi-metallic strip. Any equivalent temperature responsive means may be used that is operable to increase the effective pull of the coil **28** on its armature **32** in response to pot temperature rise and to reduce the effective pull of the coil **28** on its armature **32** in response to pot temperature decrease.

It is evident that by giving proper values to the resistance **48**, the effect of temperature rise and fall in a pot **9** upon control of raising and lowering the anodes **14** may be made such as to maintain pot temperatures within the desired range when the current is kept near the optimum amount.

As is indicated by Figure 4 of the drawings, each pot **9** has associated with it a motorized mechanism consisting of the motors **22**, screw heads **23** and shafts **21** connected to the anode supports **16** to move the anodes **14** toward and away from the cathode **11**. The individual anode carbons **14** are manually adjustable up and down in the customary manner with respect to other anodes in a pot. The motorized mechanism is actuated by control devices which are in turn responsive to the current flowing through the pot, the voltage drop across the pot, and the temperature of the electrolyte bath. The control devices are active conjointly so that for example, if the voltage is low across a pot and the current is also low, the influence of the low voltage, which is to drive the motorized mechanism in a direction to separate the anodes further from the cathode, would be opposed by the influence of the low current, which is to drive the motorized mechanism in a direction to bring the anodes **14** closer to the cathode **11**. The control devices, comprising relays **27**, **34** and **37** and the thermostat device **46**, are so interconnected that the temperature of a pot, the voltage across the pot, and the current through the pot cooperate to move the anodes **14** with respect to the cathodes.

The action of the control devices may be better seen by reference to Figures 5, 6 and 7 where the internal elements of a pot are simulated by electrical resistances. In Figure 5 the normal or desired pot condition is pictured. Here a variable resistance **1** represents the anode, a variable resistance **2** represents the cryolite-alumina bath, a third variable resistance **3** represents the molten aluminum beneath the bath, and a fourth variable resistance **4** represents the carbon lining or cathode of the pot. In the optimum operation resistance **3** is quite small, resistance **4** is large enough to produce some heat and the anode resistance **1** is also fairly small. Most of the resistance is in the bath which is represented by variable resistance **2**.

Assume that in Figure 6 we have an anode effect and the pot is "on light." In this case resistance **1** is now separated from resistance **2** by a gaseous film which is represented as a variable resistance **5**. The bath resistance increases if the amount of alumina in solution in the cryolite gets too low. This is what causes anode effects generally, so in Figure 6, resistance **2** is larger than it is in Figure 5. The resistances **3** and **4** remain essentially the same. It now takes more voltage to push current through resistance **5** and increased resistance **2** and some more heat is produced in the bath. Current in the line will be reduced. All this means that coil **28** of relay **27** will act to energize the motor **22** on this pot **9** and lower the anodes **4** to reduce both voltage and heat.

Now refer to Figure 7 which illustrates the effect of undissolved alumina getting through the bath and depositing on the carbon lining. In this condition the resistances **1**, **2**, **3** and **4** will remain about the same. However, the undissolved alumina inserts an added resistance between the resistances **3** and **4** which resistance is indicated at **6**. This resistance will reduce the current in the line and increase the pot temperature. It is particularly bad for increasing temperature because the added resistance is beneath the molten metal where all of the heat generated is communicated to the bath. The voltage rise may be very slight but the cumulative effect on relay **27** of increased temperature in the pot (which cuts down the resistance **48** in series with the coil **28**, thus effectively increasing the pull of coil **28**), and the reduced current through the coil **29** will cause the energization of the relay **34** to operate the motor **22** in a direction to lower the anodes **14**. Lowering of the anodes **14** reduces the bath resistance **2** and this of course, permits more current in the line. At the same time, the overall heat generated in the pot is reduced since much of this heat comes from the bath itself.

If it is desired to operate any pot hot for a while, the operator can close the shunt circuit around unit **46** by moving switch **47** to release the control system from the temperature responsive device **46**. A reistance **47*a*** is provided in series with the shunt switch **47** to equal the amount of resistance **48** that would be in circuit with the coil **28** at a pot temperature of 965 degrees C. Thus moving of the switch **47** to substitute resistance **47*a*** for resistance **48** frees the automatic controls from the temperature influence.

In the event that it is desired to operate any pot "on light" for a short time the resistance **43** can be adjusted for this purpose, or if it is desired to cut off the automatic control entirely from the pot, the switch **39** is opened or the two switches **40** and **41** can be used to raise and lower the anodes **14** as desired and left in neutral position. Some operating plants frown upon the practice of lowering anodes to destroy the gaseous arc in a pot "on light." With the present control system it is possible to provide means whereby the high voltage that is found across a pot "on light" will cut out the automatic regulation of the anodes. An overload relay **52** is placed across the leads from the pot **9** to the coil **28** and has its armatures **53** movable, when the voltage drop across the pot **9** exceeds a certain predetermined level, to break the power supply circuit of the motor **22** for that pot.

It is believed that the nature and advantages of my invention will be apparent from the foregoing description. The control system as described, operates to lower the anodes in all pots **9** if the current is too low and the voltage is normal or too high, unless a pot is too cold. If the pot temperature is too low the temperature control unit **46** will exert its effect to oppose lowering of the anodes by putting more of the resistance **48** in series with the coil **28** so that less force is exerted by the coil **28** to oppose the coil **29**. If the voltage is too high across the pot, this tends to give the coil **28** more force to cause it to overcome the force exerted by the coil **29**. Thus a high voltage across a pot will tend to lower the anodes **14** by energizing the motor **22** to operate in the proper direction. Whenever the coil **28** receives enough energy to overbalance the coil **29**, the anodes **14** are lowered and whenever the coil **29** receives enough energy to overbalance the coil **28**, the anodes **14** are raised. Higher temperature in a pot **9** has the effect of increasing the energy to the coil **28**. Thus under a condition of full current, normal voltage and normal temperature, the coils **28** and **29** at a pot balance. If any pot **9** cools off too much, the energy through the coil **28** of its relay **27** will be decreased so as to cause the anodes of that pot to be raised.

If the voltage across any pot **9** goes up unduly because of shortage of alumina in the bath, or because of deposit of alumina on the carbon pan, the extra energy pushed through the coil **28** of the control mechanism for that pot will cause the anodes **14** of that pot to be lowered. If the added resistance cuts down the overall current in the pot line enough, all of the pots will be affected and the controls thereon will lower their anodes. However, cold pots will not be so greatly affected as hot pots so the lowering of the anodes to make up for lost current in the line is selective.

Having thus described my invention, I claim:

1. In a reduction system for metals such as aluminum wherein a plurality of pots, each embodying a cathode and an anode and each adapted to contain a molten electrolytic bath into which the compound to be reduced is introduced and dissolved, are interconnected in series to a source of current, the improvement in control means for said pots comprising power means operatively connected to each of the anodes for moving them toward and away from the cathodes, means responsive to the amount of current flow through the pots and continuously operatively connected to the power means of each pot tending to cause the power means to move the anodes toward the cathodes upon decrease in current flow through the pots and tending to cause the power means to move the anodes away from the cathodes upon increase in current flow through the pots, means individual to each pot responsive to variations in voltage across the pot and continuously operatively connected to the power means of that pot, continuously tending to cause the power means to move the anode closer to the cathode upon a rise in voltage across the pot and to move the anode away from the cathode upon a fall in voltage across the pot, and means individual to each pot responsive to variations in the temperature of said bath and continuously operatively connected to the power means of that pot, tending to cause the power means to move the anode closer to the cathode upon a rise in temperature of the bath and to move the anode away from the cathode upon a drop in temperature of the bath.

2. In a reduction system for metals such as aluminum wherein a plurality of pots, each embodying a cathode and an anode and each adapted to contain a molten electrolytic bath connecting said electrodes into which the compound to be reduced is introduced and dissolved, are connected in series to a source of current, the improvement comprising a first means individual to each pot responsive to variations in anode to cathode voltage drop in the pot continuously operable to increase the anode-

cathode spacing upon decrease of said voltage drop and to decrease the anode-cathode spacing upon increase of said voltage drop beyond predetermined limits, a second means individual to each pot responsive to variations in current flowing through the pot continuously operable to increase the anode-cathode spacing in the pot upon increase in said current and to decrease the anode-cathode spacing upon decrease in current beyond predetermined limits, and means individual to each pot responsive to temperature variations in the pot, said last named being connected to one of said first and second means and continuously exerting a control effect thereon tending to cause said one means to increase the anode-cathode spacing upon temperature decline in the pot and to cause said one means to decrease the anode-cathode spacing upon temperature rise in the pot.

3. In a reduction system for metals such as aluminum wherein a plurality of pots, each embodying a cathode and an anode and each adapted to contain a molten electrolytic bath connecting said electrodes into which the compound to be reduced is introduced and dissolved, are connected in series to a source of current, the improvement comprising a first means individual to each pot responsive to variations in anode to cathode voltage drop in the pot continuously operable to increase the anode-cathode spacing upon decrease of said voltage drop and to decrease the anode-cathode spacing upon increase of said voltage drop beyond predetermined limits, a second means individual to each pot responsive to variations in current flowing through the pot continuously operable to increase the anode-cathode spacing in the pot upon increase in said current and to decrease the anode-cathode spacing upon decrease in current beyond predetermined limits and means individual to each pot responsive to temperature variations in the pot, said last named means being connected to said first means and continuously exerting a control effect thereon tending to cause said first means to increase the anode-cathode spacing upon temperature decline in the pot and to cause said first means to decrease the anode cathode spacing upon temperature rise in the pot.

References Cited in the file of this patent

UNITED STATES PATENTS

1,396,919	Brace	Nov. 15, 1921
2,545,411	Perrit-Bit	Mar. 13, 1951
2,545,412	Perrit-Bit	Mar. 13, 1951
2,731,412	Ferrand	Jan. 17, 1956