July 17, 1951 L. FERRAND 2,560,854

APPARATUS FOR THE CONTINUOUS OPERATION OF CELLS FOR THE ELECTROLYSIS OF MOLTEN SALTS

Filed July 16, 1946 4 Sheets-Sheet 1

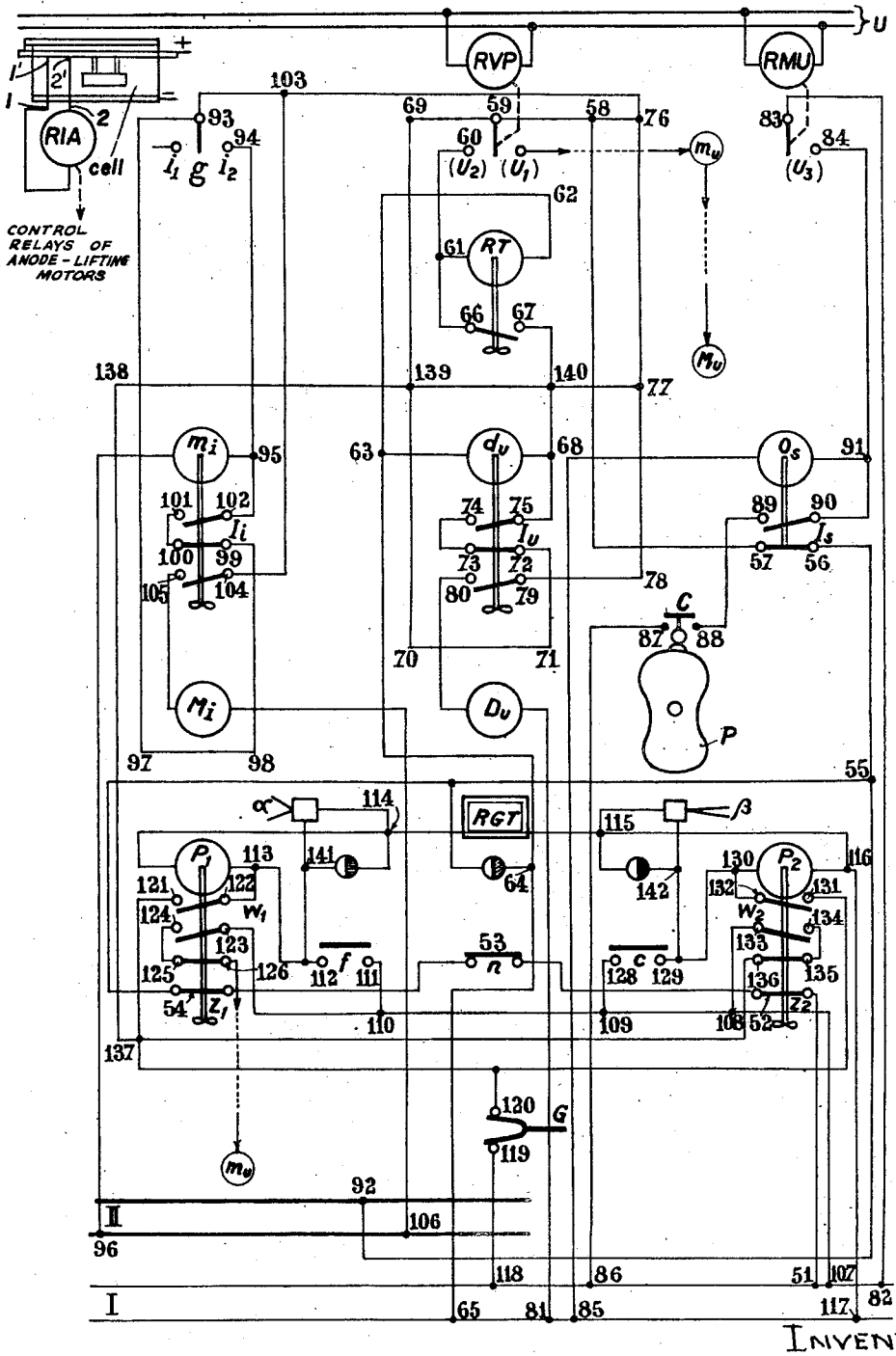


Fig.1.

INVENTOR
L. FERRAND
BY Blaschack, Cumming & Seebold
ATTYS

July 17, 1951 L. FERRAND 2,560,854

APPARATUS FOR THE CONTINUOUS OPERATION OF CELLS FOR THE ELECTROLYSIS OF MOLTEN SALTS

Filed July 16, 1946 4 Sheets-Sheet 2

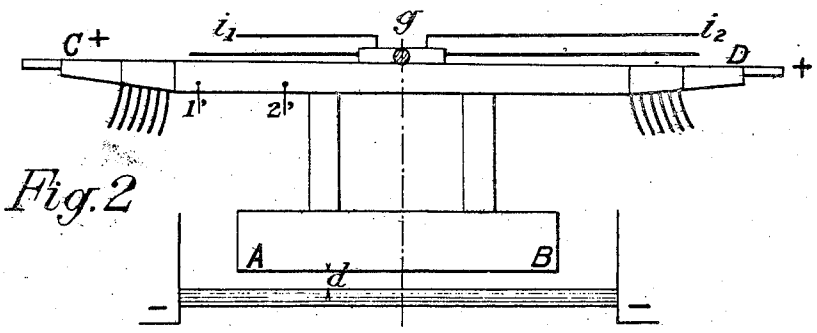


Fig. 2

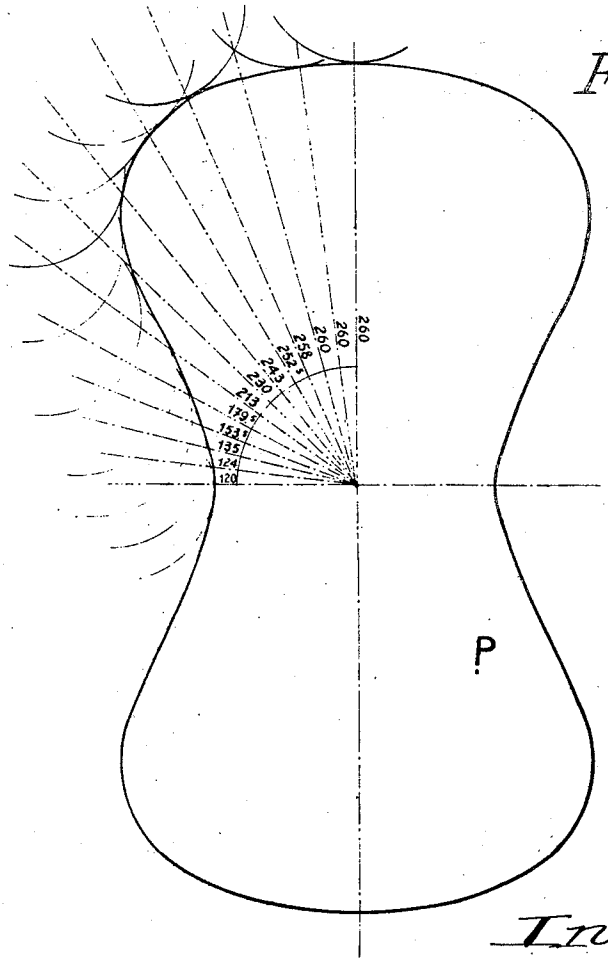


Fig. 8

Inventor
L. Ferrand
By Glascock Downing & Seckle
Attys.

July 17, 1951 L. FERRAND 2,560,854

APPARATUS FOR THE CONTINUOUS OPERATION OF CELLS FOR THE ELECTROLYSIS OF MOLTEN SALTS

Filed July 16, 1946 4 Sheets-Sheet 3

Fig. 5.

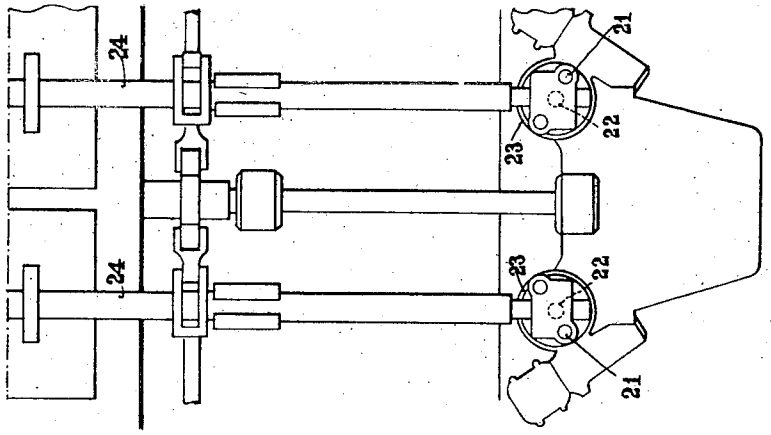


Fig. 4.

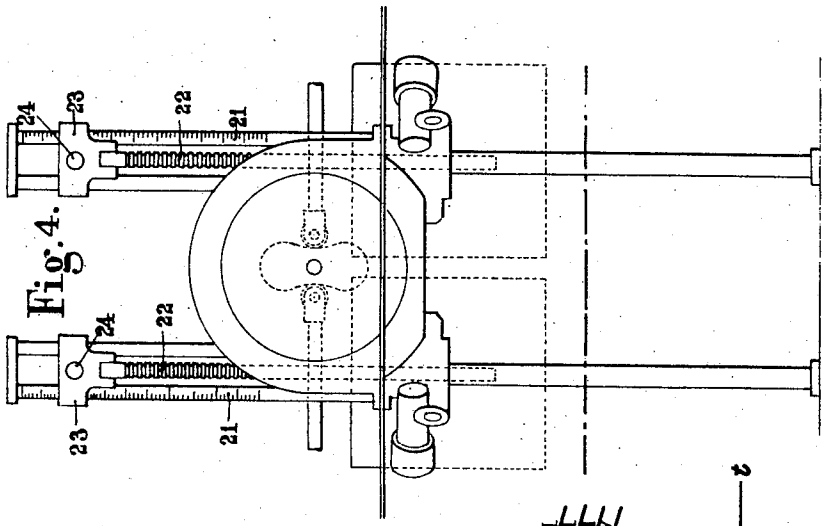
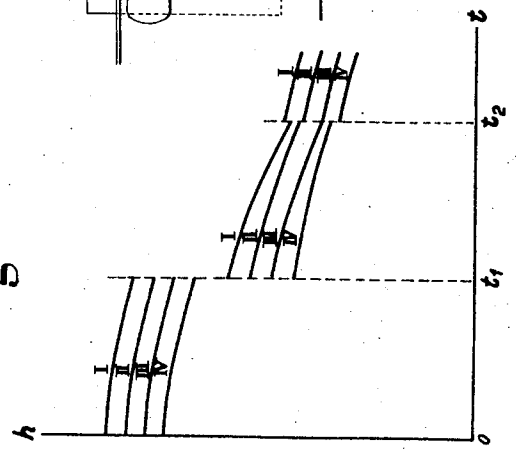


Fig. 3.



Inventor
L. Ferrand
By Glascock Downing & Seibold
Attys.

July 17, 1951 L. FERRAND 2,560,854

APPARATUS FOR THE CONTINUOUS OPERATION OF CELLS FOR THE ELECTROLYSIS OF MOLTEN SALTS

Filed July 16, 1946 4 Sheets-Sheet 4

Fig. 7.

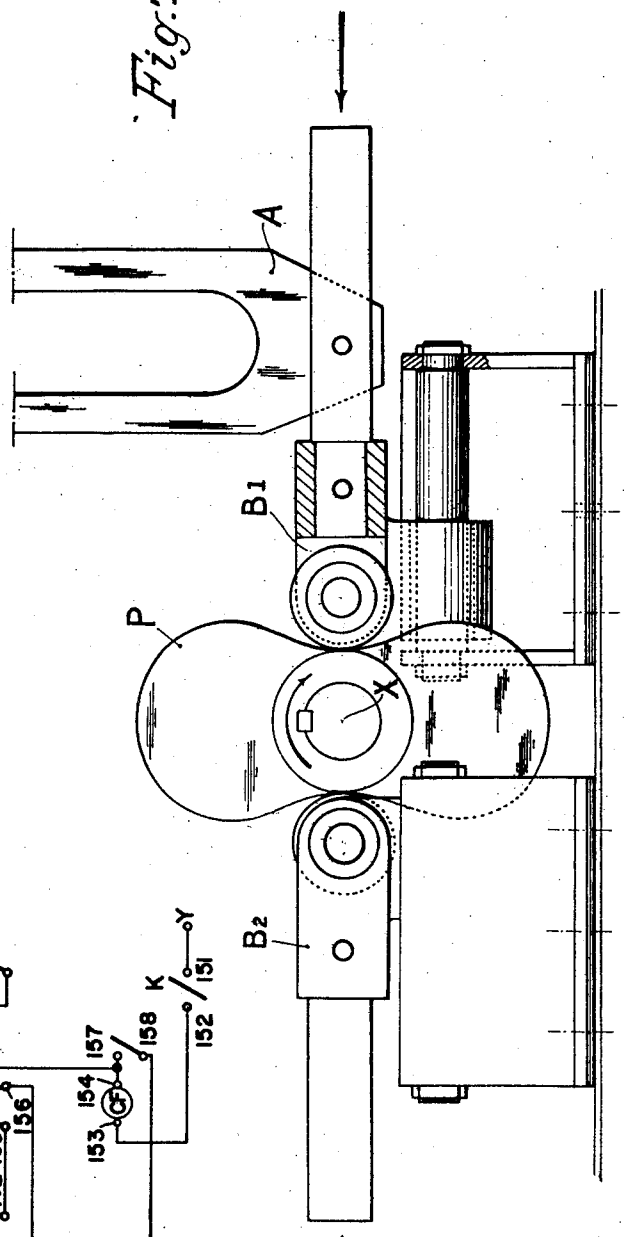
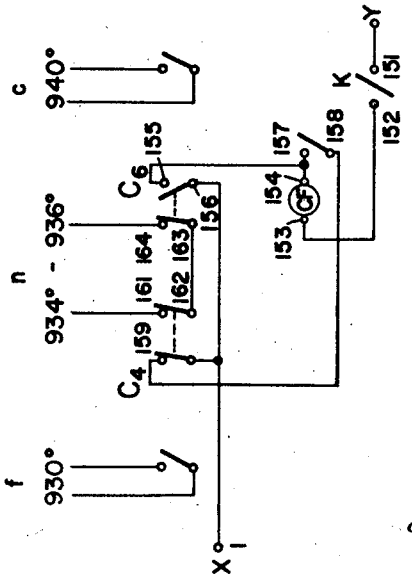


Fig. 6.



Inventor
L. Ferrand
By Glascock Downing Seibold
Attys.

Patented July 17, 1951 2,560,854

UNITED STATES PATENT OFFICE

2,560,854

APPARATUS FOR THE CONTINUOUS OPERATION OF CELLS FOR THE ELECTROLYSIS OF MOLTEN SALTS

Louis Ferrand, Paris, France

Application July 16, 1946, Serial No. 684,066
In France June 30, 1942

Section 1, Public Law 690, August 8, 1946
Patent expires June 30, 1962

6 Claims. (Cl. 204—223)

1

This invention relates to the operation of cells for the electrolysis of molten salts, and has for its principal object the provision of means by which such cells may be operated in a continuous and efficient manner both from electrical and chemical viewpoint.

In order to obtain high efficiency in cells of this type, it is important that the electrical current should be distributed most uniformly over all points of the sole of the cell, to avoid local overheating, and it is also important that the difference in densities between the metal collected at the bottom of the cell and the supernatant mixture of molten salts should be kept as high as possible. These conditions cooperate to secure a correct electrolytic separation of the metal which is produced.

In the particular instance of aluminum production, for which the cell of the invention is especially adapted, these results are secured (*a*) by keeping the temperature of the melt within narrow limits, constant if possible, even when it is desired to work at current values higher than that corresponding to thermal balance, in view of the surrounding temperature and irrespective of the current efficiency obtained for a given value of current, (*b*) by keeping the percentage of dissolved alumina constant or within narrow limits; the temperature and percentage of dissolved alumina are given such values as to maximize the difference in densities as mentioned above.

Without dwelling too much on the details of the electrometallurgical process, it may be recalled that the fulfillment of the two conditions set forth above requires the joint solution of three separate problems: (1) the electrical problem concerning the control of the voltage and the distribution of current amongst the several anodes, (2) an electro-chemical problem dealing with the regulation of the continuous supply of the dissolved substance, which should be resolved prior to the third problem, due account being taken of the current flowing through the cell and the efficiency of the electrolytic process, which in turn is dependent on the temperature of the melt, and (3) a thermal problem relating to the adjustment of the temperature, which depends not only on the electrical constants of the cell, but also on the conductivity of the salt or melt, which again depends upon the percentage of dissolved material subjected to the electrolytic process and upon the surrounding temperature, which may influence the temperature of the melt itself.

It is therefore a further object of the invention to provide means for automatically operating an electrolytic cell of the above type in such a way that the current efficiency shall be a maximum, and the current consumption a minimum.

2

The above and other objects and advantages of the invention will best be understood from the following specification of a preferred embodiment thereof, reference being made to the accompanying drawings, in which:

Fig. 1 is a diagrammatic view of the combined voltage-current-temperature regulating system for use in natural-convection operation of the cell,

Fig. 2 is a schematic view of the means for controlling current distribution along an anode-carrying shaft of the cell,

Fig. 3 is a set of curves illustrating the control of the positions of the ends of the anode-carrying shafts at different times,

Fig. 4 is a view in elevation of the means for guiding and adjusting the ends of the anode shafts,

Fig. 5 is a plan view of a pair of adjacent anode-carrying shafts with the related position-adjusting units,

Fig. 6 is a schematic view showing the particular arrangement of the normal temperature contact of the temperature regulator together with the special devices that become operative upon the occurrence of an excess current during induced convection operations,

Fig. 7 illustrates a mechanism for rocking the anode-carrying shafts, and

Fig. 8 shows in outline form the cam disc constituting the control member of the rocking mechanism.

I. Operation Under Conditions of Balanced Intensity—(Natural Convection)

1. *Voltage regulation*

Under normal operating conditions, with the current intensity at a constant value, variations in voltage can only occur as a result of variations in the interpolar distance due to the electrode consumption failing to be exactly compensated for by a variation in the height of the metal. Moreover, where the alumina is not fed continuously or should the percentage of alumina in the bath fall below a certain limit, principally in the vicinity of the anodes, as a result of an insufficient rate of feed, there is danger that the "anode effect" will appear; the consequence is that to the normal causes of voltage variations resulting from electrode consumption there is added another cause of exceptional and intermit-

tant character, which involves resorting to other means for the purpose of checking the development of working troubles and notably of temperature variations arising therefrom.

The problem of voltage regulation thus laid down is solved with the aid of several groups of members designed to perform separate functions, as follows:

1. Detecting members, constituted by highly sensitive relays capable of accurately detecting voltage variations in response to which orders are to be sent out by the same. Such elements are shown in Fig. 1 as the pair of relays RVP and RMU connected across the terminals of the voltage source U which is impressed across the cell, the former being adjusted to operate between a lower limit U_1 and an upper limit U_2 (that is, the nominal voltage $U_0 \pm 0.1$ volt), while the latter is adjusted to operate from a voltage U_3 (higher than U_2) upwards.

2. Order transmitting or selecting members or relays of a type capable of handling heavier currents. These are the auxiliary timed relays m_u and d_u, which are characterized in that their operation, and hence the movements initiated thereby, will last for a predetermined time (30 to 60 seconds or so), depending upon how widely the voltage regulation limits U_1 and U_2 are spaced from one another. When the voltage is to be raised, the auxiliary relay d_u will only be actuated through the medium of the delayed relay RT by which only those orders lasting for at least, say, 60 seconds, whereas the emitting relay RMU whose duty it is to detect voltage variations over a limit U_3 (higher than U_2) upwards has no such delaying action relay associated therewith, so that its auxiliary relay OS will be energized as soon as the voltage reaches the value U_3. In such occurrences, the orders emitted by relay RVP, by which latter the same voltage variation was also detected, will remain unobeyed on account of the delay imposed upon the same by the delayed relay RT, it being understood that the delay in operation of RT is governed by the limit of operation U_3 of relay RMU with respect to U_2. On the contrary, when the question is that of raising a voltage that became too low, once the pointer of RVP has reached the lower voltage limit the voltage-raising orders emitted by RVP will be transmitted by the auxiliary relay m_u without the interposition of any delaying relay.

3. Operating members whose duty is to perform the orders given by the emitting relays and transmitted through the auxiliary relays. As such, for the purpose of the problem under consideration, a pair of relays are used for the simultaneous switching-in of all the electrode-lifting motors pertaining to one and the same cell (M_u for the lifting and D_u for the lowering), said relays being controlled by two delayed-action switches such as I_u. For instance, if the voltage happens to rise to the upper limit U_2, the closing of contact **59—60** will at first result in the energization of the delayed-action relay RT by connecting it with the voltage on line I through the circuit **51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65**, following which (after a delay for which said relay RT is particularly set), the closing of the contact **66—67** will result in the energization of the delayed-action auxiliary relay d_u through the circuit **61, 66, 67, 68, 63, 64, 65** and at the same time in the holding of the same due to the immediate closing of its holding contact **74—75** through the path **59, 69, 70, 71, 72, 73, 74, 75, 68, 63, 64, 65**. Following the additional delay imposed by the delayed-action switch I_u, the third blade of the same will in turn close the contact **79—80**, thus switching in such order-performing members as the switch-in relay D_u by which all the anode-end position-adjusting units will be set into anode-lowering action through the circuit **59, 58, 76, 77, 78, 79, 80, 81**.

4. Preclusive members designed to prevent any incompatibility of motion that might result from conflicting orders given by the various emitting relays. As such there are employed on one hand the auxiliary relay OS of the emitting relay RMU, whose duty is to set the electrodes into oscillating movement as will be described hereinafter and whose push-pull switch I_s (which comprises two contacts either of which is closed while the other is open) cuts off the feed circuit for the remainder of the emitting relays as soon as the auxiliary relay OS is energized, so that no order can be transmitted to the anode-lifting motors after the anode effect in its initial phase has set the oscillating device into operation; and on the other hand, the feeding of the emitting relays of the voltage group and the temperature group (line I, Fig. 1) or of the current intensity group (line II) in successive cycles with the aid of a pair of separate lines that are switched in successively for predetermined periods with the aid of a periodic switch which does not form a part of the invention.

Last, it should be remarked that the auxiliary relay OS can be energized simultaneously or separately through a circuit through the pointer of relay RMU or through a circuit through switch C, which latter is lifted at the end of the working cycle of the revolving disc for the oscillating device (to be described later on) by a boss on said disc, so that until said disc has accomplished a complete revolution, to bring back the anodes into their original positions, the relay OS remains energized, even if in the meantime, with the cessation of the anode effect, relay RMU should have come again to its rest position.

For instance, upon the occurrence of the anode effect and the abrupt rising of the temperature up to the value U_3, the closing of the contact **83—84** of relay RMU will result in the energization of the auxiliary relay O_s through the circuit **82, 83, 84, 91, 85** and then in the immediate opening of the contact **56—57** of switch I_s, whereby relay RVP and the current-responsive relays are made inoperative; and owing to the immediate closing of the other contact **89—90** of said switch I_s and to the closing of a further contact (not shown) the motor that actuates the cam disc P for the rocking of the anode-carrying shafts is put into action. The result is that even if the anode effect came to its end during the first revolution of the disc P (switch C being closed) the auxiliary relay O_s would nevertheless remain energized, to complete its revolution, through the circuit **86, 87, 88, 89, 90, 91, 85** (as an alternative to the now open circuit **82, 83, 84, 91, 85**) until the switch C (**87—88**) is lifted again by the cam on the disc P whose full revolution is now completed.

2. *Current distribution*

In accordance with my prior Patent No. 2,061,146, dated November 17, 1936, the current for each anode is fed to either end of a horizontal bar mounted in such manner that its top edge CD shall be exactly parallel with the bottom face AB of the anode (Fig. 2), the minus pole of the electrolyzer being constituted by the metal

itself. Now, it will be obvious that the free surface of said metal is a horizontal plane. In order that the interpolar distance between the bottom face of the anodes and the metal shall be constant (which is absolutely required if the current is to be distributed uniformly at all points) it is necessary and sufficient that the bottom face AB and consequently the edge CD be horizontal. This can be checked most easily with the aid of a simple mason's level.

For automatic control an electric level with a drop of mercury g (Fig. 2) is available on each anode-carrying bar, which is represented in Fig. 1 by a movable member that will come into engagement with either stud i_1 or i_2 depending on whether the anode considered is lower at the left or the right. By means of such an electric level and through the medium of an auxiliary timed relay such as m_1 (Fig. 1) assigned to each electrode end, the switch-in relay of the corresponding anode-lifting motor or power means such as M_1 can thus be set into action, however only in the direction of lifting. For instance, in the case of an overload occurring on the right side, i. e. with the anode shaft dipping towards the right, the relay m_1 will be energized through the circuit **92, 55, 56, 57, 58, 76, 103, 93, 94, 95, 96** as long as relay RMU remains inoperative (contact **56—57** of switch I_5 being closed) immediately after which the said relay m_1 will be self-held owing to the closing of contact **101—102** through the circuit **93, 97, 98, 99, 100, 101, 102, 95, 96** and finally, after the delay set in the relay has elapsed, the order-performing relay M_1 will become effective through the circuit **93, 103, 104, 105, 106** to set the corresponding anode-end position-adjusting unit into lifting action. A similar circuit and similar devices control the left end of the anode shaft and become effective upon the closing of contact i_1 of relay g. Horizontality being thus secured at each anode, equality in distribution of the current amongst the several anodes in one and the same electrolyzer cell remains to be provided for.

With this end in view, recourse is had to the voltage drop ascertained on one end of the anode-carrying bar between two points **1'** and **2'** (Fig. 2) that are equally spaced on all the bars. By means of a current-responsive relay RIA connected to those points by leads **1, 2** of Fig. 1 and assigned to each anode, and through the medium of a pair of auxiliary relays assigned to the anode considered, said voltage drop is made to act, as soon as it reaches the upper limit set up therefor, upon both switch-in relays for the corresponding pair of anode-lifting motors or power means, however, only in the direction of lifting.

It will be remarked that in such regulation of both the horizontality and the intensity, the anode-lifting motors can only be operated in the direction of lifting. This might lead to contradiction between the movements involved by voltage regulation. For the purpose of avoiding such contradictions, as outlined hereinbefore, the two groups of voltage- and current-responsive relays are energized separately and in successive cycles through two independent lines I and II (Fig. 1), so that they can never become operative at the same time.

However, such regulation of the intensity as described hereinbefore, which consists essentially in providing for horizontality of the electrodes and then for equality in distribution of the current as a whole amongst the same, would be insufficient to enable detecting certain troubles in operation that make themselves evident as abnormalities in the relative movement of the electrodes in one and the same electrolyzer cell which interfere with the efficiency of the current and thus with the thermo-chemical balance sheet, whereby consequent variations will be caused in the temperature of the bath.

The fact that a particular electrode sinks more rapidly than the adjacent ones means that a solidified portion of the bath has settled on that part of the sole which is located therebelow, which caused said electrode to be sunk deeper in order that the intensity may be kept at the same level. On the contrary, the fact that any particular electrode sinks more slowly than the adjacent ones is an evidence that conductive protuberances have formed at one or several places on its surface, whereby the flow of current becomes easier at said point or points, and which caused the electrode considered to be sunk more slowly in order that the intensity therethrough may remain the same.

For the purpose of revealing such abnormalities the uprights along which the end bearings of the anode-carrying shafts are guided are provided with graduations **21** by means of which it is possible at any moment to read the elevation of either end of said shafts **24**, and in particular to check the latter as to their horizontality by reading the mark which is flush with the upper face of the bearing **23** supported by the lifting spindle **22** (Fig. 4).

Moreover, such direct reading of the heights enables one to plot the same against time and to check the curves of displacement of the anode ends as to their parallelism. Any abnormality in a curve, from the very instant when it occurs, will inform one about what happened at the anode concerned, and will indicate what steps are to be taken to restore normal conditions in the electrolytic process (see Figs. 3, 4 and 5).

As shown in Fig. 3, which is given as an example in connection with a four-electrode cell, the curves of elevation of the various anodes are strictly parallel from O to t_1, at which point an abrupt fall occurs, consequent to a tapping of metal which resulted in the sinking of the electrodes as a whole; thereafter, between t_1 and t_2, trouble becomes evident as to the operation of anodes I and IV, due in the instance of the former to metal settling on the sole (attended with accelerated sinking) and, as far as the latter is concerned, to the formation of a conductive protuberance below the same, which led to deceleration in the lowering of the same for maintaining equality in current distribution. Once such operating troubles have been identified (and before they could become detrimental to the electrolytic process), it is only necessary to apply the conventional remedies, whereafter the curves of elevation will recover their parallelism.

3. *Temperature regulation*

An indication has been given in the preamble of this specification of how important it is to properly regulate both the temperature and the composition of the bath in order to secure high efficiency in the electrolytic process, variations in such efficiency as well as in the surrounding temperature being liable to influence the said temperature. One is thus confronted with a manifold problem. As a way to resolve the same, the group of emitting relays is complemented with a temperature regulator RGT (not shown in de-

tail in the drawing) which, more particularly for the purposes of this invention, comprises three switches pertaining to the preclusive members, viz.: "too cool" with e. g. a blue flash-light signal and a low-pitch sound warning signal; *n* "normal" with a steady orange-light signal; *c* "too hot" with a red flash-light signal and a high-pitch sound warning signal (Fig. 1).

Belonging also to the group of detecting and emitting members are a pair of timed relays P_1 and P_2 that will become operative when the temperature reaches its lower limit t_1 or its upper limit t_2 to counteract such temperature variations by appropriate variations in the voltage and consequently in the power.

There is nothing particular to be said about the auxiliary members and the operative members which are the same as for the joint regulation of the voltage and the intensity.

Their duty, however, will become more elaborate inasmuch as they will have to obey an additional order emitter controlled by the third variable T.

A threefold difficulty arises:

1. Contradiction may exist between the orders given by relay RVP and relays P_1 and P_2, since the abnormalities detected thereby have not the same causes, and this all the more as, for instance, if the temperature of the bath is raised, the conductivity of the same will fall, whereby, conditions being otherwise the same and in particular with unchanged total current intensity, the voltage at the terminals of the oven will be caused to fall, thus urging relay RVP to raise the anodes whereas on the contrary and at the same time relay P_2 would give the order to lower the same.

2. It may happen that the spontaneous decrease in voltage which will result, for example, from a rise in the cell temperature when due to a casual and transient cause, will provide by itself, through the attending decrease in power if the current intensity be kept constant, for the restoration of the temperature; in such circumstances, with the self-correction of the matter, there is no need to cause relay P_2 to interfere.

3. However, it may also happen that the rise in the temperature of the bath is due to serious and durable causes, on account either of a substantial increase in the surrounding temperature or, on the contrary, of a serious trouble in the electrolytic process by which Faraday's efficiency is altered and the thermo-chemical balance-sheet is upset in the direction of an increase in that portion of the power which plays a purely heat-generating part. It is not possible to rely upon the regulating members themselves as to what steps should be taken, and the skilled service of attendants has to be resorted to.

With a view to overcoming this threefold difficulty, the following means will be called into action and described under the same paragraph numerals 1, 2 and 3 just used to state the problems:

1. The switches *f*, *n* and *c* of the temperature regulator RGT and the pair of relays P_1 and P_2 are fed from the same auxiliary supply as relay RVP (line I), so that line II is assigned exclusively to the excess-current relays.

As explained hereinbefore, the two said lines I and II are fed alternatingly with 110- or 220-volt current by means of a clockwork for adjustable lengths of time set for each cell type, the time of operation of line I being much longer than that of line II, and this, the more as a higher-powered cell endowed with a larger thermal inertia is concerned.

In that state of things, the essential principle laid down is that temperature regulation is to be privileged, which means that no voltage regulation will be possible unless the bath is at normal temperature.

With that end in view the regulator RGT is so adjusted that switch *n* will remain closed as long as the temperature of the bath remains between two limit values t' and t'' which are made closer to the normal temperature t when a sharper regulation is aimed at (for instance, $t'=934°$ C. and $t''=936°$ C. with $t=935°$ C.)

On the contrary, the over-current responsive relays remain operative during those periods when line II assigned thereto is live, whatever the temperature may be, since the intensity must be suitably distributed at all times and so much the more when the temperature is abnormal.

As soon as the temperature of the melt passes out of the limited zone, the switch *n* opens and as may be seen in Fig. 1, the auxiliary relays m_u and d_u of relay RVP can no longer be energized and consequently are rendered inoperative even if relay RVP should respond to voltage variations, since it is only necessary that any one of the three contacts **52, 53, 54** in series in the circuit **51, 52, 53, 54, 55, 56, 57, 58, 59** that feeds said relay be open to make the latter ineffective.

In the event of substantial variations in temperature, for instance if the temperature of the melt should sink to its lower limit $t_1<t'$, contact *f* would in turn be closed and thus light the blue flash-light signal through the circuit **107, 108, 109, 110, 111, 112, 141, 114, 115, 116, 117** at the same time as the delayed-action relay P_1 would become self-energized by the closing of switch w_1 fed directly through key G, and would send one single impulse the duration of which can be given any value up to 90 seconds, with the result that through the medium of the auxiliary relay m_u the anodes would be lifted a definite amount.

The circuits involved successively in this operation are as follows:

For the energization of relay P_1 and the lighting of the related blue light signal, circuit **107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117** as just described.

For the self-feeding of relay P_1, circuit **118, 119, 120, 121, 122, 113, 114, 115, 116, 117** controlled by means of key G.

For the impulse of fixed duration sent at the auxiliary anode-lifting relay m_u, the non-controlled circuit **107, 108, 109, 110, 123, 124, 125, 126.**

The symmetrical operation would take place following the closing of switch *c* if the temperature should rise to the upper limit $t_2>t''$ and thus result in the sinking of the anodes through the medium of relays P_2, d_u and D_u.

The circuits involved in that symmetrical operation are as follows:

For the energization of relay P_2 and the lighting of the related red light signal, circuit **107, 108, 109, 128, 129, 130, 116, 117.**

For the self-feeding of relay P_2, circuit **118, 119, 120, 131, 132, 130, 116, 117** which is controlled by means of the key G.

For the sending of the impulse of fixed duration at the auxiliary anode-sinking relay d_u, the non-controlled circuit **107, 108, 133, 134, 135, 136, 137, 138, 139, 140, 68, 63, 64, 65.**

It will be appreciated from the foregoing that relay RVP and relays P_1 and P_2 of the tempera-

ture regulator can never be operative at the same time.

2. In the temperature intervals t_1—t' and t''—t_2 none of the above groups of relays can be operative, since the three switches f, n and c are all open. The width of these "neutralized" zones to which a positive signal indication by means of special lights could be assigned is determined in each particular case in accordance with the desired temperature constancy and the size of the cell, the four following factors being closely interconnected: time-adjustment of relays P_1 and P_2, width of the "neutralized" zones, duration of the cycle of operation of line I and weight of the bath.

These neutralized zones at either side of the normal temperature will enable the bath, in the event of unimportant deviations, to recover its normal value automatically by a process of self-adjustment, the purpose of this being to avoid untimely correction.

3. From t_1 downwards and from t_2 upwards the operation of relays P_1 and P_2 results as explained in the lighting of the light signals and the rising or lowering of the anodes by a fixed amount.

This first emergency step being taken, and until it has become effective, it is important that any other joint operation of the anodes should be precluded as long as the people in charge, warned by the light- or the sound-signals, have not come and seen what the matter is.

For that purpose the respective auxiliary switches z_1 and z_2 of relays P_1 and P_2 will open when the corresponding relays are energized, so that any voltage regulation by RVP becomes impossible, even if in the meantime normal temperature should have been restored and switch n closed as a result of such variations in power as would have been imposed upon the cell by relays P_1 and P_2.

Three different states of things are then possible:

(a) If the temperature is brought back automatically to normal (orange light signal "on") due to the emergency operation ordered by relays P_1 or P_2, voltage regulation becomes once more possible, contingently at a new voltage value set in RVP by pushing key G (contact open), which results in the de-energization of relays P_1 and P_2 and consequently in the opening of the self-feed contacts w_1 and w_2 and at the same time in the closing of the auxiliary contacts z_1 and z_2. Relays P_1 and P_2 are then once more able to correct a new variation in the temperature as soon as the key is lifted again to its closed position.

(b) If the temperature abnormality persists (red or blue light signal "on") it is necessary first of all to shift the cell from automatic to hand control by actuating the switches (not shown) by which the system described is put out of action, then to manipulate properly the anodes or give the cell the necessary attention until normal temperature conditions are restored, after which the cell can be shifted back to automatic control.

(c) If the temperature lies within the intermediate zones (no light signal "on") there is no danger in waiting until normal temperature conditions are restored automatically as explained hereinbefore in paragraph (a), since relays P_1 and P_2 are no longer able to order a new actuation of the anodes, yet voltage regulation remains "out" as long as the orange signal light denoting normal temperature conditions is not lighted up. Where there is any reason to restore normal working conditions as soon as possible, an action should be taken as described in paragraph (b) and thereafter, upon the restoration of normal temperature conditions, as described in paragraph (a).

II. Induced-Convection Operation

If, instead of constant current intensity operation corresponding to thermal balance conditions for which the mere natural convection is sufficient, it is desired to employ a higher current intensity for the purpose of temporarily increased production, it is obvious that the thermal balance will be interfered with thereby, and that it will not be possible to restore it by influencing the interpolar distance, which is assumed to be set at the minimum consistent with satisfactory current efficiency.

It is then necessary to resort to induced convection by means of air blown into or water circulated through the cooling tubes in the sole or the walls.

In that case the threefold regulation is carried out as described hereinbefore, on the sole condition that first the emitting relays have been properly set as to voltage and current. This requires that the air (or water) feed to be employed to provide for thermal balance at the new intensity be well defined.

If such feed is not perfectly predictable, cooling should be performed by the in-and-out method and a slight fluctuation of the temperature between the limits t' and t'' by which the zone of normal temperature is defined should be accepted. In that case the switch n should be arranged and complemented as shown in Fig. 6.

As a result of that complementary arrangement the switch n is composed, instead of a pair of single-pole switches connected in series, of a pair of double-pole switches one of which, C_4, is an ordinary double-pole switch assigned to 934° C. while the other C_6, assigned to 936° C., is a push-pull switch none of whose blades can be open or closed at the same time as the other. A switch-in relay CF sets the air-blower into operation as soon as the temperature exceeds 936° C., provided the key K is inserted in its socket.

In the closed position, which is the one shown in Fig. 6, voltage regulation is possible over the range 934–936° C. through a circuit **161, 162, 163, 164** which takes the place of contact **53** in the case of Fig. 1.

As soon as the temperature exceeds 936° C. as a result of the excess current applied, and long before it reaches 940° C. (which would set relay P_2 into action and cause the sinking of the electrodes), switch n by its being opened will close the right contact of the push-pull switch C_6 (and consequently will energize the switch-in relay CF through circuit **151, 152, 153, 154, 155, 156**) and will close the self-feed contact **157—158** of said relay.

The air blower is switched in and the temperature of the melt ceases to rise, whereafter it will decrease past 936° C. without the air-blower being stopped since, although the push-pull switch is again in its closed position as shown, relay CF is still energized through its self-feed contact and circuit **151, 152, 153, 154, 157, 158, 159, 160.**

Upon the temperature dropping below 934° C. switch C_4 opens at both blades thereof and cuts out the supply to switch CF. The air-blower comes to rest and the temperature stops sinking long before it can reach 930° C. and thereby cause the operation of relay P_1, whereafter it will rise again until it reaches 936° C. and starts the air-blower again.

The condition of constant composition

Practical experience justified by various scientific theories has shown that the percentage of alumina in the binary mixture subjected to electrolysis, especially in the vicinity of the active surface of the anodes, will tend to decrease, and that below a certain limit the voltage of the electrolyzer cell will jump suddenly (the so-called anode effect).

It will be clearly apparent that such a phenomenon will not take place and that consequently the attending detrimental results (drop in current intensity, secondary decomposition of the fluorides, rise in temperature) will be avoided if one succeeds in keeping the said percentage of alumina constant by providing for continuous feed of alumina into the bath instead of the conventional bulk addition of alumina at 4 to 5 hour intervals.

The last-mentioned practice is connected with decided disadvantages, on one hand because it involves the labor of breaking up the solid crust covering the liquid bath and thus exposing the same to the open air for several minutes, and on the other hand for the reason that such bulk introduction of alumina involves an aggravation of the heat losses by radiation.

As would be corroborated by a simple computation, the said cooling effect is particularly considerable in such large cells as are being built according to the present trend, because the volume of the bath available therein in relation to the unit of current intensity is considerably less than in low-intensity cells. Thus, in a 120 ka. cell with a 22 square meter area, batch-filling at intervals of 4 to 5 hours may lead to an overall temperature drop of the order of 30° C. Moreover, the introduction of the corresponding amount of alumina, even if the latter should happen to be uniformly distributed throughout the bath, will involve a variation of the order of 9% in the mean percentage, which seriously interferes with the dissolution process.

The threefold regulating process described involves, in order to avoid the aforesaid inconveniences, that the cell be fed either continuously, or semi-continuously by small batches, with a view to preventing the occurrence of the anode effect and any substantial cooling of the melt that would attend the incorporation at one time of any considerable amounts.

This result is obtained by subjecting the horizontal anode shafts that compose the anode equipment according to U. S. Patent No. 2,061,146, dated November 17, 1936, to a slow continuous rocking movement by means that will be described hereinafter.

In the performance of this aspect of the invention, reciprocation of the electrodes is obtained with the aid of an arrangement of power mechanism illustrated in Fig. 7 and comprising a cam disc P whose outline is such that a uniform rotational movement imparted to the shaft X thereof under the control of the emitting relay RMU and the auxiliary relay OS thereof (Fig. 1) will be converted into a uniformly variable straight-line motion imparted to a pair of left and right side driving rods B_1 and B_2 to which the anode-oscillating bars A are pivotally secured. Of course, the outline of said cam disc may be modified to comply with some other law of motion by which the result aimed at could be secured more easily.

Figure 8 illustrates the law of motion in relation with the outline of the cam P.

In a first phase that extends over ⅔ of the travel and for $\frac{5}{12}$ of the time, the movement is uniformly accelerated; the anode is removed from the lean region to be progressively immersed in sloping position into a richer region. During a second phase that extends over the remaining third of the travel and lasts for $\frac{2}{12}$ of the time, the movement is uniformly decelerated; the anode is positioned in the region where the percentage of alumina is normal. In the third phase which lasts for the remaining $\frac{2}{12}$ of the stroke, the anode remains still.

The anode is returned to its position of balance according to a symmetrical law of motion by its own weight with the contribution of loading coil springs (shown as arrows) to which the invention does not extend. The motion is a very slow one; the change-speed and reducing gears necessary to revolve the cam disc shaft at the desired speed need not be described.

The alumina is added discontinuously according to conventional practice, care being taken that the anodes are permanently covered and surrounded by a sufficiently thick layer of alumina (at least 8 to 9 cm.), so that the solidified crust that separates the same from the liquid bath may be of such thinness that it will not seriously interfere with the displacement of the anodes, and so that the latter can force their way easily therethrough.

This requirement will be fulfilled without difficulty with the particular standards adopted for cells of the kind considered, which provide for a ratio between the overall anode section and the top area of the crucible which is largely higher than in conventional cells, and this, all the more as the rated current of the cell is higher (60 to 77% with cells from 25 to 120 ka.). Moreover, in order to increase the volume of the bath without extending the area in the crucible that is exposed to the open air, the side walls of the crucible are sloped, so that the ratio between the top area of the crucible and the area of the sole may be cut down to 75–88% in cells ranging from 25 to 120 ka., which means that the area of the free intervals is considerably decreased as compared with conventional cells or ovens, whereby for equal weight a much thicker layer of supernatant alumina can be maintained as explained above.

With the protection of such a thick layer of alumina, the very slow displacement of the anodes (whose linear speed at the surface of the bath is of the order of 1 to 3 mm. per minute depending on the speeds of oscillation adopted) will result in a gradual dissolution of the underlying alumina in contact with the bath. By making up such alumina once every hour or even continuously, but in any case by amounts just corresponding to what is consumed in the electrolytic process, a semi-continuous or even a continuous feed of alumina is obtained.

Of course, it is possible at occasional times, to stop the oscillating movement and to allow the anode effect to occur after which the oscillating movement is resumed, to prevent its detrimental consequences, by the intervention of relay RMU as described hereinbefore, the purpose of all this being to ascertain the percentage of alumina and to avoid any excess of the same.

The amplitude of the oscillating movement as denoted by the angle of inclination of the oscillating forks towards the vertical should always be comparatively small (3 to 6°) in order that the ends of the anode-carrying shafts can slide easily

between the legs of the oscillating forks during the slight vertical movements undergone by the anodes in the course of the various voltage-, current- and temperature-regulating processes to make it possible, if desired, to take advantage simultaneously of continuous oscillation and threefold regulation.

I claim:

1. A cell for the electrolysis of molten salts, comprising a fixed sole, a plurality of normally horizontal current - conductive rock shafts mounted for axial rotation above said sole, anodes depending from said shafts and extending towards said sole, power means for controlling the vertical positions of the ends of said shafts, power mechanism for rocking said shafts upon their axes to provide an oscillatory motion of said anodes, a first voltage-responsive relay connected for operation in accordance with the voltage across said cell, circuit means connecting said first relay and said power means for controlling the latter, a second voltage-responsive relay connected across the cell terminals, connections from said second relay to said power mechanism to control the latter, and means responsive to the condition of said second relay for rendering the operation of said first relay ineffective to energize said power means during operation of said power mechanism.

2. A cell for the electrolysis of molten salts, comprising a fixed sole, a plurality of normally horizontal current - conductive rock shafts mounted for axial rotation above said sole and in circuit with said cell, anodes depending from said shafts and extending towards said sole, individual power means for separately controlling the vertical positions of the ends of said shafts, power mechanism for rocking said shafts upon their horizontal axes to provide an oscillatory motion of said anodes, a first voltage-responsive relay connected for operation in accordance with the voltage across said cell, circuit means connecting said first relay and said power means for controlling the latter, a second voltage-responsive relay connected across the cell terminals, connections from said second relay to said power mechanism to control the latter, means responsive to the condition of said second relay for rendering the operation of said first relay ineffective to energize said power means during operation of said power mechanism, an electric level with a drop of mercury supported longitudinally of each anode shaft, and connections from each said electric level to the power means for the corresponding shaft to operate the power means for levelling such shaft.

3. The cell in accordance with claim 2, including means for measuring the voltage drop along a predetermined portion of each shaft, a relay responsive to said voltage measuring means, and time delay means controlled by the last-named relay for energizing said power means to drive such shaft upwardly a predetermined time after occurrence of an excessive voltage drop along said portion of said shaft.

4. The cell in accordance with claim 1, including bearings for the ends of said rock shafts, columns for guiding said bearings in a vertical direction, and worm spindles supporting said bearings and having driving connection with said power means.

5. The cell in accordance with claim 1, and means controlled by said first voltage-responsive relay for energizing said power means for a predetermined interval to drive all of said shafts upwardly predetermined and equal amounts in response to a predetermined drop in the voltage across said cell.

6. The cell in accordance with claim 1, and means controlled by said first voltage-responsive relay for energizing said power means for a predetermined interval to drive all of said shafts downwardly predetermined and equal amounts in response to a predetermined increase in the voltage across said cell.

LOUIS FERRAND.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,396,919	Brace	Nov. 15, 1921
2,026,466	Grolee	Dec. 31, 1935
2,061,146	Ferrand	Nov. 17, 1936