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Medovar et al.

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[54] REMELTING SYSTEM AND PROCESS UTILIZING VARYING VOLTAGE, CURRENT AND MELTING RATE

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[52] **U.S. Cl.** **13/9,** 13/12

[51] **Int. Cl.** **H05b 7/18**

[58] **Field of Search** ..... 13/13 ES, 12, 13, 9

[56] **References Cited**

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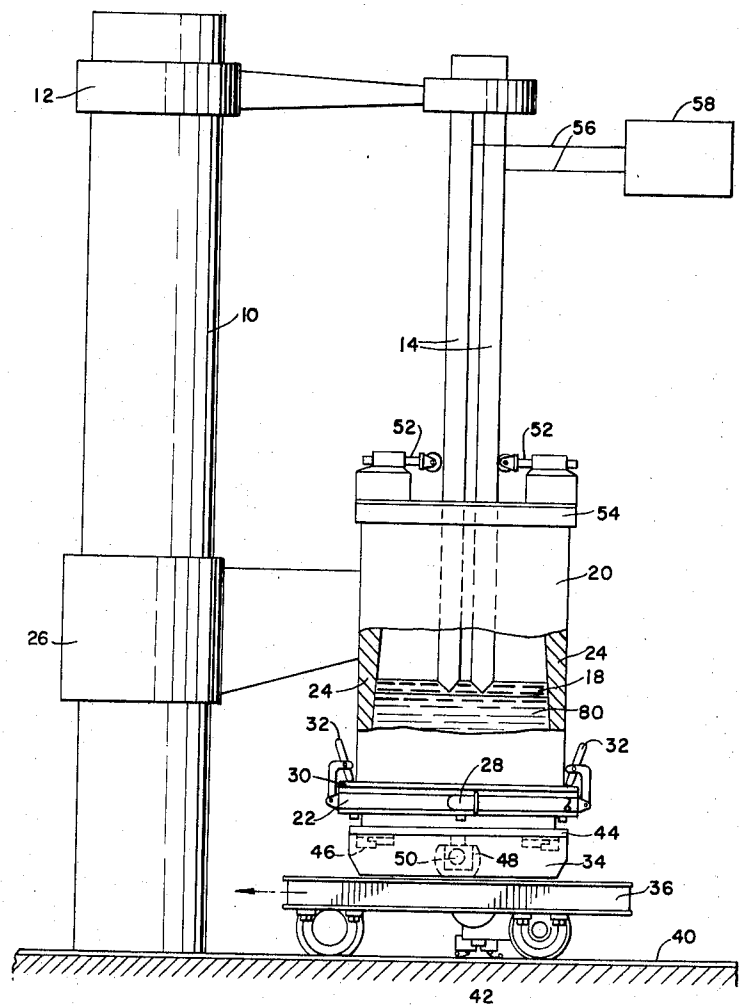
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[57] **ABSTRACT**

A bifilar electroslag remelting system is provided with a means to vary the voltage applied to the electrodes. As a result the voltage, current, and melting rate can be varied as a function of time to optimize refining efficiency, to minimize formation of cracks and strata in the finished product refined ingot, and to provide the additional advantage of eliminating the necessity of varying the water rate in the cooling element of the remelting system.

32 Claims, 8 Drawing Figures



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7 Sheets-Sheet 1

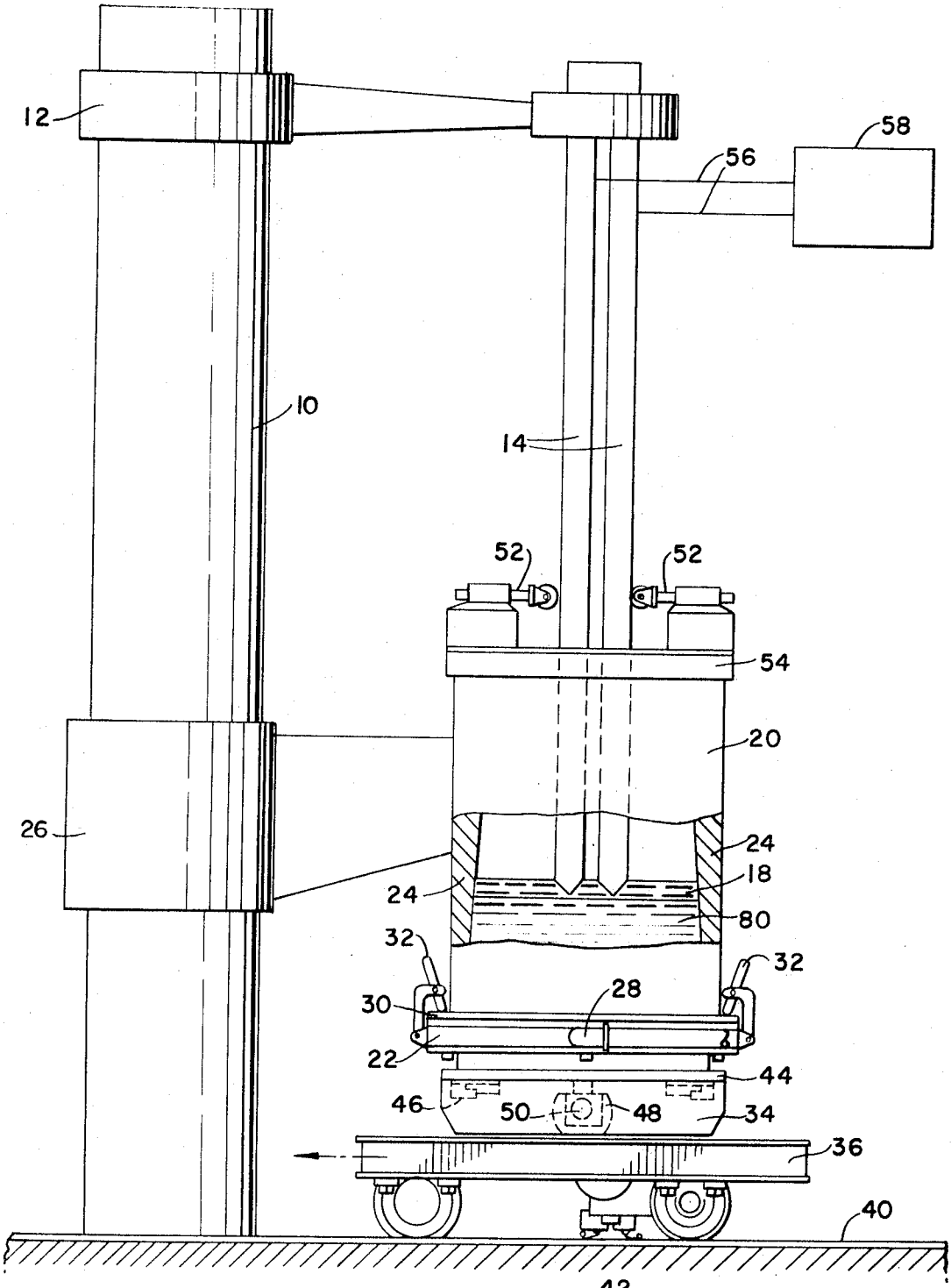


FIG. 1.

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7 Sheets-Sheet 2

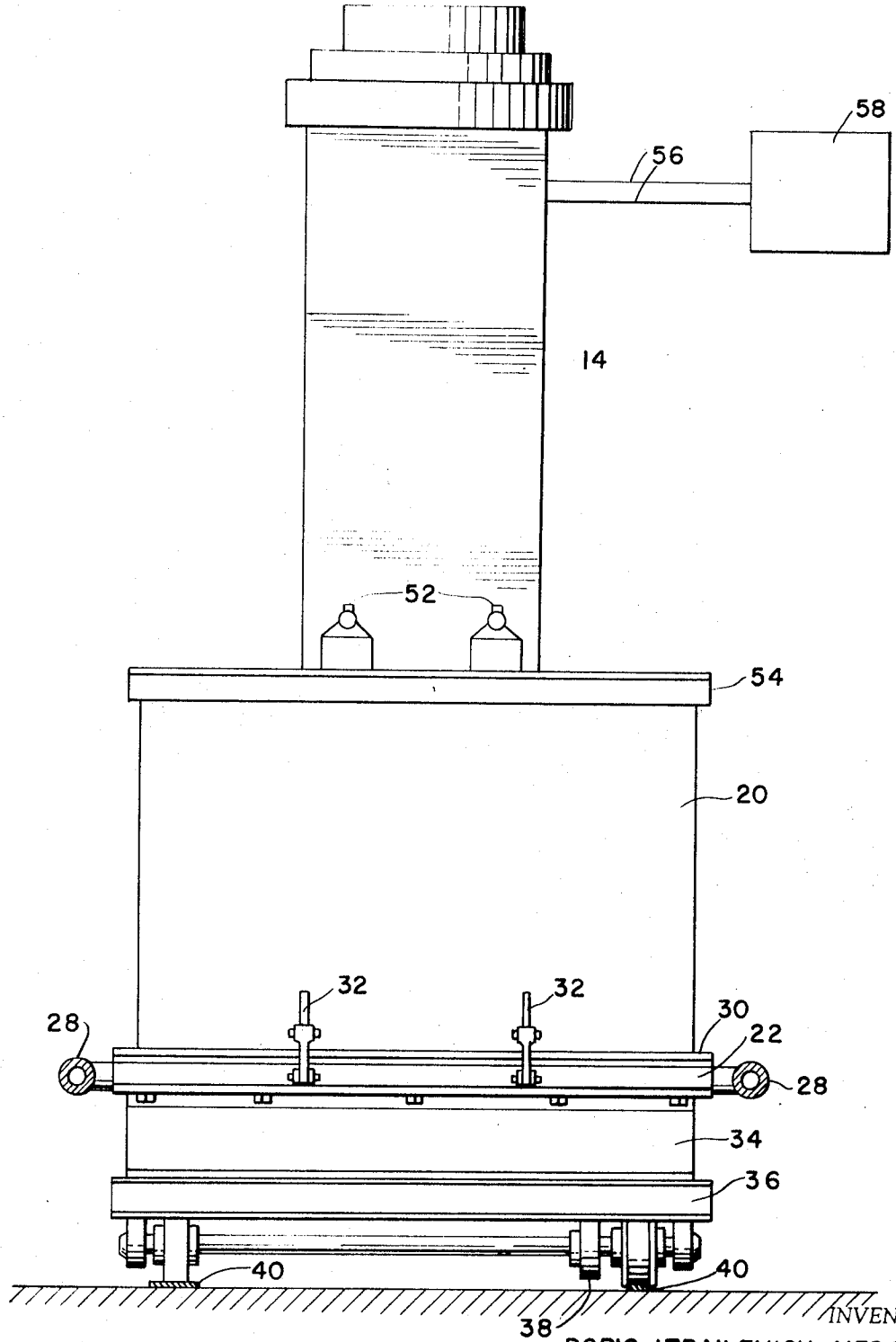


FIG. 2.

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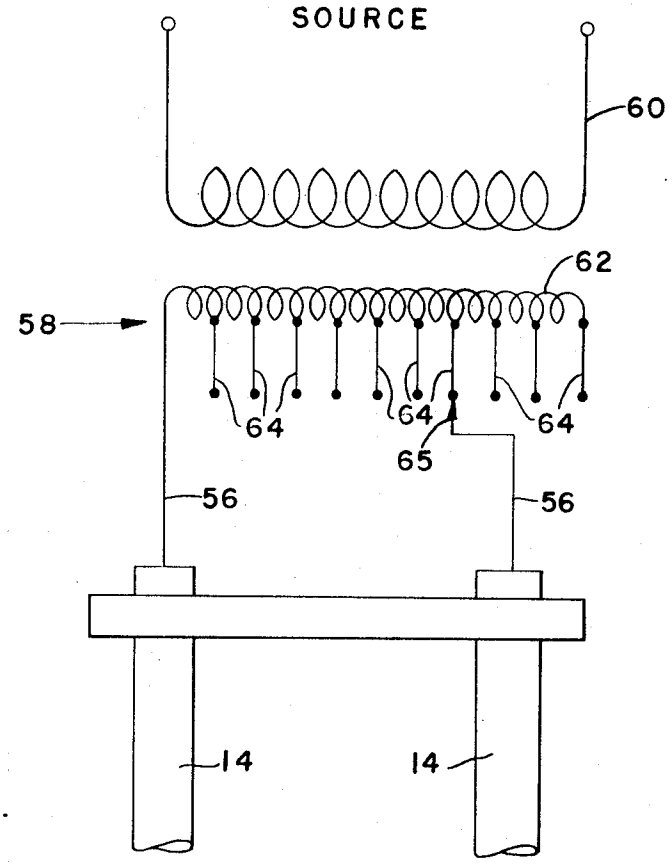


FIG. 3.

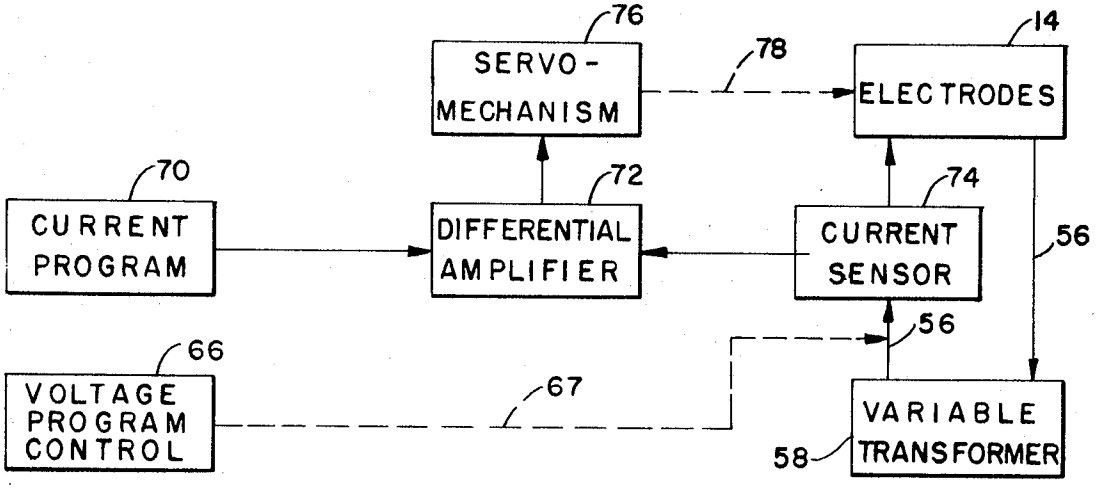


FIG. 4.

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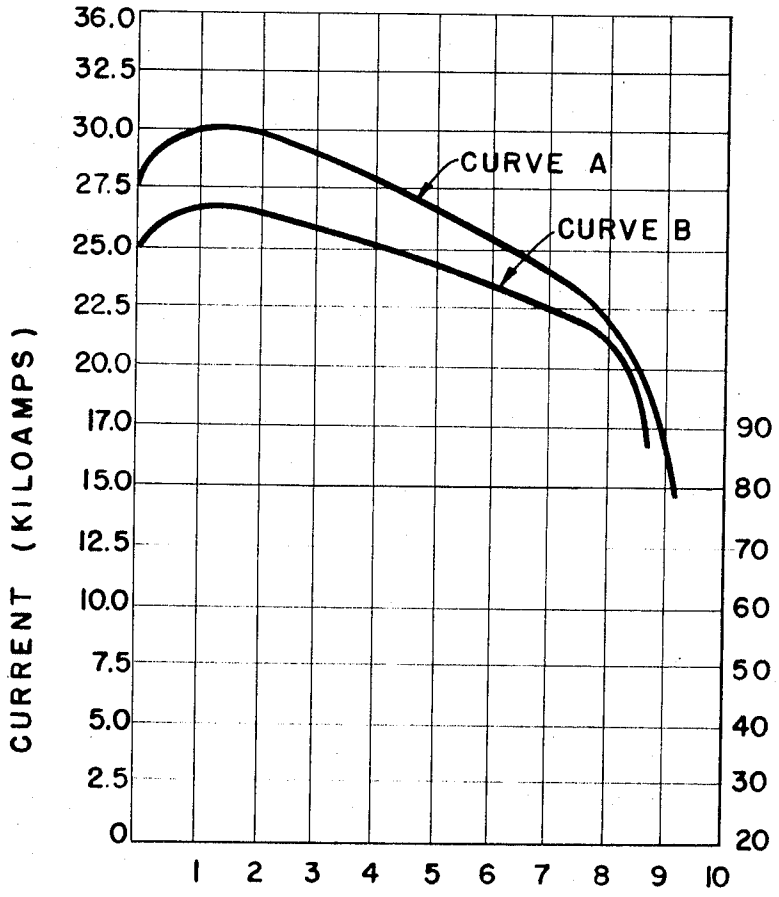


FIG.5.

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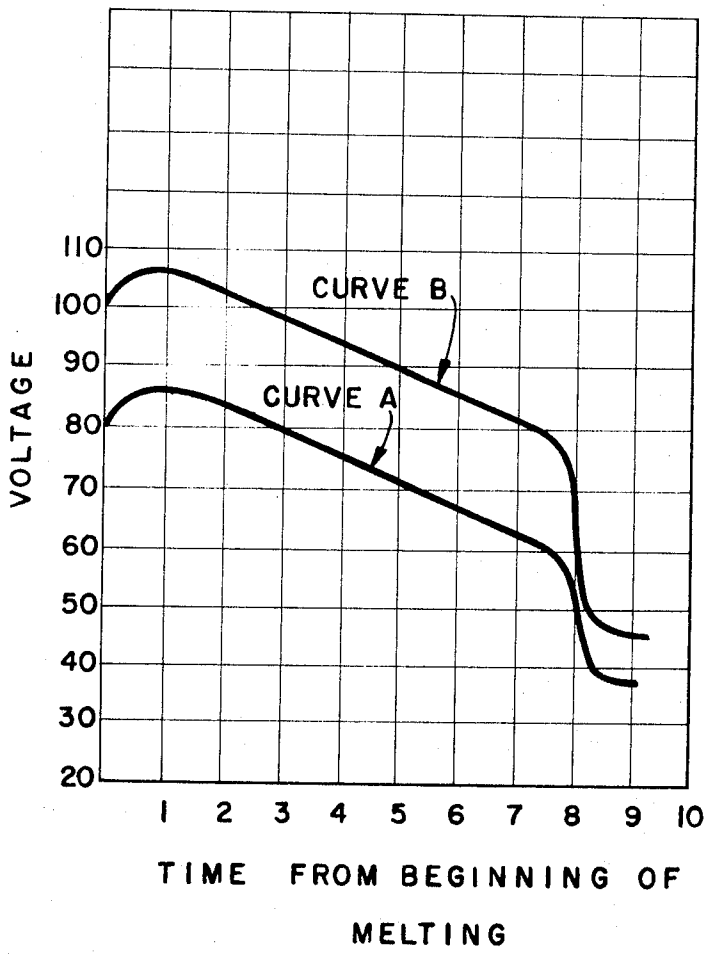


FIG. 6.

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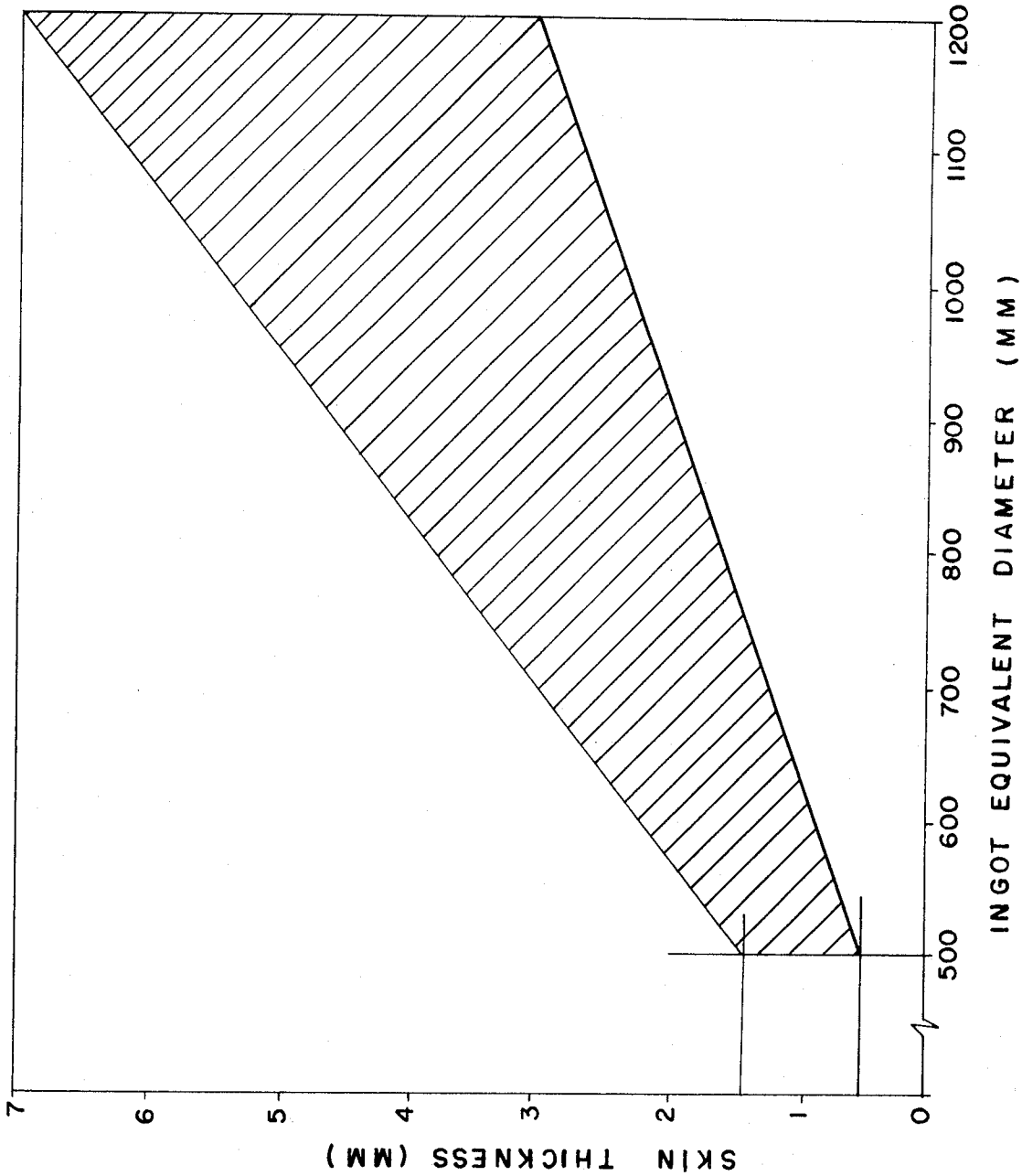


FIG. 7.

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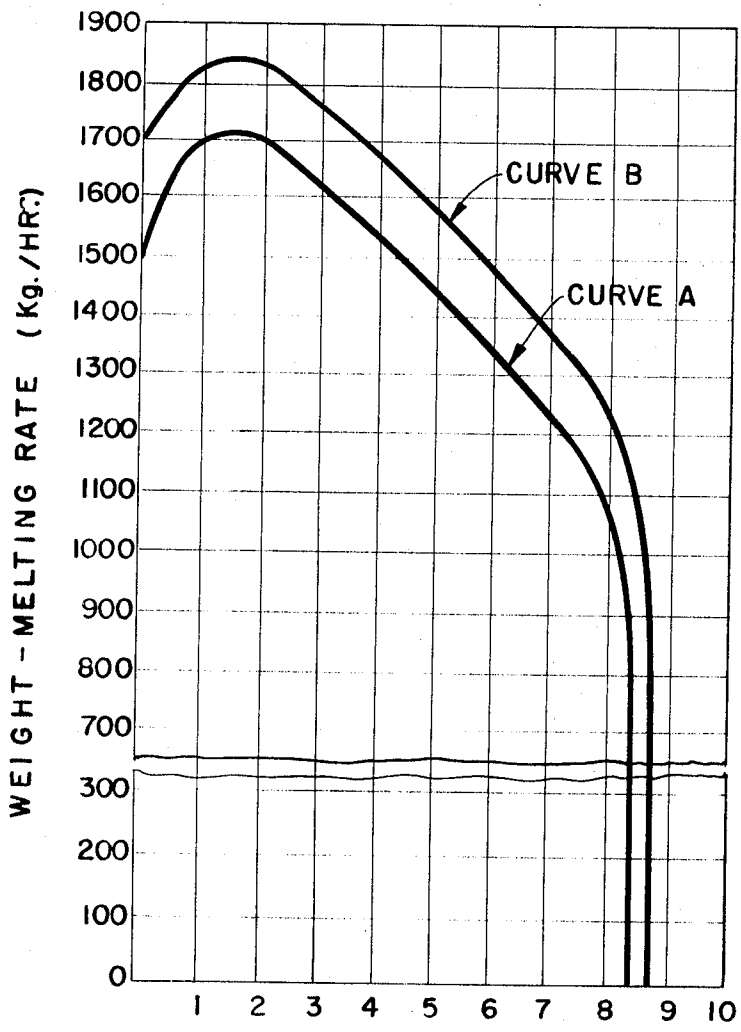


FIG. 8.

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REMELTING SYSTEM AND PROCESS UTILIZING VARYING VOLTAGE, CURRENT AND MELTING RATE

BACKGROUND OF THE INVENTION

This invention relates to an electroslag remelting process for the refining of metals and alloys of the type where two consumable electrodes (or groups of consumable electrodes) are immersed and fed into a molten slag bath in a cooled mold, and AC power is applied between the electrodes (or groups of electrodes).

The system of this type of process where AC power is applied between the electrodes is referred to as the bifilar system.

The system of electroslag remelting in which power is applied between the base of the mold and a single electrode or group of electrodes is referred to as the monophase system.

The bifilar system of electroslag remelting has significant advantages over the monophase system. Because the power is applied between two closely spaced electrodes, separation of the conductors supplying power to this system is minimized. Accordingly, the inductance of the system is significantly reduced. As a result, the bifilar system has a lower power factor than the monophase system and only 60 to 80 percent as much power is required in the bifilar system to produce a given size ingot as is required in the monophase system. In addition, a lower-power transformer can be used to produce ingots of a given size than can be used in the monophase system.

Despite the advantages of the bifilar electroslag remelting system, there are certain temperature and heat control problems associated with electroslag remelting.

In particular, the temperature of the slag in the molten bath and in the initial portion of the remelting cycle[1](1. The term "remelting cycle" is utilized herein to mean that portion of the process wherein melting of the electrodes is occurring.) is desirably controlled to a level which is lower than the temperature which is utilized later in the remelting cycle. This is because previous to the time when remelted metal solidifies providing a heat barrier layer on the top surface of the base of the mold, the mold cooling system is only of sufficient capacity to remove sufficient of the heat adjacent the base of the mold to prevent said base from being burned through if said lower temperatures are utilized. Such a heat barrier layer is built up during an initial portion of the remelting cycle. Higher slag temperatures are desired as soon as this insulation layer forms, because these higher temperatures provide more efficient refining.

As the layer of solidified metal on the top surface of the base of the mold increases in thickness, the cooling efficiency is lowered. Thus, unless the cooling capacity is progressively increased or unless the melting rate is progressively decreased after the initial portion of the remelting cycle, the solidification rate of the remelted metal will progressively decrease often resulting in an ingot having cracks, layers, discontinuities, or other structural defects.

During a final portion of the remelting cycle it is important that remelting be discontinued directly rather than gradually, so that the top surface of the ingot can be formed while the slag is still relatively hot. Otherwise, strata are formed near and at the top surface of the finished product ingot, resulting in an ingot which is subject to peeling and which does not remain integral. This direct discontinuance of remelting, and the maintenance of a relatively high slag temperature during ingot surface formation to provide a good top surface for the ingot, is referred to as "hot topping."

The mold cooling system is not satisfactory to provide an exclusive solution to these temperature and heat control problems. This is because reaction in the remelting system to cooling system changes is sluggish, resulting in control which is not precise. Moreover, a practical cooling system cannot even effect some of the aforementioned heat control requirements. Furthermore, from an engineering and operations standpoint it is preferred to utilize a constant flow rate in the cooling system. Thus, the cooling system cannot be the entire solution to the aforementioned problems.

SUMMARY OF THE INVENTION

It has been discovered in the present invention that the aforementioned problems are solved by varying the voltage and the electrode feed rate as a function of time to produce current in accordance with an empirically predetermined current curve (current vs. time for an initiation of remelting.) The use of the proper current curve and the use of the proper rate of applying power whereby the aforementioned problems are obviated are indicated by the formation of a particular-thickness slag skin on the formed ingot. The voltage and the feed rate can be controlled manually or automatically.

The electroslag remelting system of the present invention comprises a mold for forming an ingot under a bath of molten slag, said mold including sidewalls and a bottom plate; at least two consumable electrodes; means for positioning said electrodes in said mold immersed in the molten slag bath within said mold; means for feeding said electrodes downwardly into said molten slag bath; means for applying AC power between said electrodes to cause electric current to flow between said electrodes through said molten slag bath; and means for varying the voltage applied to said electrodes.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** represents a side elevational view of an installation for electroslag remelting according to the invention.

FIG. **2** represents a front elevational view of the installation of FIG. **1**.

FIG. **3** is a schematic illustration of the voltage variations means of FIGS. **1** and **2**.

FIG. **4** is a schematic illustration of an automatic current, voltage, and electrode feed control system.

FIG. **5** is a graph depicting two specific examples of current curves illustrating variations of current with time in an embodiment of the present invention.

FIG. **6** is a graph depicting two specific examples of voltage curves illustrating variations of voltage with time in an embodiment of the present invention.

FIG. **7** is a graph of slag skin thickness vs. ingot equivalent diameter for use in verifying that a proper current curve and proper rate of applying power have been utilized to solve the aforedescribed problems.

FIG. **8** is a graph depicting two specific examples of weight melting rate curves illustrating the variations of weight melting rate with time in an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

In an embodiment of the invention represented in FIGS. **1–3**, the installation is provided with a supporting column **10** mounting a mechanism **12** for simultaneously feeding electrodes **14** downwardly into a slag bath **18** which is prepared in a mold **20** which is intended for shaping an ingot (not depicted).

The mold **20** comprises a bottom plate **22** on which are disposed sidewalls **24**. The sidewalls **24** are connected with a lifting mechanism **26** mounted on column **10**. The bottom plate **22** contains a cooling means **28**. The sidewalls **24** are provided with an outwardly-extending flange **30** which rests on bottom plate **22**. Clamps **32** are mounted on the bottom plate **22** around the mold to firmly press the flange **30** down against the bottom plate.

The bottom plate **22** is positioned on a support **34** which in turn is supported on a dolly **36** which is driven by an electric motor (not shown) and a transmission including gear **38** along tracks **40** having a trolley connection **42** to move the mold horizontally in one direction. The support **34** comprises a top plate **44** which is movable along guideways **46** as driven by means of a nut **48** affixed to top plate **44** and threaded on a screw **50**, whereby top plate **44** can be moved so as to move the mold **20** in a horizontal direction perpendicular to the direction of movement provided by the dolly **36**.

The electrodes **14** are depicted as slab-shaped; although slab-shaped electrodes are most advantageously used, other

types of electrodes, for example, square-cross-section or tubular electrodes can also be used.

Rollers **52** are mounted on a support **54** which is positioned on top of the mold **20** so as to prevent the electrodes **14** from contacting the sidewalls **24**.

The electrodes **14** are electrically connected by conductors **56** to a variable transformer **58**. Electrodes **14**, conductors **56**, and transformer **58** are particularly depicted in FIG. **3**. The variable transformer **58** comprises a primary winding **60** and a secondary winding **62**. Spaced along the secondary winding **62** are taps **64**. A contact **65** connected to one of the conductors **56** is movable from tap to tap, whereby the voltage to the electrodes **14** can be varied. The voltage differential between successive taps should not exceed 4 volts. This is because the voltage must be changed gradually during the remelting cycle. If increments exceeding 4 volts are utilized, cracking or layering in the ingot can occur as a result. Optimally, the voltage differential between successive taps is 2.5 volts.

The voltage, current and electrode feed rate can be automatically controlled as a function of time from initiation of remelting by the control system depicted in FIG. **4**. This system comprises a voltage program control **66** operating to position the movable contact **65** of the variable transformer **58** to cause said variable transformer to vary the voltage as a function of time from initiation of remelting in a predetermined manner. A current program control **70** generates a signal representing the desired current as a function of time from initiation of remelting in a predetermined manner. A current sensor **74** is connected in one of the conductors **56** between the variable transformer **58** and one of the electrodes **14**, and senses the current passing through said electrodes. A differential amplifier **72** receives the signal generated by current program control **70** and a signal from sensor **74** representing the current flowing through the electrodes. The differential amplifier **72** produces an output signal representing the differential between the two applied signals and thus representing the differential between the desired current and the actual current. A servomechanism **76** receives the output signal produced by differential amplifier **72** and operates in response to said signal to control the rate of feed of the electrodes.

In the operation of the aforedescribed remelting system, the electrodes **14** are symmetrically positioned within the mold **20** by the use of the aforedescribed mechanisms for moving the mold **20** in two horizontal directions. AC power is then supplied to the electrodes **14** and molten slag is poured into the mold so as to contact the bottom of the electrodes. As soon as this contact is made, the circuit between the electrodes is completed, whereby melting of the electrodes is caused to occur.

After melting has been initiated the electrodes are fed simultaneously downwardly into the slag by mechanism **12**, whereby the ends of the electrodes are immersed in the molten slag and the electrodes are progressively melted. Ordinarily the electrodes are fed at a rate ranging from about 0.17 meters per hour to about 1.7 meters per hour.

During the melting the voltage is varied by the movement of the contact **65** between the taps **64** of variable transformer **58**. The voltage on the secondary winding ordinarily ranges from about 40 volts to about 120 volts.

The electrode feed rate and voltage variation, and the coaction between these, is described in more detail below.

As the electrodes melt the resulting liquid metal forms into drops on the electrodes. These drops fall off the electrodes into the slag bath **18**. The liquid metal passes through this slag bath **18** and forms a molten pool **80** beneath the bath **18**. The bottommost portion of the molten pool **80** progressively solidifies, building up an ingot. The slag refines the liquid metal as said metal passes through it, and as a result an ingot of high quality is formed in the mold.

In the aforedescribed system of automatic control, a voltage program control **66** is utilized to move the contact **65** between taps **64** of secondary winding **62** so as to vary the voltage to the electrodes in accord with a predetermined program. The current provided to the electrodes is sensed in conductor **56** by the current sensor **74** which signals the current to a differential amplifier **72**. The differential amplifier also receives a signal representing the desired current from a predetermined current program control **70**. If the current signaled by sensor **74** is the same as that signaled by program control **70**, the output signal of the differential amplifier is null and the servomechanism **76** does not respond. If the current signaled by the sensor **74** is greater than that signaled by program **70**, the differential amplifier **72** produces an output signal of one polarity in response to which servomechanism **76** slows the feed rate of the electrodes. If the current signaled by the sensor **74** is less than that signaled by program **70**, the differential amplifier **72** produces an output signal of the opposite polarity in response to which the servomechanism increases the electrode feed rate. The current flowing through electrodes varies directly with the depth of immersion of the electrodes in the slag bath. When the feed rate is slowed the depth of immersion is decreased and thus the current is decreased. Similarly, when the feed rate is increased the depth of immersion will be increased and the current will be increased. Thus the servomechanism, by varying the feed rate in response to the output signal of the differential amplifier **72** as described above, will control the feed rate to provide a depth of immersion which results in the current signaled by the current program control **70**.

In the preferred operation of the system of the present invention, voltage and current curves (voltage and current vs. time from initiation of remelting) are initially empirically determined. The voltage curve is then achieved by moving a contact between taps on the output of the transformer. The current curve is achieved by the variation of the voltage and the electrode feed rate as a function of time. This is done automatically as described above, or under manual control.

The voltage and current ranges utilized are functions of the cross-sectional areas of the consumable electrodes, the dimensions of the formed ingot, the composition of the remelted metal, and the composition and amount of the slag. The current utilized at any point in time during the remelting cycle is ordinarily at least about 3,000 amps. and generally does not exceed about 35,000 amps. The voltage utilized at any point in time during the remelting cycle is in the range of 30 to 120 volts.

Despite the fact that the ranges of current and voltage utilized vary, it is important to the obtainment of optimized refining efficiency and of minimization of cracks and strata in the product ingot that all current curves have essentially the same configuration and that all voltage curves have essentially the same configuration.

These voltage and current curves provide an initial increase in slag temperature to maximize refining efficiency without deleterious effects to the bottom plate occurring, adjust for the decrease in mold cooling capacity due to ingot build-up whereby ingot cracking and strata formation are minimized, provide hot-topping whereby a smooth ingot surface is achieved, and eliminate the necessity of varying water rate in the cooling elements of the remelting system.

For the obtainment of these ends a current curve is provided wherein the current is increased during at least a portion of the first quarter of the remelting cycle; the current is gradually decreased during an intermediate portion of the remelting cycle; and the current is decreased at an increasing rate during at least the final portion of the remelting cycle. Preferably the gradual decrease in said intermediate portion of the remelting cycle is linear, the rate of said linear decrease ranging from about 900 to about 1,300 amps. per hour.

Preferably the initial current is at least about 100 percent of the average current utilized during the remelting cycle; the current is then increased before the end of the first quarter of the remelting cycle to at least about 103 percent of said average current; the current is then gradually decreased during at least one-third of said remelting cycle to at least 95 percent of said average current; and finally, the current is

decreased rapidly starting at a point in the final quarter of the remelting cycle to at least 65 percent of said average current.

Two typical current curves having the aforedescribed characteristics are illustrated in FIG. 5.

Curve A in FIG. 5 is a current curve for the remelting of two electrodes, each 1,120 × 140 mm. in horizontal cross-section in a mold 1,340 × 630 mm. in horizontal cross-section utilizing a flux low in alumina content[1] (1. The flux has a chemical composition consisting by weight of 50–60% CaF_2, 10–15% CaO, 12–20% Al_2O_3, 10–15% MgO, 2–7% SiO_2, 0.3% FeO, 0.05% P, and 0.05% S.) to provide an ingot having a height of 1,900 mm.

Curve B in FIG. 5 is a current curve for the remelting of two electrodes each 370 × 370 mm. in horizontal cross-section in a mold 1,430 × 630 mm. in horizontal cross-section utilizing a flux high in alumina content[2] (2. The flux has a chemical composition consisting by weight of 60–70% CaF_2, 2–8% CaO, 26–32% Al_2O_3, 1.0% SiO_2, 0.3% FeO, 0.05% P, and 0.05% S.) to provide an ingot having a height of 1,900 mm.

If automatic regulation of current is utilized, it is preferred that the current be regulated with an accuracy of ± 750 amps. when the current is being increased, and ± 500 amps. when the current is being decreased.

The voltage curves representing the voltage applied to the electrodes selected to obtain the above-mentioned benefits, may be described as follows: the voltage is increased at a decreasing rate during at least a portion of the first quarter of the remelting cycle; the voltage is gradually decreased during an intermediate portion of the remelting cycle; the voltage is then decreased at an increasing rate; finally the voltage is maintained more or less constant. Preferably the gradual decrease in said intermediate portion of the remelting cycle is linear, for example, with said decrease caused to occur at the rate of 2–6 volts per hour.

Preferably the initial voltage is at least about 125 percent of the average voltage utilized during the remelting cycle; the voltage is then increased before the end of the first quarter of the remelting cycle to at least about 130 percent of said average voltage; the voltage is then gradually decreased during at least one-third of said remelting cycle to at least about 125 percent of said average voltage; the voltage is then decreased rapidly over no more than about one-eighth of said remelting cycle to at least about 95 percent of said average voltage.

Two typical voltage curves having the aforedescribed characteristics are illustrated in FIG. 6.

Curve A in FIG. 6 is a voltage curve for the remelting of two electrodes each 1,120 × 140 mm. in horizontal cross-section in a mold 1,340 × 630 mm. in horizontal cross-section utilizing the aforedescribed low-alumina-content flux to provide an ingot having a height of 1,900 mm.

Curve B in FIG. 6 is a voltage curve for the remelting of two electrodes each 370 × 370 mm. in horizontal cross-section in a mold 1,340 × 630 mm. in horizontal cross-section utilizing the aforedescribed high-alumina-content flux to provide an ingot having a height of 1,900 mm.

At any point in time the voltage should not be changed by a step of more than about 4 volts. This is because changes in voltage by a step of more than about 4 volts can result in ingot defects. Preferably, changes in voltage at any point in time are carried out in steps of about 2.5 volts.

The use of voltage and current curves as described above result in a power curve (power applied to the electrodes vs. time from initiation of remelting) wherein the power is increased during at least a portion of the first quarter of the remelting cycle; the power is gradually decreased during an intermediate portion of the remelting cycle; and the power is decreased at an increasing rate during the final portion of the remelting cycle.

The use of the proper current, voltage and power curves for the obtainment of the aforementioned ends is verified by the achievement, that is, the formation on the sidewalls of the finished ingot, of a uniform slag skin of a particular thickness. The proper thickness of slag skin to be obtained to achieve the aforementioned ends of refining efficiency and minimization of cracks and strata in the ingot is a function of ingot equivalent diameter.[1] (1. The term "equivalent diameter" is utilized herein to mean the diameter of a circle having the same area as the ingot horizontal cross-section.) The relationship between the slag skin thickness on the sidewalls of the finished ingot and ingot equivalent diameter is presented in FIG. 7. The obtainment of a slag skin thickness in the cross-hatched area of FIG. 7 indicates that said proper current curve and rate of applying power have been followed.

The use of the above-described voltage and current curves will result in a weight-melting rate curve (weight of metal melted per hour vs. time from initiation of remelting) of particular configuration. The aforementioned benefits will be obtained if the proper weight-melting rate curve is utilized.

According to said weight-melting rate curve, weight-melting rate is varied as a function of time so that the weight-melting rate is increased during at least a portion of the first quarter of the remelting cycle; the weight-melting rate is then gradually decreased during an intermediate portion of the remelting cycle; and the weight-melting rate is decreased at an increasing rate during the final one-eighth of the remelting cycle. Preferably the gradual decrease in said intermediate portion of the remelting cycle is linear, for example, with decrease caused to occur at the rate of 20–150 kilograms per hour.

Preferably, the initial weight-melting rate is at least about 110 percent of the average melting rate utilized during the remelting cycle; the weight-melting rate is then increased to at least 115 percent of said average melting rate at a point during the first quarter of said remelting cycle; the weight-melting rate is then decreased linearly during at least one-third of said remelting cycle to at least 100 percent of said average melting rate; the weight-melting rate is then decreased to zero during the final one-eighth of said remelting cycle. Two typical weight-melting rate curves having the aforedescribed characteristics are depicted in FIG. 8.

Curve A in FIG. 8 depicts a weight-melting rate curve for the remelting of electrodes in a mold 1,340 × 630 mm. in horizontal cross-section.

Curve B in FIG. 8 depicts a weight-melting rate curve for the remelting of electrodes in a mold 1,430 × 630 mm. in horizontal cross-section.

The use of the aforedescribed current, voltage, and melting rate vs. time relationships wherein each of these is varied so as to provide an initial increase followed by a gradual decrease followed by a more rapid decrease, allows the achievement of high refining efficiency without deleterious effects to the bottom plate of the mold, allows adjustment for ingot build-up so as to minimize defects from occurring in the ingot as it builds up due to heat transfer problems, allows the achievement of hot-topping, and eliminates the necessity for varying the cooling rate in the cooling elements of the remelting system. The use of variation in the electrode feed rate and voltage application to control the amount of power, the current, and the melting rate provides essentially instantaneous response whereby precise process control is achieved. Moreover, the use of electrode feed rate and voltage variation to vary the other process conditions provides for a system which is readily adaptable to automatic control. The provision of power to the system in such a way that a particular slag skin thickness is achieved on the sidewalls of the finished product ingot allows for a ready system of quality control.

Many modifications may be made to the abovedescribed specific embodiments of the invention without departing from the spirit and scope of the invention which is defined in the appended claims.

What is claimed is:

1. An electroslag remelting system comprising a mold for forming an ingot under a bath of molten slag, said mold including sidewalls and a bottom plate; at least two consumable electrodes; means for positioning said electrodes in said mold immersed in the molten slag bath within said mold; means for

feeding said electrodes downwardly into said molten slag bath; means for applying AC power between said electrodes to cause electric current to flow between said electrodes through said molten slag bath; reference means including a predetermined gradually changing current curve; means for varying the voltage applied to said electrodes according to a predetermined voltage curve; and said means for feeding said electrodes being controlled for instantaneous response by reference of the current flowing between said electrodes to said reference means.

2. An electroslag remelting system as recited in claim 1 wherein said means for varying the voltage is a variable transformer which is connected to said electrodes.

3. An electroslag remelting system as recited in claim 2 wherein the variable transformer comprises a primary winding and a secondary winding, said secondary winding being connected to said electrodes and having taps spaced along it.

4. An electroslag remelting system as recited in claim 3 wherein the voltage differential between successive taps does not exceed 4 volts.

5. An electroslag remelting system as recited in claim 3 wherein the voltage differential between successive taps is 2.5 volts.

6. An electroslag remelting system as recited in claim 1 wherein said system additionally comprises a system for automatically controlling voltage, current, and electrode feed rate as a function of time from initiation of remelting.

7. An electroslag remelting system as recited in claim 2 wherein said system additionally comprises a system for automatically controlling voltage, current and electrode feed rate as a function of time for instantaneous response from initiation of remelting.

8. A method of electroslag remelting comprising preparing a bath of molten slag in an electroslag remelting mold, said slag having immersed therein at least two consumable electrodes; supplying AC power between said electrodes by the application of voltage to the electrodes to cause electric current to flow between said electrodes through said molten slag bath whereby melting of the electrodes is caused to occur and an ingot is formed in said mold; feeding said electrodes downwardly into said slag bath as they melt; varying said voltage as said electrodes melt according to a predetermined voltage curve; comparing the current flowing between said electrode with a predetermined gradually changing current curve; and controlling the feeding of said electrodes for instantaneous response with respect to the current difference resulting from said comparing step.

9. A method of electroslag remelting as recited in claim 8 wherein electrode feed rate variation as a function of time and voltage variation as a function of time are utilized to vary the current flowing between the electrodes and the electrode melting rate.

10. A method of electroslag remelting as recited in claim 8 wherein the voltage at any point in time is not changed by a step of more than about 4 volts.

11. A method of electroslag remelting as recited in claim 10 wherein voltage changes at any point in time are carried out in steps of about 2.5 volts.

12. A method of electroslag remelting as recited in claim 8 wherein the voltage applied to the electrodes is varied as a function of time so that the voltage is increased at a decreasing rate during at least a portion of the first quarter of the remelting cycle; the voltage is gradually decreased during an intermediate portion of the remelting cycle; the voltage is then decreased at an increasing rate; and finally the voltage is maintained substantially constant at the end of the remelting cycle.

13. A method of electroslag remelting as recited in claim 12 wherein the gradual decrease in said intermediate portion of the remelting cycle is linear.

14. A method of electroslag remelting as recited in claim 13 wherein said linear decrease is caused to occur at a rate of 2 to 6 volts per hour.

15. A method of electroslag remelting as recited in claim 8 wherein the initial voltage is at least about 125 percent of the average voltage utilized during the remelting cycle; the voltage is then increased before the end of the first quarter of the remelting cycle to at least about 130 percent of said average voltage; the voltage is then gradually decreased during at least one-third of said remelting cycle to at least about 125 percent of said average voltage; the voltage is then decreased rapidly over no more than one-eighth of said remelting cycle to at least about 95 percent of said average voltage.

16. A method of electroslag remelting as recited in claim 8 wherein the current applied to said electrodes is increased during at least a portion of the first quarter of the remelting cycle; the current is gradually decreased during an intermediate portion of the remelting cycle; and the current is decreased at an increasing rate during at least the final portion of the remelting cycle.

17. A method of electroslag remelting as recited in claim 16 wherein the gradual decrease in said intermediate portion of the remelting cycle is linear.

18. A method of electroslag remelting as recited in claim 17 wherein the rate of said linear decrease ranges from about 900 to about 1,300 amps. per hour.

19. A method of electroslag remelting as recited in claim 8 wherein the initial current applied to said electrodes is at least about 100 percent of the average current utilized during the remelting cycle; the current is then increased before the end of the first quarter of the remelting cycle to at least about 103 percent of said average current; the current is then gradually decreased during at least one-third of said remelting cycle to at least 95 percent of said average current; and finally the current is decreased rapidly starting at a point in the final quarter of the remelting cycle to at least 65 percent of said average current.

20. A method of electroslag remelting as recited in claim 12 wherein the current is increased during at least a portion of the first quarter of the remelting cycle; the current is gradually decreased during an intermediate portion of the remelting cycle; and the current is decreased at an increasing rate during at least the final portion of the remelting cycle.

21. A method of electroslag remelting as recited in claim 20 wherein the gradual decrease in current in said intermediate portion of the remelting cycle is linear.

22. A method of electroslag remelting as recited in claim 21 wherein the rate of said linear decrease in current ranges from about 900 to about 1,300 amps. per hour.

23. A method of electroslag remelting as recited in claim 12 wherein the initial current is at least about 100 percent of the average current utilized during the remelting cycle; the current is then increased before the end of the first quarter of the remelting cycle to at least about 103 percent of said average current; the current is then gradually decreased during at least one-third of said remelting cycle to at least 95 percent of said average current; and finally, the current is decreased rapidly starting at a point in the final quarter of the remelting cycle to at least 65 percent of said average current.

24. A method of electroslag remelting as recited in claim 8 wherein said power is applied to provide an ingot having on its surface a slag skin of uniform thickness as defined in the cross-hatched area of FIG. 7.

25. A method of electroslag remelting as recited in claim 9 wherein the weight melting rate of said electrodes is varied as a function of time so that the weight melting rate is increased during at least a portion of the first quarter of the remelting cycle; the weight melting rate is then gradually decreased during an intermediate portion of the remelting cycle; and the weight melting rate is decreased at an increasing rate during the final one-eighth of the remelting cycle.

26. A method of electroslag remelting as recited in claim 25 wherein said gradual decrease in weight melting rate in said intermediate portion of the remelting cycle is linear.

27. A method of electroslag remelting as recited in claim 26 wherein said linear decrease in weight melting rate is caused to occur at the rate of 20–150 kilograms per hour.

28. A method of electroslag remelting as recited in claim 9 wherein the weight-melting rate is varied so that the initial weight melting rate is at least about 110 percent of the average melting rate utilized during the remelting cycle; the weight melting rate is then increased to at least 115 percent of said average melting rate at a point during the first quarter of said remelting cycle; the weight melting rate is then decreased linearly during at least one-third of said remelting cycle to at least 100 percent of said average melting rate; the weight melting rate is then decreased to zero during the final one-eighth of said remelting cycle.

29. A method of electroslag remelting as recited in claim 20 wherein the weight melting rate of the consumable electrodes is varied as a function of time so that the weight melting rate is increased during at least a portion of the first quarter of the remelting cycle; the weight melting rate is then gradually decreased during an intermediate portion of the remelting cycle; and the weight melting rate is decreased at an increasing rate during the final one-eighth of the remelting cycle.

30. A method of electroslag remelting as recited in claim 29 wherein the gradual decrease in weight melting rate in said intermediate portion of the remelting cycle is linear.

31. A method of electroslag remelting as recited in claim 30 wherein said gradual decrease in weight melting rate in said intermediate portion of the remelting cycle is caused to occur at the rate of 20–150 kilograms per hour.

32. A method of electroslag remelting comprising preparing a bath of molten slag in an electroslag remelting mold, said slag having immersed therein at least two consumable electrodes; supplying AC power between said electrodes by the application of voltage to the electrodes to cause electric current to flow between said electrodes through said molten slag bath whereby melting of the electrodes is caused to occur and an ingot is formed in said mold; feeding said electrodes downwardly into said slag bath as they melt; increasing said power during at least a portion of the first quarter of the remelting cycle; gradually decreasing said power during an intermediate portion of the remelting cycle; and decreasing said power at an increasing rate during the final portion of the remelting cycle.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,665,080 Dated May 23, 1972

Inventor(s) Boris Izrailevich Medovar et al

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

On the Abstract page, column 1, after "Inventors", change "Vadimorich" to --Vadimovich--.

Signed and sealed this 14th day of November 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

FORM PO-1050 (10-69)

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