July 9, 1963 A. GREFFE ETAL 3,096,550

PROCESS FOR CASTING INGOTS IN A MOLD CONTAINING SLAG

Filed Oct. 28, 1958

3 Sheets-Sheet 1

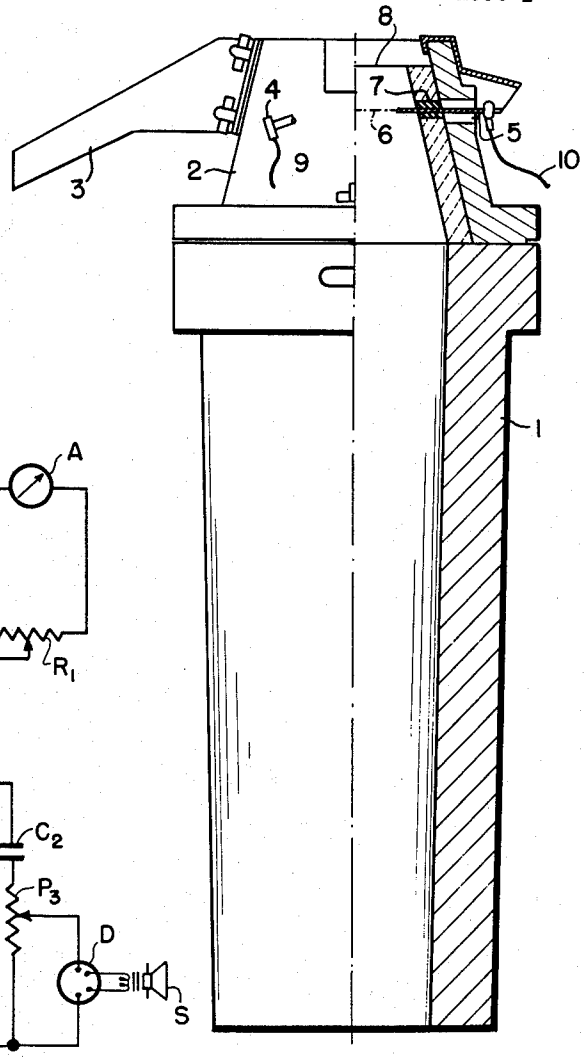


Fig. 1

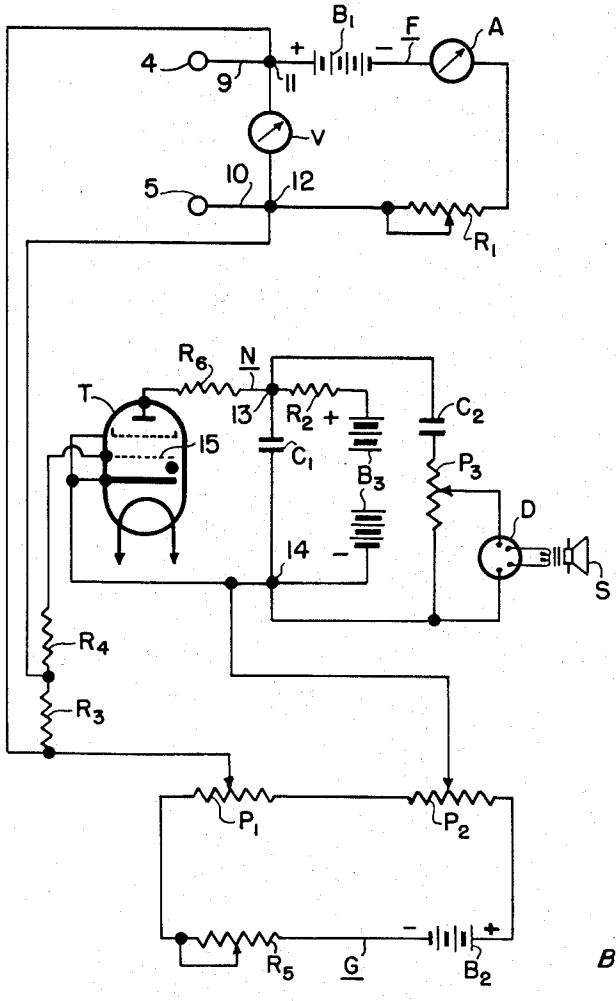


Fig. 2

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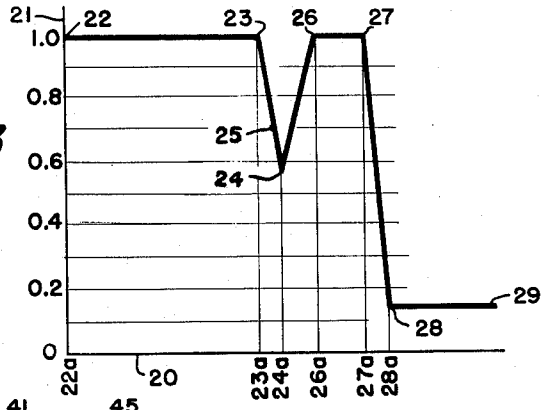
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PROCESS FOR CASTING INGOTS IN A MOLD CONTAINING SLAG

Filed Oct. 28, 1958 3 Sheets-Sheet 2

Fig. 3



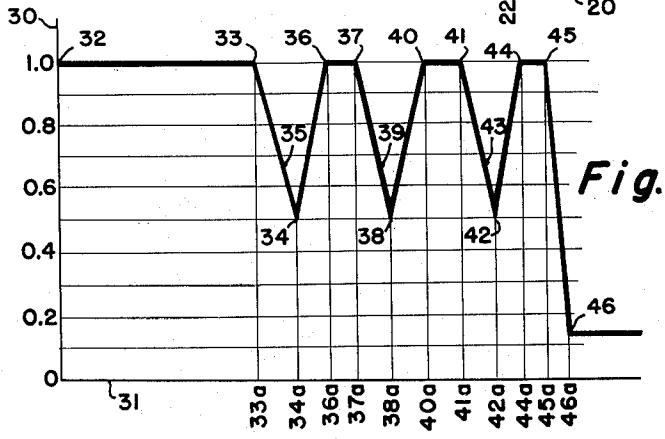


Fig. 4

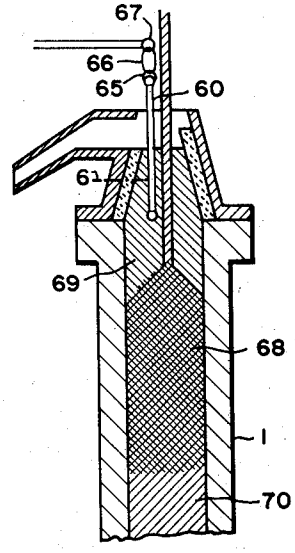


Fig. 5

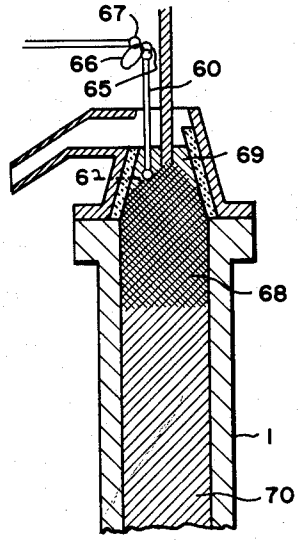


Fig. 6

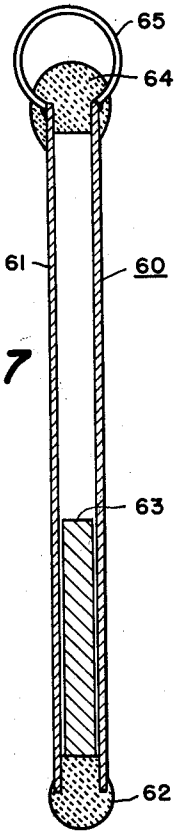


Fig. 7

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PROCESS FOR CASTING INGOTS IN A MOLD CONTAINING SLAG

Filed Oct. 28, 1958 3 Sheets-Sheet 3

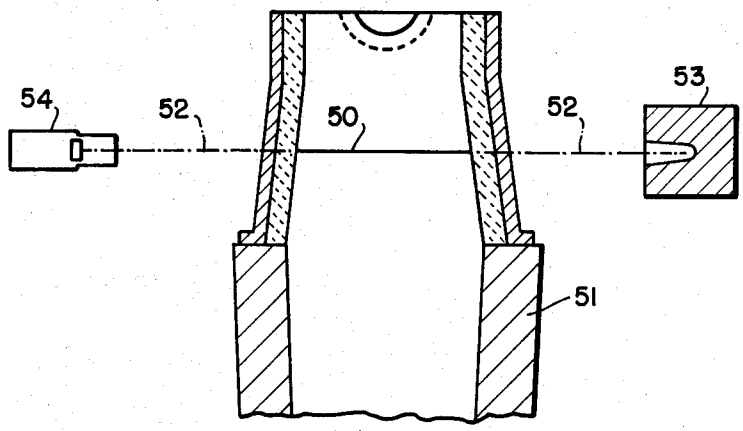


Fig. 8

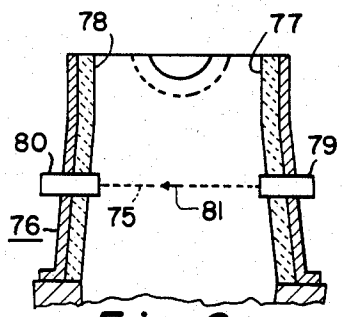


Fig. 9

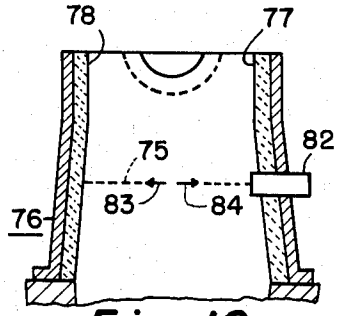


Fig. 10

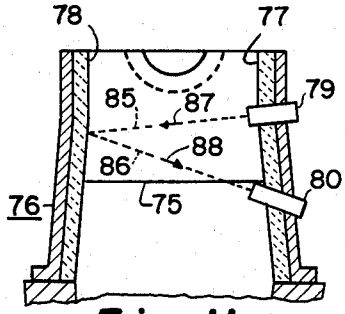


Fig. 11

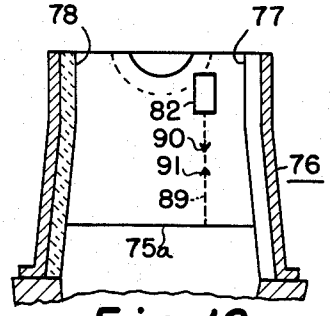


Fig. 12

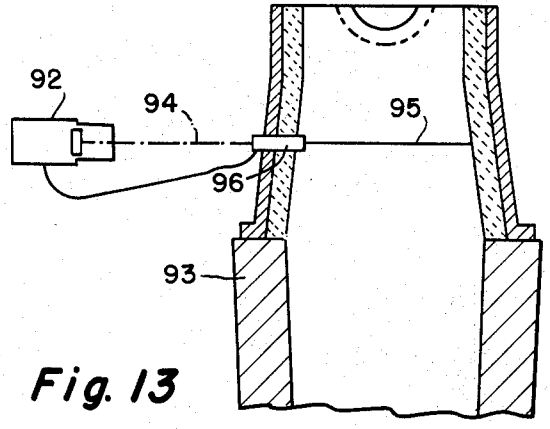


Fig. 13

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United States Patent Office

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PROCESS FOR CASTING INGOTS IN A MOLD CONTAINING SLAG

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Filed Oct. 28, 1958, Ser. No. 770,115
Claims priority, application France July 23, 1955
34 Claims. (Cl. 22—209)

This invention relates to a process for casting metal ingots and, more particularly, to a process for casting an ingot of a desired weight into an ingot mold containing a quantity of slag.

This application is a continuation-in-part of our application Serial No. 598,314 filed July 17, 1956, now abandoned.

In a copending application Serial No. 595,318, filed July 2, 1956, now abandoned, of which Messrs. André Greffe and Henri Jolivet are coinventors, there is a disclosure of a process of casting metal ingots wherein the metal is poured into a mold substantially or completely filled with slag. According to this copending application, the cast metal forms with the slag a metal-slag emulsion in the mold and simultaneously displaces from the mold slag which then overflows into a slag ladle. The metal-slag emulsion subsequently separates into a body of metal free from particles of slag and a body of slag free from particles of metal. In carrying out such a casting process, the operator cannot see or observe the level of the metal or of the metal-slag emulsion in the mold because of the slag through which he pours the metal. Therefore, he has great difficulty in controlling the rate of metal pouring to produce a specified ingot weight and to avoid loss of metal by overflow from the ingot mold. Accordingly, it is highly desirable to determine the exact metal level under the slag during pouring and to terminate pouring at a predetermined level in the mold so that a desired weight of ingot is produced. This is especially important since casting of the metal is terminated with a layer of slag above the body of metal. It is also highly desirable in carrying out the process covered by the copending application to terminate the pouring of metal at a point where a layer of slag of about 10 to 20 cm. remains above the body of metal. This layer of slag which preferably remains at a temperature above the solidification point of the metal at least until the metal has substantially solidified reduces materially, if not eliminates pipe and also lowers the amount of segregation.

Ability to produce successive ingots of substantially the same weight effects valuable savings in production costs for it permits setting up metal rolling and fabricating practices which do not require adjustment therein between successive ingots, thereby increasing output in a given time and simplifying operations. Where there is a material difference in weight between successive ingots, one of two courses of action is available to the roller or fabricator. The first course of action is adjustment of the rolling or fabricating practice to accommodate changes in weights between the ingots in the rolling or fabricating practices in order to obtain maximum yields from each. The second course of action is to disregard making such adjustments in rolling or fabricating practices and to limit the piece or pieces made therefrom to a certain minimum weight and/or size, thus experiencing low yields. To determine which course of action is best, one must balance the economic costs, specifically, whether it is more economical to adjust the rolling or fabricating practice to effect maximum yields, thereby lengthening production time and making operations more complex or whether it

is more economical to limit the practice to a minimum size and/or weight thereby experiencing low yields.

In the process of casting metal ingots wherein the metal is poured into a body of slag in the ingot mold and wherein a metal-slag emulsion is formed, it is important that the rate of metal pouring be regulated to insure a separation of the metal and slag from the emulsion and to avoid a loss of metal from overflow of the metal-slag emulsion or of the metal from the ingot mold. Generally, there is a layer of slag at the top of the mold with the metal-slag emulsion being below the layer of slag. This layer of slag at the top of the mold is present during metal pouring and until the mold has almost been completely filled with metal. Accordingly, prior to the time that the metal-slag emulsion reaches the top of the mold and overflows therefrom, it is desirable to detect the present of the metal-slag emulsion at a predetermined height in the mold below the top of the mold. Thus, one can control the metal pouring so that metal loss is avoided and successive ingots of substantially the same weight are produced. Accordingly, detection of the presence of the metal-slag emulsion at a predetermined height in the mold enables one to control the amount of metal cast and thus change the rate of metal pouring to avoid metal loss.

We have developed a process of casting metal into slag whereby one can control the amount of metal cast into a mold containing a body of slag, can control the amount of slag displaced from the mold, can avoid metal loss and can produce successive ingots of substantially the same weight. Specifically, our method of casting metal into a mold containing liquid slag comprises pouring metal into the slag in the mold and during pouring sensing or detecting at a predetermined height in the mold the character of the material in the mold. When the character of the material at the predetermined height begins to change appreciably, we decrease the rate of metal pouring and stop the metal pouring when the character of the material at the predetermined height is all metal.

Detecting the character of the material at the predetermined height in the mold is effected in a number of ways. One way comprises utilization of differences in certain physical properties of the slag, metal and metal-slag emulsion. Some of the physical properties of the slag, metal and metal-slag emulsion which we utilize in sensing or detecting the character of the material at the predetermined height in the mold are electrical conductivity or resistivity, absorption of a medium directed through the material, reflection of a medium directed at the material and density of the material.

In making use of differences in physical properties of the slag, metal and metal-slag emulsion, we direct a medium through the material at the predetermined height in the mold and sense or detect changes in the medium caused by the differences in the physical properties of the metal, slag and metal-slag emulsion and in this way, ascertain the character of the material at the predetermined height in the mold. Some of the mediums which we employ in practicing our process are electric current, gamma rays, X-rays, and ultrasonics.

An additional way of detecting a change in the character of the material at the predetermined level comprises introducing a radioactive tracer into either the slag or the metal and measuring the intensity of the radioactivity of the tracer at the predetermined height in the mold. The radioactive tracer must be of such character that, when introduced into the metal, it does not pass into the slag and that, when introduced into the slag, it does not pass into the metal.

We have discovered that the electrical conductance of a slag-metal emulsion increases as the quantity of metal dispersion in the slag increases and that the conductance

ranges from a minimum value when the material at the predetermined height in the mold is pure slag to a maximum value when it is pure metal. Thus, by immersing in a body of liquid slag, in a liquid metal-slag emulsion or in a body of molten metal, a device which measures the electrical conductance of the material, one can determine at least approximately the character of the material, i.e., whether it is pure slag, metal-slag emulsion, or pure metal. Measurement of the electrical conductance of the material thereby enables one to sense or determine the character of the material at a predetermined height in the mold and then accurately control the amount of metal cast into a mold containing a body of slag and control the amount of slag displaced by the metal. When the electrical conductance of the material begins to increase appreciably from its starting value, we decrease the rate of metal pouring and stop the pouring when the electrical conductance corresponds to that of the metal.

Specifically, one embodiment of our process comprises pouring metal into a mold containing liquid slag and during the pouring, measuring at a predetermined height in the mold the electrical conductance of the material therein. When the electrical conductance of the material begins to increase appreciably from its starting value, we decrease the rate of metal pouring and stop the pouring when the electrical conductance of the material corresponds to that of the metal.

Our invention utilizes measurements of electrical conductance of a metal-slag material or emulsion, of a slag and of a metal at a predetermined height in an ingot mold. At the outset of metal casting of an ingot into a mold substantially filled with a liquid slag, the electrical conductance of the slag is low. When the material at the predetermined height in the mold becomes a metal-slag emulsion, there is a marked and/or a sudden and variable increase in the electrical conductance. This is caused by displacement of some of the slag particles by metal particles. When this marked and/or sudden and variable increase in the electrical conductance of the material at the predetermined level occurs, we reduce the rate of pouring of the metal and continue pouring at a rate which permits separation of the metal-slag emulsion or material into its components until the electrical conductance corresponds to that of the metal. When the conductance equals that of the metal, the cast metal in the mold is at the predetermined level and there is a layer of slag above this predetermined level which slag reduces the amount of pipe and segregation in the ingot. Accordingly, pouring is then stopped so that the ingot has a desired weight and so that there is a requisite amount of slag on top of the metal.

Sometimes we interrupt the casting of the metal when the measurement of the electrical conductance of the material indicates a marked increase or a sudden fluctuation. Then, after a short interval, pouring is resumed at a reduced rate and terminated when the measured conductance has ceased fluctuating and is at a value appreciably above its starting value. When the pouring is stopped or the rate of pouring reduced upon observance of a marked or fluctuating increase in the electrical conductance, the values of conductance vary within a considerable range in accordance with the degree of separation of the emulsion into its components and with the degree of enrichment of the emulsion by the metal. Once the marked increase of fluctuation in conductance occurs, it is highly dersirable that pouring continue at a substantially lower rate while carefully observing the increase in conductance until the conductance ceases fluctuating or corresponds to the value of the metal.

When employing a medium such as X-rays, gamma rays,

and ultrasonics, we practice our process in substantially the same manner as described in regard to utilizing electrical conductance of the metal, slag and metal-slag emulsion. Specifically, we measure the intensity of a beam of X-rays, gamma rays, and ultrasonics which passes through the material at the predetermined level in the height of the mold. We have found that the intensity of the beam which has passed through the metal is less than the intensity of the beam which has passed through the slag because the metal has greater absorption properties than the slag. We have also found that the intensity of the beam passing through the metal-slag emulsion is intermediate the intensity of the beam which has passed through the metal and of the beam which has passed through the slag. Accordingly, by noting changes in the intensity of the beam which has passed through the material at the predetermined height in the mold, we determined the character of the material at that predetermined height, i.e., whether it is slag, metal, or metal-slag emulsion.

Where we direct a medium such as ultrasonic waves at the material in the mold at the predetermined height to produce a reflected beam, we measure the intensity of the reflected beam and from changes or variations in the measured intensity, ascertain whether the material at the predetermined height is slag, metal or metal-slag emulsion. We have discovered that the intensity of a reflected beam is different when the material is metal than when it is slag and that the intensity is intermediate in value when the material is the metal-slag emulsion as compared to when it is all metal or all slag.

Where a radioactive tracer is introduced into either the slag or the metal, measurement of the intensity of radioactivity at the predetermined height in the mold permits us to ascertain the character of the material. For example, if the tracer is placed in the metal, no radioactivity is detected when slag is at the predetermined height. However, when the metal-slag emulsion or the metal reaches the predetermined height, radioactivity is sensed due to the presence of radioactive tracer in the metal. Of course, the intensity of radioactivity measured is higher when all metal is present than when the metal-slag emulsion is present.

Variation or absence of variation in electrical conductance of the material measured or in the intensity of the medium directed through or at the material or in the intensity of radioactivity of the tracer governs the casting operation rather than absolute conductance values obtained and observed or than absolute intensity values measured. This is because absolute values observed at the same stage between different castings do not necessarily indicate that the same weight and/or size of ingot has been cast because differences or variations in the size and shape of molds and in the kind and shape of the measuring devices employed and differences or variations in the metal and slag compositions make absolute values unreliable for determining at what point to terminate casting. Whatever may be a conductance or intensity value at the start of each casting during the casting operation, the value will fluctuate and by taking into account the direction and amount of fluctuation observed, one can determine when to terminate the casting to produce a large number of ingots of a desired weight and size. We have obtained accuracies through use of our process of up to 10 mm. in height for a 5-ton ingot.

Our process can be carried out by many devices which measure the electrical conductance of the material and which convert measured conductance values into easily observed or heard signals, which advise a casting crew when to reduce the pouring rate and when to terminate pouring. One device which we have found suitable com-

prises two electrodes, at least one of which is located in a plane corresponding to the height at which it is desired to pour the metal. The two electrodes are part of an electric circuit in which the material, i.e., slag, metal-slag emulsion or metal, is a variable resistance.

Another device which we have found satisfactory has an electrode at the bottom of an ingot mold and a second movable electrode which is plunged downwardly in the mold into the material therein. When the movable electrode is at the top of a layer of slag, the conductance value is low. As the electrode is lowered, the thickness of the slag layer between the electrode at the bottom of the mold and the movable electrode decreases and correspondingly the conductance measured linearly increases in proportion to the decrease in thickness of the slag layer. When the movable electrode comes into contact with liquid metal, there is a marked and sudden increase in the conductance values.

In the accompanying drawings, we have shown devices which can be satisfactorily employed in carrying out our process in which,

FIGURE 1 is a side elevation view partly in section showing an ingot mold and hot top equipped with a device for measuring electrical conductance of a medium in the mold;

FIGURE 2 is a wiring diagram of the device of FIGURE 1;

FIGURES 3 and 4 are representative time-resistivity curves obtained in testing two different slags to determine metal pouring practice;

FIGURES 5 and 6 are section views of an ingot mold provided with apparatus to sense changes of density of the material at the predetermined height in the mold;

FIGURE 7 is a section view of a float which is part of the apparatus of FIGURE 5;

FIGURE 8 is a section view of the upper part of an ingot mold provided with apparatus for sensing the character of the material in the mold by measuring the intensity of a beam of gamma rays or X-rays directed through the mold;

FIGURE 9 is a schematic view of apparatus for sensing the character of the material in the mold by measuring intensity of ultrasonic waves directed through the material in the mold;

FIGURES 10, 11 and 12 are schematic views of apparatus for sensing the character of the material in the mold by measuring intensity of reflected ultrasonic waves directed into the material in the mold; and

FIGURE 13 is a section view of the upper part of an ingot mold provided with apparatus for sensing the character of the material in the mold by measuring the intensity of radioactivity of a tracer introduced into either the metal or the slag.

As shown in FIGURE 1, an ingot mold has a hot top **2** mounted thereon and a slag run-off spout **3** affixed to the hot top.

The apparatus for measuring the electrical conductance of a material in the mold and a hot top comprises two electrodes **4** and **5** mounted in the hot top and arranged therein so that one end of each electrode extends through the hot top and into a material which fills the mold and extends up into the hot top. Electrode **5** is located at a desired level **6** to which the metal is to be cast. We provide insulation **7** which surrounds each electrode and through which each electrode is inserted, whereby there is electric insulation between each electrode and the hot top. **8** designates the upper level of the liquid slag when the casting is terminated. Leads **9** and **10** connect the electrodes **4** and **5**, respectively, to the apparatus which measures the electrical conductance of the material in the mold.

In FIGURE 2, F designates the electrical indicater apparatus which measures the electrical conductance of the material filling the mold **1** and extending up into the hot top **2**. The indicator apparatus F comprises a 6-volt supply battery B_1 in circuit with the two electrodes **4** and **5** arranged at the desired level **6** as noted in the ingot-mold at which the cast metal will reach its desired height. The leads **9** and **10** for the electrodes **4** and **5** have the respective terminals **11** and **12** across which a voltmeter V is connected; the voltmeter shows the voltage between the terminals **11** and **12**. The battery B_1 supplies direct current to the electrodes **4** and **5** through an ammeter A and a variable resistor R_1 in series with the ammeter. The battery B_1 supplies between terminals **11** and **12** a voltage which varies in accordance with the resistance of the liquid material which is between **4** and **5**. The resistor R_1 is used to adjust the current flowing through the ammeter to produce at the beginning of each operation any desired maximum reading at V for the voltage drop between **4** and **5**; at this time the electrodes **4** and **5** are plunged into the slag which is slightly conducting. For a fixed position of the resistor R_1, the potential difference between the electrodes **4** and **5** varies with the particular electrical conductance or resistance offered by the path of conducting material therebetween and thereafter the magnitude of this voltage is indicative at any time of the character of the material then present in the interelectrode path.

In addition to changing the readily perceptible voltmeter reading at V, the potential difference between the terminals **11** and **12** can be used to control an oscillator network N and a speaker S connected thereto which is continuously driven by the oscillations in a manner whereby each change in such voltage is registered by a decided change in the character of the steady audible sound being emitted by the speaker. The oscillator network N may include an amplifier D interposed at the output side thereof to drive the speaker S with an input signal of the proper amplification. Further included in the network N is a resistor-capacitor circuit consisting of a resistor R_2 and a capacitor C_1 which are series connected in circuit in customary manner with a source of D.C. supply B_3 having the resistor R_2 connected to its positive side. The capacitor C_1 has its terminals indicated at **13**, **14** which are periodically discharged by a thyratron switch T of the filament heated type. A 2D21 thyratron-tetrode tube has been found satisfactory for this switching purpose and this tube or switch T has an anode-cathode path arranged with a control grid **15** interposed therein and with an anode resistor R_6 connected to the positive terminal **13** of the capacitor C_1. Another capacitor C_2 in series with a potentiometer P_3 is connected across the terminals **13**, **14** of the condenser C_1. The amplifier D is connected between one terminal and the adjustable slider of the potentiometer P_3 for receiving and amplifying the resulting oscillating voltage after its adjustment to the proper amplitude.

A resistor R_3 which has its leads connected to the terminals **11** and **12** in the electrical indicator apparatus F, forms part of a grid biasing circuit G for biasing the grid **15** of the thyratron switch T negative with respect to its cathode. The grid biasing circuit G further includes a grid resistor R_4 connected between the resistor R_3 and the grid **15**, a first potentiometer P_1 whose slider is connected to the same resistor R_3, and a second potentiometer P_2 whose slider is connected to the cathode of the thyratron switch T. A 3-volt battery B_2 is connected through a variable resistor R_5 to the first and second potentiometers P_1 and P_2 in a manner to circulate current whereby the slider of the grid connected potentiometer P_1 is negative so as to exert a bias upon the grid **15** with respect to the cathode.

This potentiometer P_1 is adjustable to adapt the electrical indicator apparatus F to mechanical variations in the system such as the spacing of the electrodes **4** and **5** and the nature of the poured metal, the slag, and the electrodes **4** and **5**. The potentiometer P_2 is adjustable to recalibrate the system in the event that the thyratron

tube functioning as the switch T is replaced with another tube.

In operation, the network N functions as a relaxation oscillator for generating sawtooth waves and the series-connected resistor-capacitor R_2C_1 form a time constant circuit of known character to bring the oscillating frequency within the audible range, it being appreciated that an increase in either the resistance or the capacitance will cause a decrease in frequency so as to reduce it to the audible range desired. The negative bias on the grid **15** is the cumulative bias between sliders of the potentiometers P_1 and P_2 and the voltage across the resistor R_3 and this cumulative bias is at a maximum when the electrodes **4** and **5** are not conducting, that is, when the ingot-mold is empty. When the mold holds slag so as to provide a current path having high resistance between the electrodes **4** and **5**, the voltage across the terminals **11** and **12**, therefore across the resistor R_3, decreases and the grid **15** becomes slightly less negative to the cathode. In neither case does the speaker S emit a sound. The speaker commences with a rather loud sound of low frequency pitch when the intermixture layer of molten steel highly diluted with the slag reaches the level of the electrodes **4** and **5** so as to increase the conductivity therebetween. The presence later of the undiluted molten steel offers a lower resistance path between the electrodes **4** and **5** to bring them closer to the same potential, causing the grid **15** to become even less negative with the result that the tube T oscillates the speaker S with smaller amplitude and at a higher frequency so that the sound from the speaker S is somewhat less intense in volume, but has a relatively high pitch.

In one physically constructed embodiment of the invention, the voltage across the terminals **11** and **12** was 1.0 volt when slag was present between the electrodes **4**, **5**. This voltage reduced to 0.3 volt when undiluted metal was present. Thus, during the pouring operation, the speaker S was quiet as long as only slag was present in the path of the electrodes and it initially responded with a loud low-pitched note when the slag began to be replaced by the rising layer of partially enriched slag and this note tended to warble as the voltage between the terminals **11** and **12** fluctuated unsteadily in the range between 1.0 and 0.3 volt as the percentage composition of the rising mixture varied. At the instant the line of metal-slag separation rose to the point where both electrodes could dip into the actual molten metal, the voltage between the terminals **11** and **12** became steady at 0.3 volt and the sound emitted by the speaker stabilized and remained steady with its slightly lesser intensity but perceptibly higher pitch.

An example of pouring 5,000 kg. ingots of 18% chromium and 8% nickel stainless steel demonstrates that practice of our process produces successive ingots which have little variation in weight and size between each other. The stainless steel was poured into ingot molds equipped with the foregoing electrical indicator apparatus with the two electrodes being 10 mm. diameter graphite sections and sealed in a hot top with insulating material. The electrodes protruded 3 to 4 cm. from the inside surface of the hot top with their ends about 30 cm. apart. We poured the metal into a slag having the following composition:

SiO_2	CaO	Al_2O_3	MgO	Na_2O	TiO_2
32%	21%	19%	11%	10%	7%

Pouring practice comprised casting at a rate of 2 liters per second until there was marked oscillation or fluctuation in the signal transmitted by the indicator apparatus whereupon casting was stopped for a few seconds. Casting was resumed at a rate of 1 liter per second until the signal ceased oscillating or fluctuating and indicated a tone of different pitch than that received at the start of the casting. This different tone informed the pouring crew that the desired amount of stainless steel had been cast into the mold. Successive castings produced 5010 kg. to 5050 kg. ingots which represent a height variation of the ingots of 10 to 12 mm.

The time-resistivity curve of FIGURE 3 shows changes in electrical conductance at the predetermined level **6** in the mold of FIGURE 1 during pouring of an ingot. These changes represent presence of slag, metal-slag emulsion and metal. The abscissa **20** of the curve is time plotted in seconds and the ordinate **21** is representative of electrical resistivity but is not an absolute value of electrical resistance of the material at the level **6**. The ordinate is a measured quantity proportional to electrical resistance.

Line **22**, **23** represents substantially all slag at the level **6** in the mold **1** and has a measured value of 1 on the ordinate **21** and represents a time interval during which metal is poured into the mold. During the time interval represented by the line **22**, **23**, the metal poured into the slag in the mold forms a metal-slag emulsion in the mold below the level **6**. Line **23**, **24** represents the presence of metal-slag emulsion at the level **6** and shows a drop in the measured value to about 0.6 at **24**. At point **25** on line **23**, **24**, pouring is stopped or slowed down upon operation of a signal such as the horn S of FIGURE 2. This drop in the measured value is proportional to a drop in electrical resistance between the electrodes **4** and **5** of FIGURE 1. Line **24**, **26** represents separation of the metal-slag emulsion into metal and slag with the material at the level **6** becoming substantially all slag at **26**. The measured value at **26** is again about 1 and when value 1 is again reached at **26**, pouring of metal is resumed at a slower rate than that employed for the period represented by line **22**, **23**. Metal pouring continues at the reduced rate to **27**. Line **27**, **28** represents the presence of all metal at the predetermined level **6** whereupon casting of the ingot is terminated immediately after point **28** is reached. Line **28**, **29** represents a value of substantially 0.15 on the ordinate **21**.

The time elapsed for the line **24**, **26**, which represents presence of metal-slag emulsion, is shown on the abscissa as **24***a*, **26***a* and indicates the time required for separation of the emulsion and as shown in FIGURE 3 is about 2 to 4 seconds. The time during which pouring is resumed at a slower rate and as represented by the line **26**, **27** is about 5 seconds and is shown on the abscissa as **26***a*, **27***a*. However, pouring times represented by lines **22**, **23**; **23**, **24**; **24**, **26** and **26**, **27** are dependent upon ingot size and nozzle size. For example, for 1-ton ingots, the time represented by line **22**, **23** on the abscissa **22***a*, **23***a* is 60–70 seconds, whereas for 5-ton ingots, the time 200 seconds. The amount of time represented by lines **23**, **24** and **27**, **28** (as shown on the abscissa as **23***a*, **24***a*, and **27***a*, **28***a*) is a few seconds.

The time-resistivity curve of FIGURE 4 shows changes in electrical conductance at the predetermined level **6** in the mold wherein metal pouring has been interrupted several times upon deflection of the presence of the metal-slag emulsion at the level **6**. The ordinate **30** and the abscissa **31** are the same as the ordinate **21** and the abscissa **20** of the curve of FIGURE 3. Line **32**, **33** represents the metal pouring through slag to the first detection of metal-slag emulsion at the level **6** and line **33**, **34** represents the presence of metal-slag emulsion at the level **6** with metal casting being stopped or continued at a reduced rate at point **35** on the line **33**, **34**. Line **34**, **36** represents separation of the emulsion into metal and slag and line **36**, **37** indicates resumption of metal casting at a reduced rate compared to that employed during the pouring represented by line **32**, **33**. Lines **37**, **38** and **41**, **42** represent appearances of metal-slag emulsion and are the same as line **33**, **34**. Lines **38**, **40** and **42**, **44** indicate separation of the emulsion and lines **40**, **41** and **44**, **45**

represent resumption of metal pouring. Line **45, 46** shows appearance of all metal at the predetermined level and termination of metal casting. Point **39** on line **37, 38** and point **43** on line **41, 42** represent the stopping of metal pouring or continued pouring of metal at a reduced rate upon sensing or detection of the metal slag emulsion at the level **6**.

On the abscissa the times such as **33***a*, **34***a*; **34***a*, **36***a*; **36***a*, **37***a*; **37***a*, **38***a*; **38***a*, **40***a*; **40***a*, **41***a*; **41***a*, **42***a*; **42***a*, **44***a*; **44***a*, **45***a*; and **45***a*, **46***a* are short and of the order of substantially about 2–4 seconds.

FIGURE 8 shows one apparatus which may be used to sense or detect the character of the material at the predetermined height **50** in an ingot mold **51** by directing a beam **52** of gamma rays or X-rays through the material. Outside the mold, spaced apart therefrom is a source **53** of gamma rays or X-rays which directs the beam of rays through the mold and through the material in the mold at the predetermined height **50** to a scintillation counter **54** which measures intensity of the beam of directed rays at the predetermined height **50**. The scintillation counter is also outside the mold and disposed on the opposite side thereof from the source so that it receives the beam of gamma rays passing through the mold and through the material. The counter has screening and protection so that its operation and measurement of the beam of gamma rays is not affected by secondary radiations. Connected to the scintillation counter is a signal device (not shown) such as a light or a horn which is actuated by the output of the counter and which indicates to one pouring the metal when to slow down or stop pouring.

We have found that the accuracy of location of the metal-slag emulsion and of the level of metal in the mold is enhanced by increasing the intensity of the beam and by employing a narrow beam.

In practicing our process using gamma rays, the mold is either filled with slag or partially filled with slag and the intensity of the beam received by the counter observed when slag is at the predetermined level. Then during pouring of metal through the slag into the mold, the metal pourer is alert for a noticeable or marked variation in the intensity of the beam received by the counter which variation may be indicated by a light or horn. This variation in intensity indicates presence of the metal-slag emulsion at the predetermined height in the mold. Upon observation of the variation in intensity, metal pouring is stopped or continued at a slower rate. During the time that the metal pouring is stopped or continued at a reduced rate, the metal-slag emulsion separates and upon completion of separation, the intensity of the beam is once again substantially that of intensity observed when slag was present at the predetermined level. Then metal pouring is either resumed or continued at a reduced rate until measurement of the beam intensity corresponds to that of the metal at which time metal casting is terminated.

In the apparatus of FIGURE 8, the source of gamma rays must have sufficient penetrating power both from a quantitative and a qualitative standpoint. We have found that cobalt 60 is a suitable source for the beam of gamma rays. The coefficient of linear absorption μ of gamma rays for slag is 0.14 cm.$^{-1}$ and for steel is 0.4 cm.$^{-1}$. Where the beam of gamma rays passes through a 2-metric ton mold, where the length of the path of travel of the beam through the material in the mold at the predetermined level is 40 cm. and where cobalt 60 is the radiation source, the intensity of the beam received by the counter is about 30,000 times stronger for slag than for steel.

Determination of the intensity of the beam when it passes through slag and when it passes through steel is obtained from use of the formula $I=I_0e^{-Z\mu}$ wherein I is the intensity of the beam which has passed through the material in the mold. I_0 is the intensity of the beam generated by the source of gamma rays such as the source **53** and Z is the thickness of the material through which the beam travels and μ is the coefficient of linear absorption of the material at the level.

Where I_l is the intensity of the beam transmitted through liquid slag and where I_m is the intensity of the beam transmitted through steel, the formula is

$$\frac{I_l}{I_m}=e^{-Z(\mu_l-\mu_m)}$$

in which μ_l and μ_m are the linear absorption coefficients of slag and metal respectively.

Practice of our process can be carried out with the apparatus of FIGURE 8 wherein the cobalt 60 source has an emission voltage of about 1.25 mv. (millions of volts) and a power of about 3 curies, wherein the scintillating counter has with a crystal having a work surface of about 10 cm.^{2} and wherein the source and the counter are spaced about 2 meters apart. With this apparatus, we can detect presence of slag, metal, or metal-slag emulsion at the desired level or height in the mold to within a few millimeters in less than one second.

When X-rays are employed in place of gamma rays, the source of the X-rays preferably has an emission voltage above 1 mv. (one million volts). We use as the source of X-rays conventional X-ray tubes with high emission voltage, Van de Graaf accelerators, linear accelerators or betatrons. To measure the intensity of the X-rays, a scintillation counter such as the counter **54** is used.

FIGURES 5, 6 and 7 show apparatus which detects changes in density of the material at the predetermined level **6** in the mold **1**. The apparatus comprises a weighted float **60** made from a pipe **61** of a high melting point material such as silicon carbide. Sealed in the lower end of the pipe by a clay plug **62** is a weight **63** and a second clay plug **64** closes the upper end of the pipe. Connected to the upper end of the pipe is a suspension ring **65** which links with a second ring **66** carried by a fixed support **67**.

To detect changes in the density of the material at the predetermined height and thereby sense a change in the character of the material at the predetermined height, the mold is filled or partially filled with a layer of slag **69** and the float **60** is suspended from its fixed support by the second ring **66** which is linked with the suspension ring **65** so that the float is suspended down into the mold. The weight **63** in the float is selected so that when the lower end of the float is in slag, it will not rise upwardly towards the fixed support but when the lower end of the float is in either metal or metal-slag emulsion, it rises toward the fixed support. The float is so weighted that when its lower end is in a metal-slag emulsion, it rises slowly towards the fixed support but when its lower end is in metal, it rises suddenly upwardly close to the fixed support and slips the second ring **66**, thus indicating to the metal pourer that metal is present at the predetermined level.

Practice of our process using the apparatus of FIGURES 5, 6 and 7 comprises observing when the second ring **66** slips as shown in FIGURE 6 and how quickly the slip occurs. When the float rises slowly and the slip of the ring is likewise slow, the metal-slag emulsion is at the level **6** and the metal pouring is stopped or continued at a reduced rate. In FIGURE 6, the metal-slag emulsion **68** has caused the second ring **66** to slip. During the time that the pouring is stopped or continued at a reduced rate, the emulsion separates into a layer of metal **70** and a layer of slag **69** and following separation, the float falls to its fully suspended position such as that shown in FIGURE 5, whereupon pouring is resumed at a reduced rate or continued at a reduced rate. When the float rises suddenly causing the ring **66** to slip quickly, metal casting is terminated for the metal is present at the predetermined level.

FIGURES 9–12 inclusive show apparatus which we employ to detect the presence of metal, slag or metal-slag emulsion at the predetermined level in the ingot

mold by the use of ultrasonics. Ultrasonics permit use of either transmitted waves or reflected waves to sense or detect metal, slag or metal-slag emulsion at the predetermined level in the ingot mold. We employ ultrasonic wave frequencies which preferably fall within a range of about 0.2 and 10 m. H_z. (millions of Hertz) and for the source of ultrasonic waves, we have found direct or impulse emitters satisfactory.

Where a direct emitter is used, we regulate metal pouring by observing variation in the intensity of the transmitted sonic wave when the metal-slag emulsion replaces the slag at the predetermined level or when the metal replaces either the slag or the metal-slag emulsion at the predetermined level. Where an impulse emitter is used, we control metal pouring by observing variation in the intensity of the impulses traveling through the material at the predetermined level and/or by observing variations in time required for travel of the sonic waves through the material, which variations in time occur because of different speeds of sonic waves in slag, in metal, and in the metal-slag emulsion.

FIGURE 9 shows apparatus arranged for practice of our process wherein we transmit ultrasonic waves through the material at a predetermined level **75** in an ingot mold **76** which has sidewalls **77** and **78**. Extending through the sidewall **77** at the predetermined level **75** is an ultrasonic wave emitter **79** which may be either the direct or the impulse type and which directs ultrasonic waves through the material in the mold. Disposed directly opposite the emitter on the opposite side of the ingot mold and in the sidewall **78** is an ultrasonic wave receiver **80** also positioned at the predetermined level **75**. Arrow **81** represents the direction of travel of the sonic waves.

The ultrasonic wave receiver **80** senses the intensity of the waves directed through the material at the predetermined level in the mold. Connected to the receiver **80** is a signal device (not shown) such as a horn or light which is controlled by the receiver **80** and which operates in accordance with changes in the intensity of the waves directed through the material. Thus, the man controlling pouring of the metal is alert for a signal from the signal device or for a change in the signal from the signal device and regulates pouring of the metal accordingly.

FIGURE 10 shows apparatus arranged for practicing our process wherein we use reflected sonic waves directed through the material at the predetermined level **75** in the ingot mold **76**. Extending through the sidewall **77** is a sonic wave impulse emitter and receiver **82** arranged to transmit sonic waves through the material so that they impinge upon the opposite sidewall **78** of the ingot mold perpendicularly thereto and are then reflected back through the material to the emitter, receiver **82**. Arrows **83** and **84** indicate the path of travel of the transmitted and reflected waves. The emitter, receiver **82**, like the receiver **80**, senses the intensity of the waves directed through the material at the predetermined level in the mold. The emitter, receiver **82** is also connected to signal device (not shown) which operates similarly to that connected to the receiver **80**.

In FIGURE 11, we show apparatus also arranged for practicing our process wherein we use reflected ultrasonic waves directed through the material to the predetermined level **75** in the ingot mold **76**. Positioned in the sidewall **77** of the ingot mold **76** is the direct or impulse emitter **79** disposed so that it directs ultrasonic waves along a path **85** which falls obliquely upon the wall **78**. The ultrasonic waves are reflected by the wall **78** and travel along path **86** to the receiver **80** also positioned in the sidewall **77**. Arrows **87** and **88** indicate the direction of travel of the sonic waves along paths **85** and **86**. As shown, the reflection angle is equal to the incidence angle.

In FIGURE 12, we show another way of practicing our process wherein we use reflected ultrasonic waves directed by the vertically located impulse emitter and receiver **82** down into the slag or metal or metal-slag emulsion to sense the separating surface *75a* between slag and metal or between slag and metal-slag emulsion. The emitter, receiver **82** is suspended above the separating surface *75a* and disposed relative to the mold **76** and its sidewalls **77** and **78** so that it directs the ultrasonic waves along a path **89**. Arrow **90** shows the direction of travel of the directed waves and arrow **91** the direction of travel of the reflected waves.

When the separating surface *75a* coincides with the predetermined level to which the metal is to be poured, metal pouring is terminated. The time interval required for the ultrasonic waves to travel from the emitter, receiver **82** to the separating surface *75a*, be there reflected and return to the emitter, receiver **82** depends upon the distance between the separating surface and the emitter, receiver **82**. The time interval also depends upon the thickness of the layers of slag unmixed with metal between the separating surface and the emitter, receiver **82**. Accordingly, a certain thickness of slag, unmixed with metal, corresponds to a certain interval of time required for travel of the ultrasonic waves from the emitter, receiver **82** to the separating surface and back thereto.

Therefore, when the metal or the metal-slag emulsion reach a predetermined level in the ingot mold below the top of the slag in the mold, there is a certain thickness of slag unmixed with metal between the emitter, receiver **82** and the separating surface *75a* and this certain thickness is sensed or determined by the time interval for travel of the ultrasonic wave to the separating surface *75a* and return. Thus, when the interval of time corresponds to the desired thickness of the layer of slag unmixed with metal, metal or metal-slag emulsion is at the predetermined level. Thereafter, to produce the desired weight of ingot, metal pouring is slowed down and then stopped or stopped and then continued at a slow rate depending upon whether the time interval increases indicating presence of the metal-slag emulsion or remains substantially constant indicating metal at the predetermined level.

In practicing our process using ultrasonic waves, we have made use at times of a formula which is as follows:

$$K=\frac{6\mu f^2\eta}{3\rho V^3}$$

In the formula, K is the absorption coefficient of the material at the predetermined level in the mold. f is the frequency of the directed ultrasonic waves. η is the viscosity of the material at the predetermined level and ρ is the specific mass of the material at the predetermined level. V is the propagation speed which is dependent upon the modulus of elasticity, the Poisson coefficient and the specific mass ρ.

FIGURE 13 shows another way in which we can practice our process, namely, by introduction of a radioactive tracer into either the metal or into the slag. The radioactive tracer must be soluble in only one of the metals and the slag and be capable of emitting gamma rays. We have found that cobalt 60 is a satisfactory radioactive tracer for introduction into metal and that lanthanum 140 is a satisfactory radioactive tracer for slag.

As shown in FIGURE 13, a scintillation counter **92** properly screened and protected from secondary radiations is disposed relative to ingot mold **93** so that its axis **94** is located in the plane of the predetermined level **95** where the metal is to be poured. We locate the scintillation counter outside the ingot mold and preferably dispose a graphite rod **96** in the ingot mold and at the predetermined level **95**. The presence of the graphite rod enables the scintillation counter to detect the radioactive element at the predetermined level through sensing presence of gamma rays which are emitted by the tracer.

In practicing our process using radioactive tracers or elements in either the metal or slag, the metal pourer is alert for a signal from either a horn, light or other signal-transmitting device (not shown) connected to the

counter 92 which comprises a photomultiplier and an electronic counter or a change in the signal transmitted by this counter. In the event that the radioactive tracer has been introduced into the metal, the signal device becomes active when either metal or metal-slag emulsion is present at the predetermined level. If the metal-slag emulsion is present at the predetermined level, the signal generated through operation of the scintillation counter is weaker than if metal is present at the predetermined level.

If, however, a radioactive element is introduced into the slag, then control of metal pouring is dependent upon whether, at the predetermined level, there is slag, metal or metal-slag emulsion with the signal being strongest when slag is present, weaker when metal-slag emulsion is present and non-existent when metal is present.

Another way of practicing our method is similar to the method of FIGURES 1 and 2 and uses two electrodes, each electrically insulated from the mold and disposed in the ingot mold. One electrode, the lower one, is located so that its bottom end is below the bottom end of the other electrode, the upper one. The predetermined level to which the metal is to be poured is at the position of the bottom end of the electrode which is below the other.

Sensing of the presence of metal or metal-slag emulsion at the predetermined level is dependent upon the electrical conductance of metal, slag and metal-emulsion or upon the electrical potential between the two electrodes. When we use electrical potential, the two electrodes are connected to a sensitive and quick response recording potentiometer.

When both electrodes are in slag or in metal or in metal-slag emulsion, the potentiometer indicates Null. When one electrode is in slag and the other in metal, the potentiometer indicates a maximum potential and when one electrode is in slag and the other in metal-slag emulsion, the potentiometer indicates a potential intermediate between the maximum potential and Null. Thus by observing the potential values indicated by the potentiometer, we control pouring of metal so that neither the metal nor the metal-slag emulsion rise above the predetermined level. In other words, the potentiometer indicates Null during pouring of the metal with both electrodes engaging slag. When the metal-slag emulsion reaches the bottom end of the lower electrode, the potentiometer indicates an intermediate potential value and metal pouring is either stopped and then continued at a slower rate or continued at the slower rate. When metal reaches the bottom end of the lower electrode, the potentiometer indicates a maximum potential and metal pouring is terminated. Practice of this method may be carried out by connecting the potentiometer to a signal device such as a horn.

Our invention has important advantages in that practice thereof produces ingots having substantially uniform weights. Ability to manufacture such ingots in unlimited numbers and particularly high alloy ingots brings about substantial savings to rollers and fabricators of metal products in that a single setup in rolling or fabricating practices suffices for a large number of ingots, thereby materially increasing production rates and providing uniform products. In addition, this ability effects maximum yields from ingots and from products rolled therefrom, thus lowering manufacturing costs especially where high alloy metals are employed.

Since our invention not only enables one to control the amount of metal poured into a mold containing slag but also permits one to control the amount of slag displaced from the mold, a user thereof can so regulate casting of an ingot that there is a layer of slag of appropriate thickness above the body of metal. Terminating pouring at a predetermined level below the top of the mold or of the hot top surmounting the mold provides a layer of slag of sufficient depth on top of the metal to prevent formation of segregation of alloys in the metal and to reduce if not eliminate pipe in the ingot. Preferably, this layer of slag is about 10 to 20 cm. in thickness. Thus, our invention enjoys the advantage of ability to increase yields and improve uniformity in the product through reduction and in some cases, elimination of pipe and segregation.

The invention is not limited to the preferred embodiments but may be otherwise embodied or practiced within the scope of the following claims.

We claim:

1. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, during pouring of the metal into the slag in the mold measuring at a predetermined height in the mold the electrical conductance of material at said height, at said predetermined height said material being at different times during metal pouring slag, metal-slag emulsion and metal, said measuring detecting at said predetermined height presence of slag, of metal, and of metal-slag emulsion, said predetermined height defining that height in the mold to which metal is poured to produce said ingot of a given weight, being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, said electrical conductance having a different value for each of slag, of metal and of metal-slag emulsion, decreasing the rate of metal pouring when the electrical conductance of the material begins to increase appreciably from that value which corresponds to slag and stopping the metal pouring when the electrical conductance of the material corresponds to that of metal.

2. The method of claim 1 characterized by stopping the metal pouring when measuring said electrical conductance of the material at the predetermined height indicates a change from that value corresponding to slag, after a short interval resuming pouring of the metal at a decreased rate and stopping the metal pouring when measuring said electrical conductance of the material at the predetermined height indicates a value corresponding to presence of metal.

3. The method of claim 1 characterized by during pouring of the metal into the slag in the mold, measuring at said predetermined height in the mold the electrical conductance of material therein between two fixed members at least one of which is located at said predetermined height.

4. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, during pouring of the metal into the slag in the mold, sensing at a predetermined height in the mold a value of a character of a material in the mold at said predetermined height, at said predetermined height said material being at different times during metal pouring slag, metal-slag emulsion and metal, said sensing detecting at said predetermined height presence of slag, of metal and of metal-slag emulsion, said predetermined height defining that height in the mold to which metal is poured to produce said ingot of a given weight, being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, said character having a different value for each of slag, of metal, and of metal-slag emulsion, decreasing the rate of metal pouring when sensing said character of the material at the predetermined height indicates a change from that

value corresponding to presence of slag and stopping the metal pouring when sensing said character of the material at the predetermined height indicates a value corresponding to presence of metal.

5. The method of claim 4 characterized by stopping the metal pouring when sensing said character of the material at the predetermined height indicates a change from that value corresponding to presence of slag, after a short interval, resuming pouring of the metal at a decreased rate and stopping the metal pouring when sensing said character of the material at the predetermined height indicates a value corresponding to presence of metal.

6. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, during pouring of the metal into the slag in the mold directing a medium of energy through material in the mold at a predetermined level therein, at said predetermined level said material being at different times during metal pouring slag, metal-slag emulsion and metal, said predetermined level defining that height in the mold to which metal is poured to produce said ingot of a given weight, being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, said medium of energy being capable of traversing said material during pouring of the metal into the slag in the mold sensing at said predetermined level a value of strength of said medium traversing said material at said predetermined level, said sensing detecting at said predetermined level presence of slag, of metal, and of metal-slag emulsion, said strength of said medium traversing said material having a different value for each of slag, of metal, and of metal-slag emulsion, decreasing the rate of metal pouring when sensing said strength of said medium at said predetermined level indicates a change from that value corresponding to presence of slag and stopping the metal pouring when sensing said strength of said medium at said predetermined level indicates a value corresponding to presence of metal.

7. The method of claim 6 characterized by stopping the metal pouring when sensing said strength of said medium at said predetermined level indicates a change from that value corresponding to presence of slag, after a short interval resuming pouring of the metal at a decreased rate and stopping the metal pouring when sensing said strength of said medium at said predetermined level indicates a value corresponding to presence of metal.

8. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, during pouring of the metal into the slag in the mold directing a beam of gamma rays through the material in the mold at a predetermined level in the mold, at said predetermined level said material being at different times during metal pouring slag, metal-slag emulsion and metal, said predetermined level defining that height in the mold to which metal is poured to produce said ingot of a given weight, being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, during pouring of metal into the slag in the mold sensing at said predetermined level the intensity of said gamma rays directed through said material, said sensing detecting at said predetermined level presence of slag, of metal, and of metal-slag emulsion, said intensity of said gamma rays traversing said material having a different value for each of slag, of metal, and of metal-slag emulsion, decreasing the rate of metal pouring when the intensity of said gamma rays begins to change appreciably from that value which corresponds to slag and stopping the metal pouring when the intensity of the gamma rays indicates a value corresponding to that of metal.

9. The method of claim 8 characterized by stopping the metal pouring when sensing said intensity of the gamma rays at the predetermined level indicates a change from that value corresponding to slag, after a short interval resuming of the pouring of metal at a decreased rate and stopping the metal pouring when sensing said intensity of said gamma rays at said predetermined level indicates a value corresponding to presence of metal.

10. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, during pouring of the metal into the slag in the mold directing a beam of ultrasonic waves through the material in the mold and against a wall of said mold to produce reflected ultrasonic waves at a predetermined level in the mold, at said predetermined level said material being at different times during metal pouring slag, metal-slag emulsion and metal, said predetermined level defining that height in the mold to which metal is poured to produce said ingot of a given weight, being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, during pouring of the metal into the slag in the mold sensing at said predetermined level the intensity of said reflected ultrasonic waves traversing said material, said sensing detecting at said predetermined level presence of slag, of metal, and of metal-slag emulsion, said intensity of said reflected ultrasonic waves traversing said material having a different value for each of slag, of metal, and of metal-slag emulsion, decreasing the rate of metal pouring when sensing said intensity of the reflected ultrasonic waves at said predetermined level indicates a change from that value corresponding to presence of slag and stopping the metal pouring when sensing said intensity of said reflected ultrasonic waves at said predetermined level indicates a value corresponding to presence of metal.

11. The method of claim 10 characterized by stopping the metal pouring when sensing said intensity of said reflected ultrasonic waves indicates a change from that value corresponding to presence of slag, after a short interval resuming pouring of the metal at a decreased rate and stopping the metal pouring when sensing said intensity of said reflected ultrasonic waves indicates a value corresponding to presence of metal.

12. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, one of said metal and said slag having had introduced thereinto a radioactive tracer, during pouring of the metal into the slag in the mold sensing at a predetermined level in the mold the intensity of radioactivity of said tracer in material in the mold, said material being at different times during metal pouring slag, metal-slag emulsion and metal, said sensing detecting at said predetermined level presence of slag, of metal, and of metal-slag emulsion, said predetermined level defining that height in the mold to which metal is poured to produce said ingot of a given weight, being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, at said predetermined level said intensity of radioactivity of said tracer having a different value for presence of each of slag, of metal and of metal-slag emulsion, decreasing the rate of metal pouring when the

intensity of radioactivity of said tracer indicates a change from that value corresponding to presence of slag and stopping the metal pouring when sensing said intensity of radioactivity of said tracer indicates a value corresponding to presence of metal.

13. The method of claim 12 characterized by stopping the metal pouring when sensing said intensity of radioactivity of said tracer indicates a change from that value corresponding to presence of slag, after a short interval resuming pouring of the metal at a decreased rate and stopping the metal pouring when sensing said intensity of radioactivity of said tracer indicates a value corresponding to presence of metal.

14. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, during pouring of the metal into the slag in the mold directing a beam of X-rays through material in the mold at a predetermined level in the mold, at said predetermined level said material being at different times during metal pouring slag, metal-slag emulsion and metal, said predetermined level defining that height in the mold to which metal is poured to produce said ingot of a given weight, being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, during pouring of metal into the slag in the mold sensing at said predetermined level the intensity of said X-rays directed through said material, said sensing detecting at said predetermined level presence of slag, of metal, and of metal-slag emulsion, said intensity of said X-rays traversing said material having a different value for each of slag, of metal, and of metal-slag emulsion, decreasing the rate of metal pouring when the intensity of said X-rays begins to change appreciably from that value which corresponds to slag and stopping the metal pouring when the intensity of the X-rays indicates a value corresponding to that of metal.

15. The method of claim 14 characterized by stopping the metal pouring when sensing said intensity of said X-rays at said predetermined level indicates a change from that value corresponding to presence of slag, after a short interval resuming pouring of the metal at a decreased rate and stopping the metal pouring when sensing said intensity of said X-rays at said predetermined level indicates a value corresponding to presence of metal.

16. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, during pouring of the metal into the slag in the mold directing a beam of ultrasonic waves through material in the mold at a predetermined level in the mold, at said predetermined level said material being at different times during metal pouring slag, metal-slag emulsion and metal, said predetermined level defining that height in the mold to which metal is poured to produce said ingot of a given weight, being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, during pouring of metal into the slag in the mold sensing at said predetermined level the intensity of said ultrasonic waves directed through said material, said sensing detecting at said predetermined level presence of slag, of metal, and of metal-slag emulsion, said intensity of said ultrasonic waves traversing said material having a different value for each of slag, of metal, and of metal-slag emulsion, decreasing the rate of metal pouring when the intensity of said ultrasonic waves begins to change appreciably from that value which corresponds to slag and stopping the metal pouring when the intensity of the ultrasonic waves indicates a value corresponding to that of metal.

17. The method of claim 16 characterized by stopping the metal pouring when sensing said intensity of ultrasonic waves at the predetermined level indicates a change from that value corresponding to slag, after a short interval resuming of the pouring of metal at a decreased rate and stopping the metal pouring when sensing said intensity of said ultrasonic waves at said predetermined level indicates a value corresponding to presence of metal.

18. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, during pouring of the metal into the slag in the mold directing a beam of ultrasonic waves through the material to a predetermined level in the mold to produce reflected ultrasonic waves, at said predetermined level said material being at different times during metal pouring slag, metal-slag emulsion and metal, said predetermined level defining that height in the mold to which metal is poured to produce said ingot of a given weight, being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, during pouring of the metal into the slag in the mold sensing at said predetermined level the intensity of said reflected ultrasonic waves traversing said material, said sensing detecting at said predetermined level presence of slag, of metal and of metal-slag emulsion, said intensity of said reflected ultrasonic waves traversing said material having a different value for each of slag, of metal and of metal-slag emulsion, decreasing the rate of metal pouring when sensing said intensity of said reflected ultrasonic waves at said predetermined level indicates a change from that value corresponding to presence of slag and stopping the metal pouring when sensing said intensity of said reflected ultrasonic waves at said predetermined level indicates a value corresponding to presence of metal.

19. The method of claim 18 characterized by stopping the metal pouring when sensing said intensity of the reflected ultrasonic waves at said predetermined level indicates a change from that value corresponding to presence of slag, after a short interval resuming pouring of the metal at a decreased rate and stopping the metal pouring when sensing said intensity of said reflected ultrasonic waves at said predetermined level indicates a value corresponding to presence of metal.

20. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, during pouring of the metal into the slag in the mold, sensing the electrical potential between a first electrode having its bottom end located at a predetermined level in the mold and in engagement with material present at the said predetermined level and a second electrode having its bottom end located above the bottom end of said first electrode and in contact with said material in the mold, at said predetermined level said material being at different times during metal pouring slag, metal-slag emulsion and metal, said sensing detecting at said predetermined level presence of slag, of metal, and of metal-slag emulsion, said predetermined level defining that height in the mold to which metal is poured to produce said ingot of a given weight, being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, said electrical potential having a different value for each of slag, of metal, and of metal-slag emulsion, decreasing the rate of metal

pouring when sensing said electrical potential indicates a change from that value corresponding to presence of slag, and stopping the metal pouring when sensing the electrical potential indicates a value corresponding to presence of metal.

21. The method of claim 20 characterized by stopping the metal pouring when sensing said electrical potential indicates a change from that value corresponding to presence of slag, after a short interval resuming pouring of the metal at a decreased rate and stopping the metal pouring when sensing said electrical potential indicates a value corresponding to presence of metal.

22. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, during pouring of the metal into the slag in the mold directing a beam of ultrasonic waves downwardly through material in said mold from a point to a separating surface defined at one time by an area of division between a layer of slag and a layer of metal-slag emulsion and at another time by an area of division between a layer of slag and a layer of metal to produce reflected ultrasonic waves, said material in said mold being at different times during metal pouring slag, metal-slag emulsion and metal, during pouring of the metal into the slag in the mold sensing thickness of a layer of slag between said point and said separating surface by determining a time interval for travel of ultrasonic waves from a given place to said separating surface and back to said given place, decreasing the rate of metal pouring when said time interval first corresponds to a given thickness of slag between said point and said separating surface, said given thickness of slag determining a desired height to which metal is to be poured in said mold to produce said ingot of a given weight, said height being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring and stopping said pouring of metal when said time interval becomes substantially constant and corresponds to said given thickness of slag between said point and said separating surface.

23. The method of claim 22 characterized by stopping the metal pouring when said time interval first corresponds to said given thickness of slag between said point and said separating surface, after a short interval resuming pouring of the metal at a decreased rate and stopping the metal pouring when said time interval becomes substantially constant and corresponds to said given thickness of slag between said point and said separating surface.

24. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, during pouring of the metal into the slag in the mold sensing at a predetermined level in the mold density of material therein, at said predetermined level said material being at different times during metal pouring slag, metal-slag emulsion and metal, said sensing detecting at said predetermined level presence of slag, of metal and of metal-slag emulsion, said predetermined level defining that height in the mold to which metal is poured to produce said ingot of a given weight being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, said density having a different value for each of metal, of slag, and of metal-slag emulsion, decreasing the rate of metal pouring when sensing said density of the material at the predetermined height indicates a change from that value corresponding to presence of slag and stopping the metal pouring when sensing said density of said material at said predetermined level indicates a value corresponding to presence of metal.

25. The method of claim 24 characterized by stopping the metal pouring when sensing said density of said material at said predetermined level indicates a change from that value corresponding to presence of slag, after a short interval resuming pouring of the metal at a decreased rate and stopping the metal pouring when sensing said strength of said material at said predetermined level indicates a value corresponding to presence of metal.

26. The method of claim 24 characterized by sensing at said predetermined level in the mold said density of the material therein by observing motion of a float suspended in said materail with a first part thereof extending above the top of said mold and with a second part disposed at said predetermined level, decreasing the rate of metal pouring when said first part of the float rises relative to a station disposed above the upper surface of said material thereby indicating a change in density at said predetermined level from that corresponding to slag and stopping the metal pouring when said float rises quickly relative to said station, thereby indicating at said predetermined level that density corresponding to metal.

27. The method of claim 26 characterized by stopping the metal pouring when said first part of said float rises relative to said station, thereby indicating a change in density at said predetermined level from that corresponding to slag, after a short interval resuming pouring of the metal at a decreased rate and stopping the metal pouring when said float rises quickly, thereby indicating at said predetermined level that density corresponding to metal.

28. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, during pouring of the metal into the slag in the mold, sensing at a predetermined height in the mold a value of a character of a material in the mold at said predetermined height, at said predetermined height said material being at different times during metal pouring slag and metal, said sensing detecting at said predetermined height presence of slag and of metal, said predetermined height defining that height in the mold to which metal is poured to produce said ingot of a given weight, being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, said character having a different value for each of slag and of metal, decreasing the rate of metal pouring when sensing said character of the material at the predetermined height indicates a change from that value corresponding to presence of slag and stopping the metal pouring when sensing said character of the material at the predetermined height indicates a value corresponding presence of metal.

29. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, during pouring of the metal into the slag in the mold directing a medium of energy through material in the mold at a predetermined level therein, at said predetermined level said material being at different times during metal pouring slag and metal, said predetermined level defining that height in the mold to which metal is poured to produce said ingot of a given weight, being below the top of the mold and

being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, said medium of energy being capable of traversing said material, during pouring of the metal into the slag in the mold sensing at said predetermined level a value of strength of said medium traversing said material at said predetermined level, said sensing detecting at said predetermined level presence of slag and of metal, said strength of said medium traversing said material having a different value for each of slag and of metal, decreasing the rate of metal pouring when sensing said strength of said medium at said predetermined level indicates a change from that value corresponding to presence of slag and stopping the metal pouring when sensing said strength of said medium at said predetermined level indicates a value corresponding to presence of metal.

30. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, during pouring of the metal into the slag in the mold measuring at a predetermined height in the mold the electrical conductance of material at said height, at said predetermined height said material being at different times during metal pouring slag and metal, said measuring detecting at said predetermined height presence of slag and of metal, said predetermined height defining that height in the mold to which metal is poured to produce said ingot of a given weight, being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, said electrical conductance having a different value for each of slag and of metal, decreasing the rate of metal pouring when the electrical conductance of the material begins to increase appreciably from that value which corresponds to slag and stopping the metal pouring when the electrical conductance of the material corresponds to that of metal.

31. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, during pouring of the metal into the slag in the mold directing a beam of gamma rays through material in the mold at a predetermined level in the mold, at said predetermined level said material being at different times during metal pouring slag and metal, said predetermined level defining that height in the mold to which metal is poured to produce said ingot of a given weight, being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, during pouring of metal into the slag in the mold sensing at said predetermined level the intensity of said gamma rays directed through said material, said sensing detecting at said predetermined level presence of slag and metal, said intensity of said gamma rays traversing said material having a different value for each of slag and of metal, decreasing the rate of metal pouring when the intensity of said gamma rays begins to change appreciably from that value which corresponds to slag and stopping the metal pouring when the intensity of the gamma rays indicates a value corresponding to that of metal.

32. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, one of said metal and said slag having had introduced thereinto a radioactive tracer, during pouring of the metal into the slag in the mold sensing at a predetermined level in the mold the intensity of radioactivity of said tracer in material in the mold, said material being at different times during metal pouring slag and metal, said sensing detecting at said predetermined level presence of slag and of metal, said predetermined level defining that height in the mold to which metal is poured to produce said ingot of a given weight, being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, at said predetermined level said intensity of radioactivity of said tracer having a different value for presence of each of slag and of metal, decreasing the rate of metal pouring when the intensity of radioactivity of said tracer indicates a change from that value corresponding to presence of slag and stopping the metal pouring when sensing said intensity of radioactivity of said tracer indicates a value corresponding to presence of metal.

33. A method of casting metal into a mold containing a liquid slag to produce an ingot of a given weight which comprises pouring metal into the slag in the mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, during pouring of the metal into the slag in the mold directing a beam of X-rays through material in the mold at a predetermined level in the mold, at said predetermined level said material being at different times during metal pouring slag and metal, said predetermined level defining that height in the mold to which metal is poured to produce said ingot of a given weight, being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, during pouring of metal into the slag in the mold sensing at said predetermined level the intensity of said X-rays directed through said material, said sensing detecting at said predetermined level presence of slag and of metal, said intensity of said X-rays traversing said material having a different value for each of slag and of metal, decreasing the rate of metal pouring when the intensity of said X-rays begins to change appreciably from that value which corresponds to slag and stopping the metal pouring when the intensity of the X-rays indicates a value corresponding to that of metal.

34. A method of casting metal into a plurality of molds each of which contains a liquid slag to produce a plurality of ingots each of a given weight but not necessarily the same weight, as to each ingot said method comprising pouring metal into the slag in said mold, said slag in the mold being in an amount such that some of said slag overflows from said mold during pouring said metal thereinto to produce said ingot of a given weight, during pouring of the metal into the slag in the mold measuring at a predetermined height in the mold the electrical conductance of material at said height, at said predetermined height said material being at different times during metal pouring slag, metal-slag emulsion and metal, said measuring detecting at said predetermined height presence of slag, of metal, and of metal-slag emulsion, said predetermined height defining that height in the mold to which metal is poured to produce said ingot of a given weight, being below the top of the mold and being above the upper surface of metal during metal pouring and substantially at the upper surface of metal upon completion of metal pouring, said electrical conductance having a different value for each of slag, of metal and of metal-slag emulsion, decreasing the rate of metal pouring when the electrical conductance of the

material begins to increase appreciably from that value which corresponds to slag and stopping the metal pouring when the electrical conductance of the material corresponds to that of metal.

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