United States Patent [19]

Levi et al.

[11] **3,838,727**

[45] **Oct. 1, 1974**

[54] **NORMALIZED OPTICAL INPUT LEVEL CONTROL IN CONTINUOUS CASTING PROCESS AND APPARATUS**

[76] Inventors: **Israel Levi,** 85 Woodridge Cres.; **Marek Sucharczuk,** 135 Woodridge Cres., both of Ottawa, Canada

[22] Filed: **July 16, 1973**

[21] Appl. No.: **379,796**

[52] **U.S. Cl.** .... **164/4,** 164/82, 164/154, 250/237 R, 250/222 R, 239/293

[51] **Int. Cl.** **B22d 11/10,** B22d 11/12

[58] **Field of Search** .... 164/4, 82, 154, 155; 73/293; 250/222 R, 237 R, 574

[56] **References Cited**

UNITED STATES PATENTS

2,246,907	6/1941	Webster	164/155
2,825,104	3/1958	Jones	164/4
2,832,108	4/1958	Vossberg	164/4
3,229,564	1/1966	Meltzer	250/237 R
3,521,066	7/1970	Joy et al.	250/237 R X
3,536,408	10/1970	Norwood	250/237 R X

FOREIGN PATENTS OR APPLICATIONS

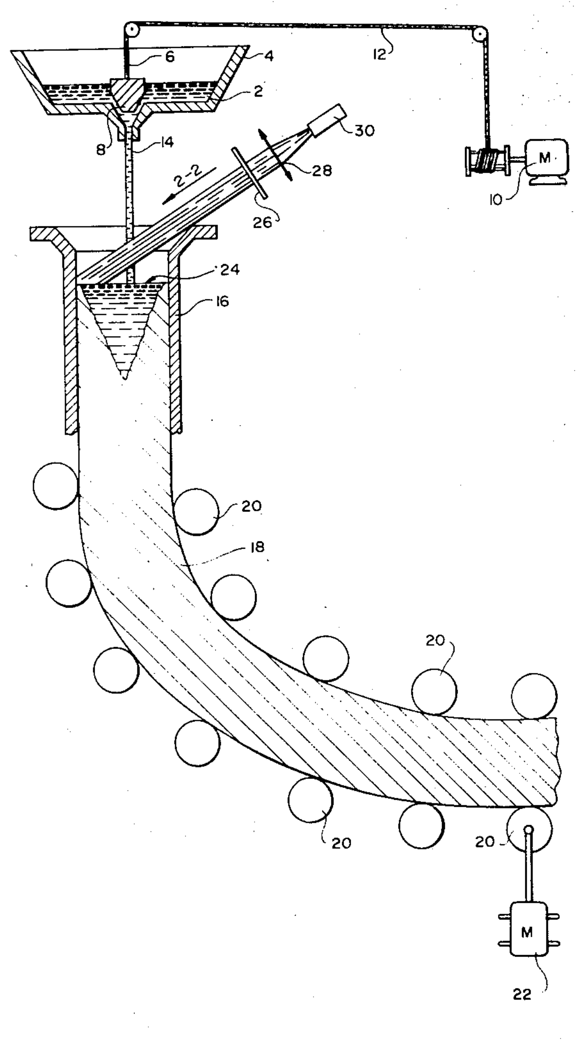
656,757	1/1965	Belgium	164/4

Primary Examiner—R. Spencer Annear

[57] **ABSTRACT**

Method and apparatus for the detection and control of the molton metal level in the mold of a continuous casting machine by means of an optoelectronic sensor are disclosed. Level variations are detected by measuring the radiant light energy emitted from the upper surface of the molten metal. An electrical signal which is proportional to the emitted energy is normalized using an electrical normalizing energy signal derived independently from a small portion of the radiating surface. The normalized signal is directly proportional to the molten metal level and is independent of molten metal temperature variations, slag accumulation and flames of burning lubricants on the surface. This signal can be used to regulate the molten metal level in the mold by operating either on the solidified bar withdrawal speed or the tundish stopper actuating mechanism which controls the flow from the tundish into the mold.

5 Claims, 13 Drawing Figures



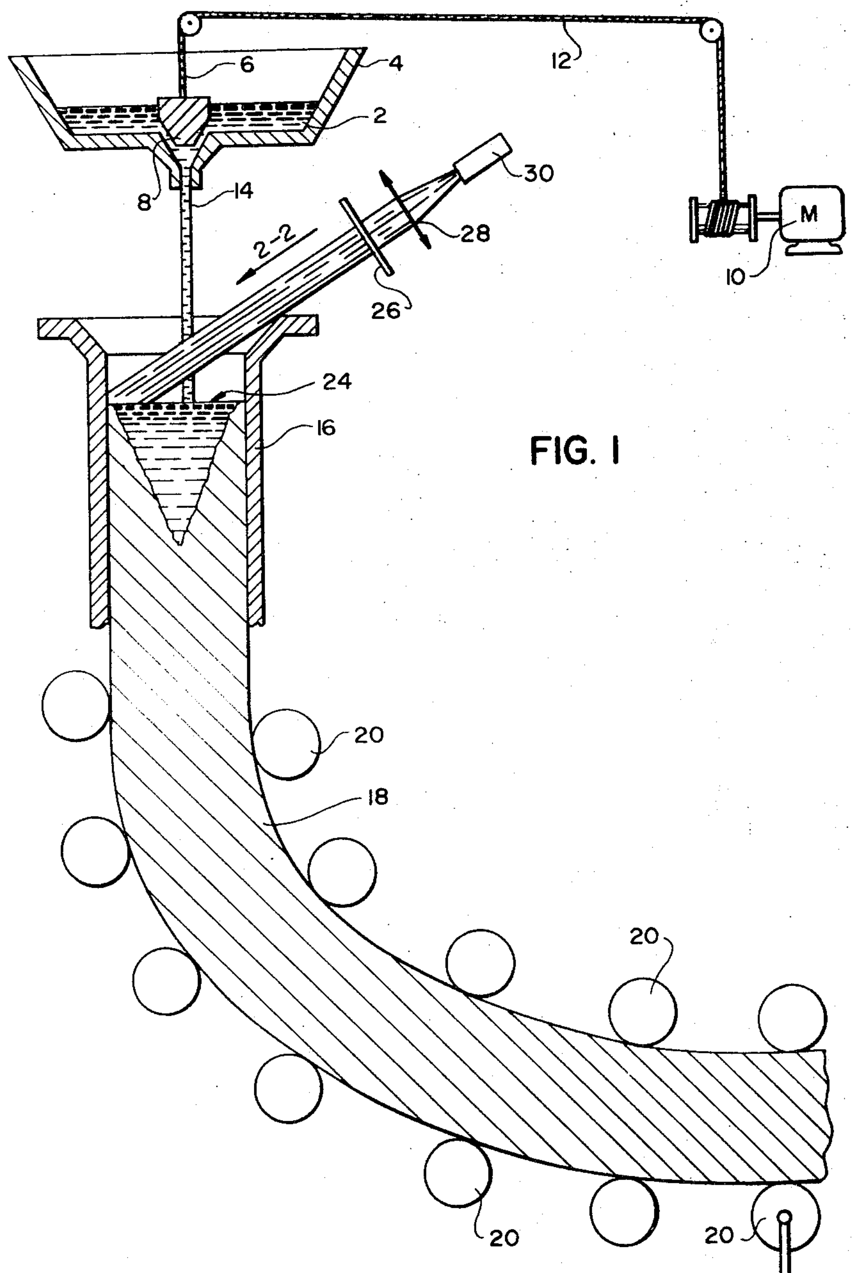


FIG. 1

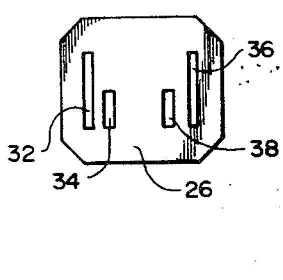


FIG. 2

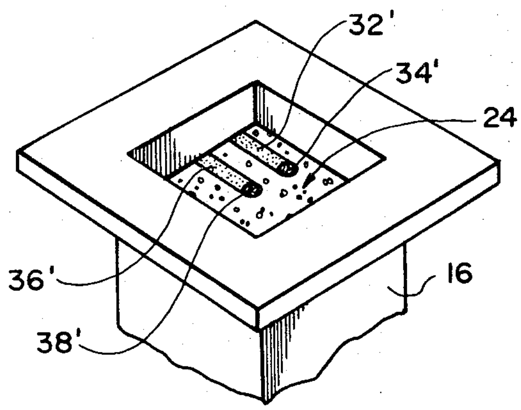


FIG. 3a

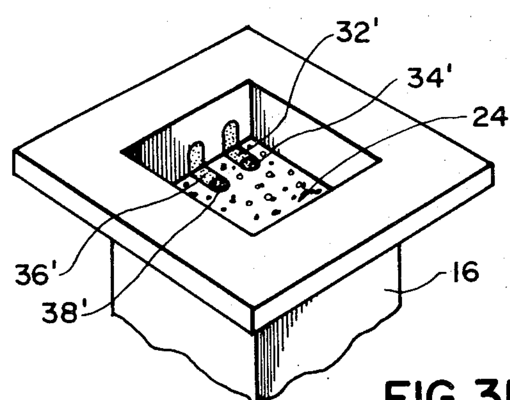


FIG. 3b

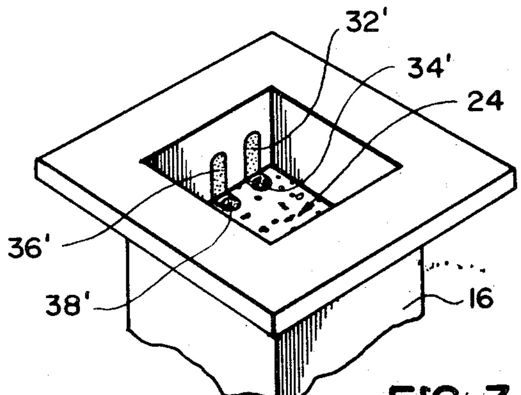


FIG. 3c

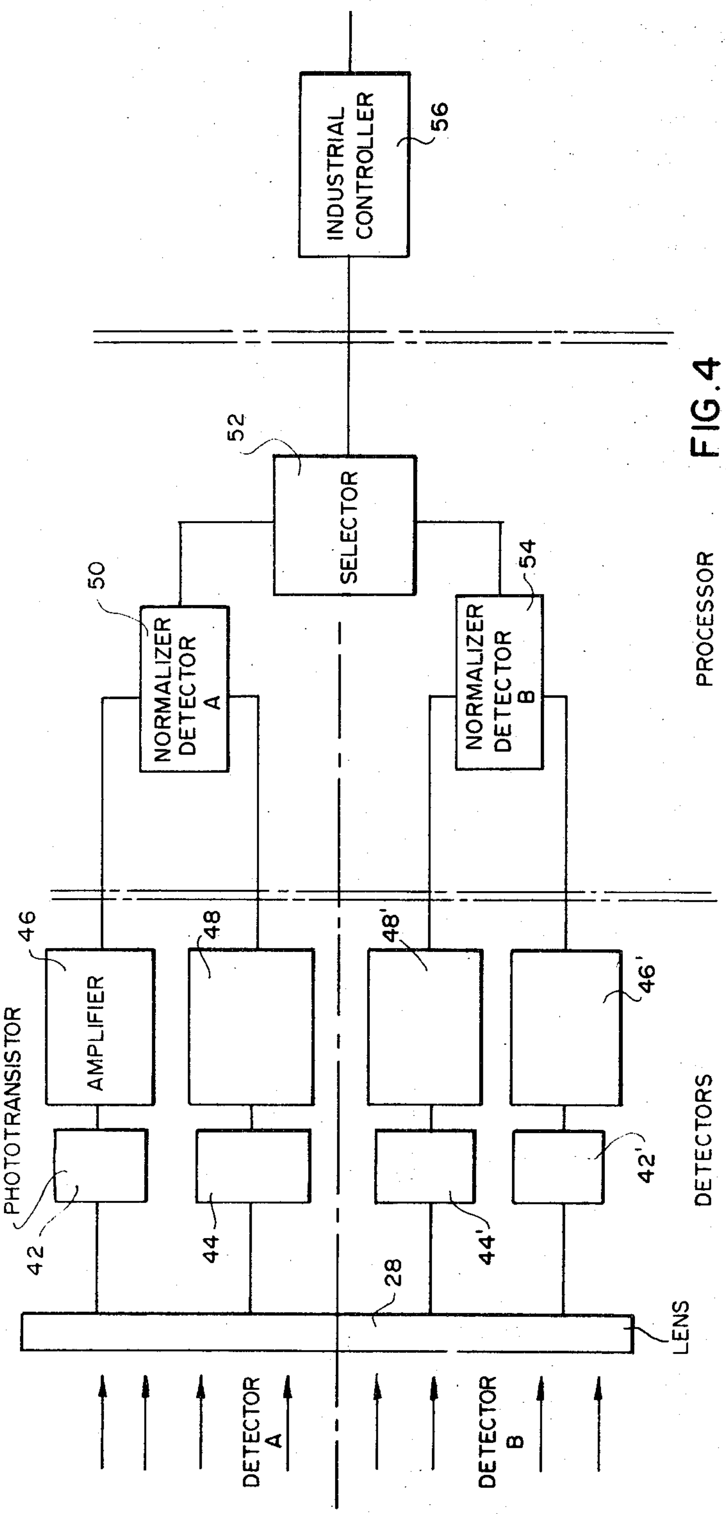

INDUSTRIAL CONTROLLER
56
52
SELECTOR
50
NORMALIZER DETECTOR A
54
NORMALIZER DETECTOR B
PROCESSOR
46
AMPLIFIER
48
48'
46'
PHOTOTRANSISTOR
42
44
44'
42'
DETECTORS
28
LENS
DETECTOR A
DETECTOR B

FIG. 4

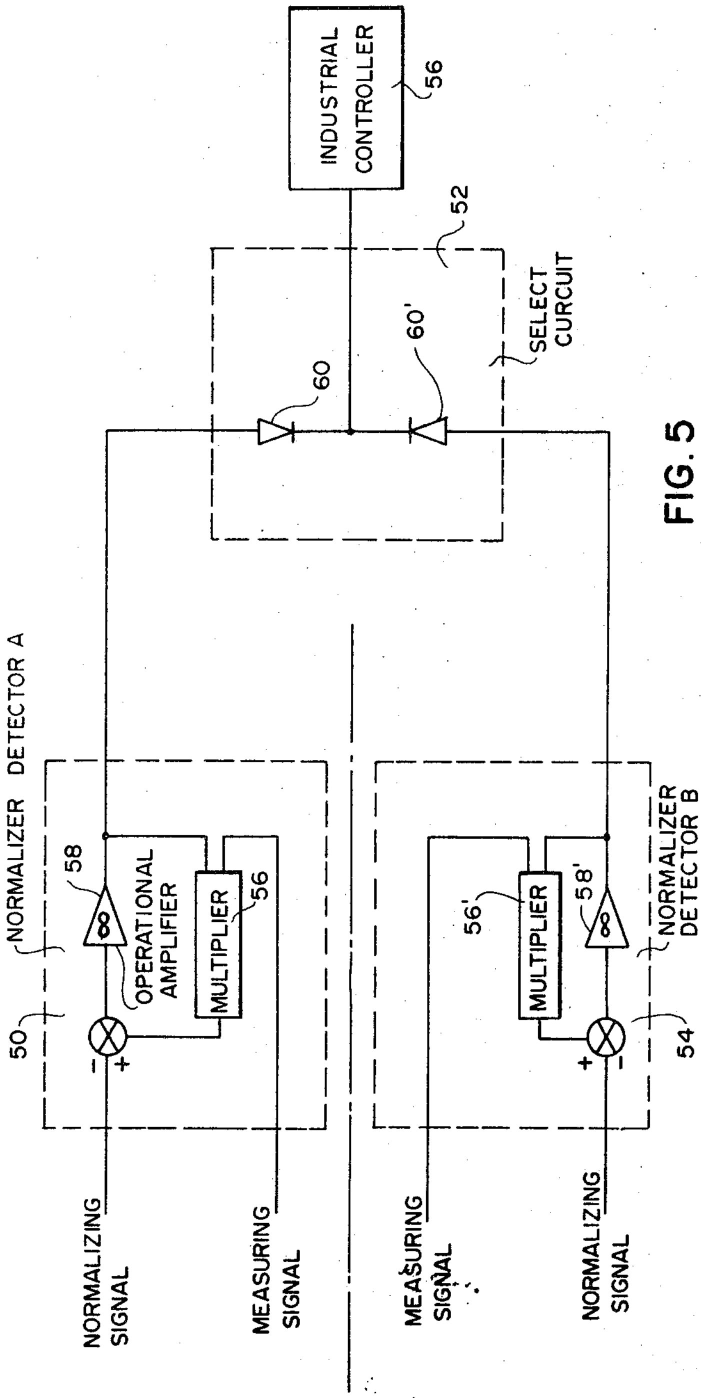

INDUSTRIAL CONTROLLER
56
52
SELECT CURCUIT
60
60'
NORMALIZER DETECTOR A
50
58
OPERATIONAL AMPLIFIER
MULTIPLIER
56
NORMALIZING SIGNAL
MEASURING SIGNAL
MEASURING SIGNAL
NORMALIZING SIGNAL
MULTIPLIER
56'
58'
NORMALIZER DETECTOR B
54

FIG. 5

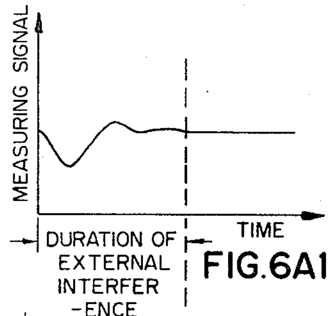


FIG.6A1

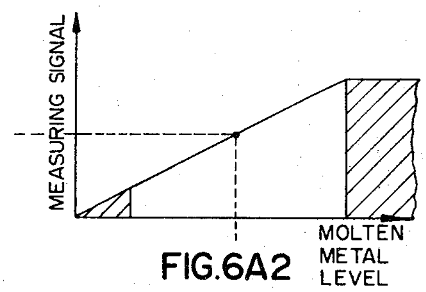


FIG.6A2

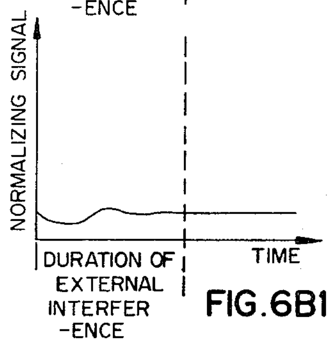


FIG.6B1

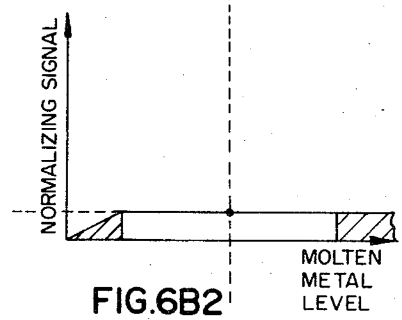


FIG.6B2

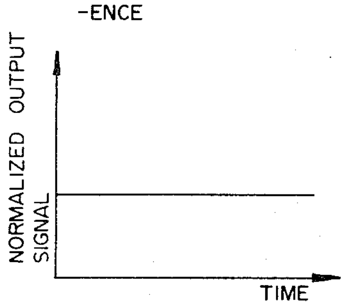


FIG.6C1

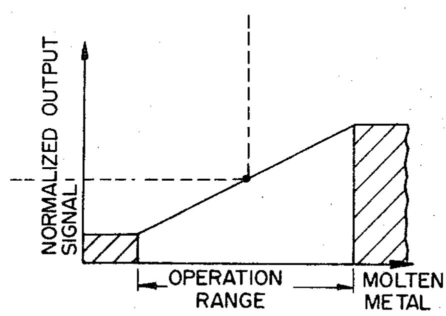


FIG.6C2

NORMALIZED OPTICAL INPUT LEVEL CONTROL IN CONTINUOUS CASTING PROCESS AND APPARATUS

The present invention relates to detection and control method and apparatus for use in a continuous casting process which involves pouring molten metal from a tundish into one end of a water cooled mold while solidified metal is continuously withdrawn from the other end of the mold in the form of a bar. During such a casting process, it is essential to maintain the level of metal substantially constant in the mold, and this can be achieved by varying the withdrawal speed of the solidified bar or by varying the flow rate of the molten steel into the mold.

DESCRIPTION OF PRIOR ART

It is a common practice to employ an operator whose duties include continuous manual adjustment of the withdrawal speed in order to keep the molten metal in the mold at a preferred level. In attempts to minimize the possibility of human error as well as dependency on skilled personnel, a number of methods have been proposed for the detection of level variations for the purpose of automatic level control. The basic difference between known methods lies in the sensing devices, i.e., the concepts employed and thus the apparatus used for detecting the level of the metal in the mold.

The output signal of the level sensing device is usually an electrical signal which is further processed and conditioned to drive an industrial controller which in turn controls the speed of a direct current motor which drives the solidified bar withdrawal mechanism or a tundish stopper actuating mechanism.

Various prior art methods which have been found practical implementation are described below:

1. Radiation pyrometers located above the mold which measure the amount of heat radiated from the top surface. Canadian Patent No. 834,370, issued Feb. 10, 1970, to A. Thalmann et al. is representative of apparatuses utilizing a heat radiation detector to detect and control the level of molten metal. The basic disadvantage of such a method is that heat radiation from other sources (not related to the level of metal in the mold) as well as temperature variations of the molten metal itself cannot successfully be compensated for.

2. Thermocouples embedded in the wall of the mold which measure the level of the metal by means of temperature gradient measurement along the mold. Canadian Patent No. 520,745 issued Jan. 17, 1956, to Ratcliffe etal discloses this concept but since the molds must be replaced periodically the disadvantage of this approach is one of prohibitive cost.

3. A radioactive source located on one side of the mold and a radiation detector on the opposite side. Canadian Patent No. 717,446 issued Sept. 7, 1965, to M.S. Boitchenko et al. is representative. The amount of radioactive radiation detected is inversely proportional to the level of the metal in the mold and although this method has found relatively wide use in the industry there is a reluctancy on the part of foundry and mill personnel to use apparatus which employs hazardous radioactive radiation and high tension voltages. Additionally, the installation and maintenance costs are high and strict control and supervision by experienced personnel is required.

4. Pierre Poncet in U.S. Pat. No. 3,459,949 issued Aug. 5, 1969, and entitled "Detection of the Level of the Metal Bath in the Molds for Continuous Casting" discloses the use of at least one detecting photoelectric cell to provide molten metal level control with the cell detecting degree of light radiation. In other embodiments U.S. Pat. No. 3,459,949 discloses the use of pairs of detecting cells with the responses of these detecting cells being additive. While U.S. Pat. No. 3,459,949 makes a valuable contribution to the art the inherent problem of such apparatus is that each detecting cell views a different portion of the surface of the molten metal in the mold and while this arrangement is satisfactory when the depth of slag on the surface is constant, the formation of slag in one viewed area to a depth greater than in another viewed area (with resultant light loss due to slag cover) will result in distorted "additive" readings in the pair of cells. While it is the responsibility of employees in the mill to maintain slag formation at a minimum the possibility of one viewed surface area having a greater depth of slag formation is very difficult indeed to avoid. Of course, with the apparatus of U.S. Pat. No. 3,459,949, the accumulation of slag (even if to a constant depth over all viewing areas) will reduce the degree of radiation from the metal and the detecting cells will indicate a lower level than is actually present. Thus, the accuracy of the apparatus in U.S. Pat. No. 3,459,949 is dependent upon slag accumulation depth in the particular viewed areas with varying depths resulting in inconsistent and erroneous level readings. The basic differences between U.S. Pat. No. 3,459,949 and the present invention is in the method (and apparatus) of obtaining a signal which is proportional to the level of the molten metal in the mold. The patentee employs an objective lens for obtaining an optical image of the complete surface of the metal and then a photosensitive device (photocell) is placed in the plane of the image. Since the active area of the photocell is small compared to the size of the image it is effected only by a very small portion of the light creating the image. The response of the photocell resembles an ON-OFF type system since small variations in liquid level will change the illumination of the cell from very weak to very intense.

Unlike U.S. Pat. No. 3,459,949 the present method (and apparatus) provides a continuous signal which increases proportionally with the level of metal in the mold with the signal being achieved by collecting light from a selected area on the surface of the molten metal. A cylindrical condenser lens and a photosensitive device (phototransistor) located at the focal point of the lens are used. No image formation of any kind is used but rather the total amount of light from the selected area is collected by the phototransistor.

Various embodiments of U.S. Pat. No. 3,459,949 employ auxiliary reference cells in order to account for temperature variations in the molten metal with photocells detecting the temperature of the molten metal stream entering the mold. However, the temperature of the metal stream is not necessarily related to the temperature of the particular surface area under observation due to variable amounts of surface slag, etc. In the present invention, a normalizing signal derived from a surface area within a larger surface area viewed by the measuring channel is used with the normalizing signal automatically compensating for variations in the temperature of the molten metal and/or presence of slag to provide a clean level dependent signal.

DESCRIPTION AND OBJECTS OF INVENTION

The present invention overcomes the inherent disadvantages of the various methods described above. The level detector is positioned a distance from and obliquely above the mold and hence does not effect normal mold maintenance routine, and the principle of operation is such that the output signal which is proportional to the metal level in the mold, is independent of steel temperature variations, radiation of the inflowing molten metal stream and other external radiationg sources, slag accumulation and flames due to burning lubricants on the surface. No radioactive sources or high tension voltages are used.

In the present invention by providing at least one detector consisting of a pair of light viewing channels, one being a light measuring channel (first path of light) and the other a light normalizing channel (second path of light) and by positioning the viewing channels in overlapping relationship with the normalizing channel viewing a defined second area within a larger first area viewed by the measuring channel, it is possible to obtain a precise level measurement by normalizing the light radiations received by both channels to provide an electric control signal for regulating the level of the molten metal in the mold which is completely independent of the intensity of light rays being emitted by the molten metal. While one detector will provide a satisfactory signal of metal level, it is preferred to use two detectors with each detector viewing a surface area on each side of the inflowing molten metal stream to enable normal foundry and mill procedures without interference to the level signals.

In the present apparatus and method the signal from a first path of light and the signal from a second path of light are normalized to provide a normalized electrical signal, which signal is proportional solely to the level of the metal in the mold and is not influenced by the degree or brightness of radiated light, nor the accumulation of slag on the surface of the liquid in the mold (which will result in lessening radiation brightness) nor upon the temperature of the molten metal in the mold or other factors influencing temperature, nor upon flames on the surface of the mold.

It is the object of the present invention then to provide method and apparatus for determining accurately and rapidly the level of molten metal in a mold.

It is another object of the invention to provide apparatus for determining molten metal level in a mold with the apparatus being sufficiently rugged to meet and withstand severe high temperature conditions in a foundry or mill.

It is another object of the invention to provide an automatic level control system whwch is reliable and simple in operation.

It is another object of the invention to provide two detectors in one system for the purpose of allowing an operator a slag removal function other other normal mill operations without effecting the normal operation of the control system.

It is an additional object of the present invention to provide a method of determining and controlling the level of molten metal in a mold in a continuous metal casting apparatus which includes means for adjusting the volume of molten metal being poured into the mold and means for adjusting the means of withdrawal of a solidified metal bar from the mold, the method comprising detecting light radiated from a first area (measuring) on the surface of molten metal in the mold, and detecting light radiated from a second area (normalizing) within the first area, and normalizing the light received from the first and second areas and passing the resultant normalized electrical signal to controller means to maintain desired metal level.

It is a further and preferred object of the present invention to provide a method of determining and controlling the level of molten metal in a mold in a continuous metal casting apparatus which includes means for adjusting the volume of molten metal poured into the mold and means for adjusting speed of withdrawal of a solidified metal bar from the mold, and comprising detecting light radiated from first and second areas on the surface of metal in the mold to provide first (measuring) and second (normalizing) light paths respectively to a first detector, and detecting light radiated from first and second areas from a different area than received by the first detector on the surface of the metal in the mold to provide first (measuring) and second (normalizing) light paths respectively to a second detector, and normalizing light intensity of the first and second light paths in each detector to provide first and second normalized electrical signals respectively, and selecting the greater of the normalized signals and utilizing the selected signal as a level of metal in the mold to control volume of molten metal supplied to the mold and/or withdrawal of metal bars from the mold.

It is still a further object of the present invention to provide apparatus for determining and controlling the level of molten metal in a mold in a continuous metal casting apparatus which includes means for adjusting the volume of molten metal added to the mold and means for adjusting speed of withdrawal of a solidified metal bar from the mold, and consisting of a condenser lens positioned obliquely above the vertical axis of the mold and an apertured screen positioned between the lens and the surface of metal in the mold, the screen having a first aperture for the passage therethrough of a first path of light (measuring) and a second aperture for the passage therethrough of a second path of light (normalizing) and a detector receiving the first and second paths of radiated light passing through the lens, and a normalizer for normalizing the intensities of the first and second paths of light to provide an electrical signal indicative of molten metal level in the mold, and controller means responsive to the electrical signal to maintain the desired metal level.

It is still a further object of the present invention to provide apparatus as described wherein the apertured screen is provided with two pairs of first and second apertures to provide a pair of first and second paths of radiated light (measuring and normalizing), and the detectors and a normalizer for each pair of paths of light to provide first and second normalized electrical signals, respectively, and selector means to select the greater of the normalized electrical signals, and controller means receiving the selected normalized electrical signals to control volume of molten metal supplied to the mold and/or withdrawal of metal bars from the mold.

These and other objects of the invention are achieved by measuring the amount of radiated light energy from the molten metal surface which enters the viewing window of a detector. A suitable form of device for measuring the amount of incident light in a light sensitive transistor (phototransistor) placed at the facal point of a cylindrical condenser lens with both transistor and lens being positioned such that their sensing axes are disposed above and obliquely with respect to the vertical axis of the mold. The phototransistor provides an electrical output signal which is directly proportional to the detected light intensity.

DESCRIPTION OF DRAWINGS

The invention will now be more fully described with reference to the accompanying drawings (not drawn to scale) wherein:

FIG. **1** is a diagrammatic perspective view of apparatus suitable for continuous metal casting illustrating a portion of the inventive level control apparatus;

FIG. **2** is an enlarged front view of a viewing window or apertued screen which defines the respective viewing areas of the detectors;

FIGS. **3A, 3B,** and **3C** are enlarged perspective views of the top of the level of the molten metal in the mold taken generally along arrow **2—2** of FIG. **1.** FIG. **3A** shows the viewed area when the level is high; FIG. **3B** when the level is normal; and FIG. **3C** when the level in the mold is low;

FIG. **4** is a schematic block diagram of the level detector components and circuitry according to the present invention;

FIG. **5** is a schematic block diagram of the processor portion of the detector circuitry shown in FIG. **4** in more detail; and

FIGS. **6A1, 6A2, 6B2, 6C1** and **6C2** are a series of graphs illustrating measuring signal, normalizing signal and normalized output signal versus time and molten metal level.

With reference now to the attached drawings, and particularly FIG. **1,** molten metal **2** is poured from a tundish **4** by actuating stopper rod **6** which controls stopper valve **8.** The opening and closing and controlling of stopper valve **8** is actuated by any suitable means such as by an electric motor **10** through cable **12.** When the valve **8** is open molten metal in the form of a stream **14** fills the mold **16** and solidifies around the walls of the mold which are water cooled (not shown). A fully solidified metal bar **18** is continuously withdrawn from the mold by means of support and withdrawn rolls **20** at least some of which are positively driven in rotation by motor **22.**

The level **24** of the molten metal in the mold can be controlled either by regulating the volume of stream **14** (by stopper **8** and motor **10**) or by regulating withdrawal speed of the solidified bar (by driven rollers **20** and motor **22**) or by a selective combination of both.

According to the present invention level control is achieved by at least one detector assembly shown at **30** in FIG. **1,** with each detector consisting of a measuring channel viewing a first path of radiated light from a selected first area on the surface of the molten metal in the mold, and a normalizing channel which views a second path of light from a smaller selected second area within the first area viewed by the measuring channel; the signals from the two detectors are then normalized to provide a correct level reading signal which is fed to an industrial controller to regulate the stopper plug and/or withdrawal motor to maintain proper surface level.

The inventive detection and control apparatus is shown in FIG. **1** as consisting of apertured screen **26,** condenser lens **28** and phototransistor detector device **30,** with the aperture screen being shown in enlarged front view in FIG. **2.** The screen **26** shown in FIG. **2** provides for the viewing of two separate detectors (A & B in FIGS. **4** and **5**). Aperture or slot **32** permits the passage of light to one measuring channel (first path of light) and aperture or slot **34** permits the passage therethrough of light to one normalizing channel (second path of light) of one detector (A), while apertures **36** and **38** provide light for the measuring and normalizing channels respectively of a second detector (B).

Light emitted from the molten surface **24** passes through the apertures in screen **26** to activate detectors A and B in a manner which will be described in more detail below.

Each level detector consists of a pair of separate light detecting channels (first and second paths of light) situated side by side; with each detector detecting light only from a narrow strip on the surface on one side of the inflowing metal stream. Both channels are generally similar in construction with the only difference being that the measuring channel has a much larger and longer viewing window. The viewing window of the normalizing channel is arranged such that its viewing area is always fully illuminated by parallel light rays emitted from the surface of the metal regardless of the level of the metal. On the other hand, the viewing window of the measuring channel is arranged such that its viewing area which is illuminated by the parallel light rays emitted from the surface of the metal is unique to a distinct level in the mold.

This will be appreciated from a review of FIG. **3** wherein the measuring channel or one detector A views an area represented by shaded area **32′** on the surface **24** of metal in the mold **16** whereas the normalizing channel views an area represented by more heavily shaded area **34′** which is smaller than and within area **32′**. FIG. 3B represents the areas viewed when the level is considered normal, FIG. 3A when the metal level is high, and FIG. 3C when the level is low. The areas viewed by the second detector B are shown at **36′** and **38′**.

In FIG. **3**, the inflowing molten metal stream **14** has been omitted for clarity. Also while two detector viewing areas are shown it is possible that one detector only could be employed.

FIG. **4** illustrates in block diagram form a level control assembly consisting of two detectors A and B. Light passing through lens **40** is received by measuring channel phototransistor **42** and normalizing channel phototransistor **44** of detector A, the signals are amplified by amplifiers **46** and **48** respectively, and passed to detector A normalizer **50.** The normalized signal from normalizer detector A then passes to selector **52** where it is processed against the signal from normalizer **54** in detector B, and the resultant signal then passes to industrial controller **56** for level control purposes. The circuitry in detector B is identical with that of detector A, and the reference numbers in detector B have simply been primed for easy reference.

FIG. **5** is a more detailed view of the processor unit shown in FIG. **4** and the interconnection between normalizer detectors A (**50**) and B (**54**) and the selector circuit **52**. Each normalizer or processor **50, 54** consists of a four quadrant analog multiplier **56, 56'** connected in the feedback path of an operational amplifier **58, 58'** which provides the arithmetic divide function. The signal at the output of the amplifiers **58, 58'** is the ratio of the two input signals (normalizing and measuring). The selector circuit **52** consists of two diodes **60** and **60'** connected back to back, and the output signal from the selector circuit **52** will follow the largest of the two input signals to control the industrial controller **56** accordingly. The processor automatically selects the signal of the detector which operates without interference.

FIG. **6** is a series of graphs depicting the measuring signal (FIG. **6A2**); the normalizing signal (FIG. **6B2**) and the normalized output signals (FIG. **6C2**) versus the level of molten metal. Graphs **6A1, 6B1** and **6C1** illustrate the measuring signal, the normalizing signal, and the normalized output signals, respectively, versus time in the presence of external interference. It will be noted that the normalized output signal is not effected by the interference.

The electrical signals from the phototransistors **42, 42'** of the normalizing channel as well as the signals from the phototransistors **44, 44'** of the measuring channel are both effected in the same manner by disturbances such as light intensity fluctuations due to slag or fumes above the molten metal surface. Therefore, by electronically normalizing the signal from the measuring channels (**44, 44'**) using the signals of the normalizing channels (**42, 42'**) it is possible to obtain a normalized electrical signal which is proportional solely to the level of the molten metal in the mold but is independent of the disturbing effects mentioned above. The normalization process takes place in a processor unit (**50, 52, 54**) which is an integral part of the apparatus. In order to give the operator freedom for slag removal without disturbing the two separate and spaced apart detectors A and B are preferably employed. During the slag removal function it is conceivable that the operator's hand or the slag removing rod may interfere with the viewing field of one of the detectors. Under normal working conditions it is impossible for the operator to block the viewing fields of two detectors simultaneously and accordingly, two detectors are preferably employed in one system.

While the foregoing disclosure relates to level control in the mold itself it will be appreciated that the apparatus is equally applicable to controlling the level of molten metal in the tundish, and has equal application in billet casting processes. Also, the apparatus can be used to determine and/or control the level of any material which radiates light apart from molten metal itself.

I claim:

1. Method of determining and controlling the level of molten metal in a mold in a continuous metal casting apparatus which includes means for adjusting the volume of molten metal poured into the mold and means for adjusting the speed of withdrawal of a solidified metal bar from the mold, comprising detecting light radiated from a first area on the surface of molten metal in the mold, and detecting light radiated from a second area within the first area, and normalizing the radiated light received from said first and second areas and passing the resultant normalized electrical signal to controller means to maintain desired metal level.

2. Method according to claim **1**, comprising detecting light radiation from first and second areas on the surface of metal in the mold to provide first and second light paths respectively to a first detector and detecting radiated light from first and second areas from a different area on the surface of the metal in the mold to provide first and second light paths respectively to a second detector, and normalizing light intensity of the first and second light paths in each detector to provide first and second normalized electrical signals respectively, and selecting the greater of the normalized signals and utilizing the selected signal as a level of metal in the mold to control at least one of volume of molten metal supplied to the mold withdrawal of metal bar from the mold.

3. Apparatus for determining and controlling the level of molten metal in a mold in a continuous metal casting apparatus which includes means for adjusting the volume of molten metal added to the mold and means for adjusting speed of withdrawal of a solidified metal bar from the mold, consisting of a condenser lens positioned obliquely above the vertical axis of the mold and an apertured screen positioned between the lens and the surface of metal in the mold, the screen having a first aperture for the passage therethrough of a first path of light and a second aperture for the passage therethrough of a second path of light, and a detector receiving the first and second paths of radiated light passing through the lens, and a normalizer for normalizing the intensities of the first and second paths of light to provide an electrical signal indicative of molten metal level in the mold, and controller means responsive to the electrical signal to maintain desired metal level.

4. Apparatus according to claim **3** wherein the apertured screen is provided with two pairs of first and second apertures to provide a pair of first and second paths of radiated light, and detectors and a normalizer for each pair of paths of light to provide first and second normalized electrical signals respectively, and selector means to select the greater of the normalized electrical signals, and controller means receiving the selected normalized electrical signal to control at least one of volume of molten metal supplied to the mold withdrawal of metal bar from the mold.

5. Apparatus according to claim **4**, each detector consisting of a phototransistor and amplifier for each of the first and second paths of light; the normalizer including a four quadrant analog multiplier and an operational amplifier.

* * * * *