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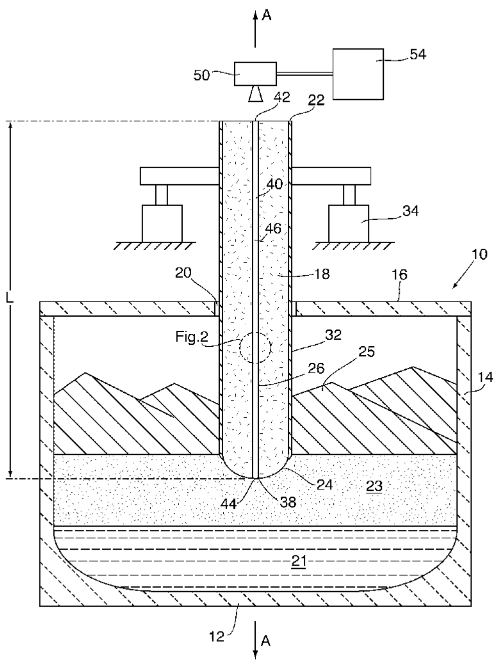
(54) Title: METHOD AND APPARATUS FOR MEASURING THE LENGTH OF AN ELECTRODE IN AN ELECTRIC ARC FURNACE

Fig. 1



(57) Abstract: A method for determining a length parameter of an electrode during operation of an electric arc furnace. An internal duct extends through the length of the electrode and is open at its lower end. A waveguide having a solid core is received in the internal duct and comprises a material having a low dielectric constant and high temperature resistance. The solid core of the waveguide includes at least one target. An electromagnetic radiation signal is emitted from a source and transmitted through the waveguide and the signal is diffracted and/or reflected from at least one target to produce at least one return signal which is transmitted back through the waveguide. A time or frequency difference between the emitted signal and the return signal is measured and the length parameter is calculated based on this difference.

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METHOD AND APPARATUS FOR MEASURING THE LENGTH OF AN ELECTRODE IN AN ELECTRIC ARC FURNACE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to and the benefit of United States Provisional Patent Application No. 62/162,158 filed May 15, 2015, the contents of which are incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The invention generally relates to the operation of electric arc furnaces, and particularly to a method and apparatus for determining the electrode tip position by measuring the length of a consumable electrode during the operation of an electric arc furnace.

BACKGROUND OF THE INVENTION

[0003] A typical electric arc furnace for a melting or smelting operation comprises a refractory-lined enclosure in which feed material is melted by one or more cylindrical electrodes that pass through ports in the furnace roof. Electric power, often as arcs, is emitted from the lower ends of the electrodes to melt the charge materials and maintain a bath of molten material within the furnace. The electrode tips are gradually and continuously consumed during furnace operation. To compensate for electrode consumption, the electrodes are fed downwardly into the furnace, while new sections are added to the tops of the electrodes.

[0004] The position of the electrode tip in relation to various furnace contents, such as slag and metal bath levels, as well as the position in relation to various fixed components such as the taphole and hearth, is a critical parameter for operational control of the furnace. The position of the tip in relation to these various components has a direct and appreciable effect on furnace efficiency, ability of the furnace to operate at the desired power input as well as the metallurgical reactions therein. Thus electrode tip position and control are critical to produce a low cost, high quality product. Currently the operators of electric arc furnaces are unable to determine the position of the electrode tip as the tip is often submerged beneath material "charge banks" and, on occasion, submerged in the liquid slag layer and therefore not visible. The operator is however able to determine the position of fixed mechanical support components in the upper electrode column. If the distance from the electrode tip to a known reference point on the upper electrode could be determined accurately, this length in conjunction with the distance between the known position of the reference point and the fixed components could be used to determine the exact position of the electrode tip relative to the fixed components.

[0005] In addition the location of the slag/metal interface or the slag/burden interface is not known which, if known, could be used to determine the level and inventory of molten material in the furnace. By knowing the position of the electrode tip, operators can use a procedure known as a "sounding test" to determine the thickness of the slag layer and the matte or metal layer. "Sounding tests" are performed by monitoring the changes in electrical resistance of a probe as it moves through various molten layers within the furnace and is common practice. Knowing the thickness of the molten components in the furnace greatly assists the operators to optimize furnace operation, reduce cost and increase the campaign life of the furnace. "Sounding tests" are commonly conducted with a dedicated apparatus, typically comprising a robust steel rod, which must be forced through the solid charge material and into the slag layer. Besides resulting in additional cost, these sounding rods are subject to bending and breakage by the solid burden covering the slag layer. If the electrode length was known the electrode itself could be used as a sounding rod to determine the interface locations.

[0006] According to common practice, electrode length is empirically determined by each site and calibrated on a regular basis by emptying or "burning down" the furnace "charge banks" to expose the electrode tips, if possible, for either physical measurement or a visual estimation. This practice not only influences throughput as it requires the furnace load to be reduced but places the electrodes under unnecessary mechanical and thermal stress as well as exposing mechanical components in the furnace to extremely high heat loads due to exposed molten material. "Burning down" the furnace "charge banks" seldom exposes the full tips of the electrodes due to the limited mechanical stroke on each electrode and the depth of the furnace. As a result, even after taking these steps, the final length is generally a subjective visual estimate by the operator. Alternatively, physically measuring the length of the electrode requires the operator to insert a metal measuring bar into the furnace which not only takes time but involves several high safety risk steps to be performed, including furnace electrical isolation. This method also suffers from a high potential for errors and poor repeatability.

[0007] The inventors are aware of three commercially available and patented electrode length estimation systems. Each system uses secondary mechanical or electrical information to estimate the electrode length. Two of the commercially available systems (ELKEM ELMO and TENOVA Pyromet EBDS) rely on the measurement of the weight of the entire electrode column either through load cells or through hydraulic pressures in cylinders. The original patent (US 3,379,818) for the weighing of the electrode column issued in 1968 to Lectromelt Corporation. ELKEM subsequently applied for two related patents (WO 2000001996 and US 6330270B1) related to this approach. TENOVA Pyromet describes a similar system based on oil pressure measurement in a 2006 publication (US 2006/0050757). Both approaches suffer from at least one major technical limitation. The key assumption behind these techniques is that the electrode and electrode column are fully supported by the mechanical components in the upper columns and thus the force measured either by load cells or oil pressure is the full weight of the electrode and column only. It will be appreciated that as a substantial portion of the electrode is submerged in a dense liquid bath and/or unmelted burden dynamic and unknown buoyancy forces play a significant role in supporting the electrode and electrode column. Additionally the ability to install load cells in existing equipment is extremely challenging. The MINTEK system (WO 2006/089315) utilises an algorithm based on calculated electrical parameters in conjunction with electrode slip measurements to estimate the electrode length and thus tip position. The MINTEK patent application outlines the use of the electrode reactances to calculate the electrode lengths. MINTEK, in their patent application, claim an accuracy of 200 – 300 mm. For the MINTEK algorithm to work the reactance in each electrode is assumed to be equal. The reactance of each electrode and circuit is largely dependent on the length of the electrical path which due to varying electrode length and furnace conditions are seldom equal.

[0008] Some systems have been proposed in which electrode length is measured with consumable waveguides, made of a gas-filled conductive tube, extending throughout the length of each electrode. In these systems, a pulse of electromagnetic radiation, often radar, is transmitted from the top to the bottom of the waveguide, and is diffracted and reflected back, due to the change in medium at the end of the waveguide, to a receiver located at the top of the electrode, to provide an estimation of electrode length. In theory, the pulse of electromagnetic radiation will be diffracted and reflected back from the tip of the electrode, on the assumption that the both the electrode and the waveguide will be consumed at the same location. Examples of such systems are disclosed in US Patent No. 4,843,234 (Berthold et al.), US 2013/0127653 A1 (Dienenthal et al.) and WO 2014/002192 A1 (Hamada et al.). The inventors believe that these systems are complex; requiring gas pressurized systems, and suffer from several technical limitations. The limitations are primarily the structural integrity of the gas-filled tube at high temperatures in a dynamic environment, as well as the likelihood that debris within the tube will result in early diffraction of the signal and overall signal loss.

[0009] Additional systems (US 4,843,234) have been proposed in which an optical fibre is continuously inserted into the electrode and an optical time-domain reflectometer is used to determine the distance between the source and the melted tip of the fibre by emitting infrared or visible light down the fibre. The inventors are not aware of any known commercially available optical fibre, even a protected one, which can withstand sufficient temperature to survive operationally until in close proximity to the electrode tip.

[0010] The inventors are thus aware of no accurate and cost-effective means of determining the electrode length and thus electrode tip position for a submerged electric arc furnace. There remains a need for an accurate and cost effective means of measuring the electrode length and thus determining the electrode tip position in an electric arc furnace.

SUMMARY OF THE INVENTION

[0011] In one aspect, there is provided a method for determining a length parameter of an electrode during operation of an electric arc furnace containing a bath. The method comprises: (a) providing the electrode, wherein the electrode has an upper end situated outside the furnace, a lower end situated inside the furnace, a length defined from the upper end to the lower end, and an internal duct extending along the length of the electrode, wherein the internal duct is open at the lower end of the electrode; (b) providing a waveguide having a first end, a second end and a solid core, wherein the waveguide is at least partly received in the internal duct of the electrode with its second end located at or proximate to the lower end of the electrode, wherein the solid core of the waveguide comprises a material having a low dielectric constant and high temperature resistance, and wherein the solid core of the waveguide includes at least one target; (c) emitting an electromagnetic radiation signal, from a source and transmitting the emitted signal through the solid core from the first end toward the second end of the waveguide; (d) diffracting and/or reflecting the emitted signal from the at least one target to produce at least one return signal and transmitting the at least one return signal through the solid core from the at least one target toward the first end of the waveguide; (e) receiving the at least one return signal from the solid core at the first end of the waveguide; (f) measuring a time or frequency difference between the emitted signal and the at least one return signal; and (g) calculating the length parameter based on this difference.

[0012] In an embodiment, the bath contains one or more molten materials selected from molten metal, molten matte, and molten slag. In an embodiment, the lower end of the electrode is in contact with the one or more molten materials in the bath.

[0013] In an embodiment, the lower end of the electrode has a tip, and the internal duct is open at the tip of the electrode. In an embodiment, the internal duct extends throughout the length of the electrode from the upper end to the lower end, and is open at the upper end of the electrode. In an embodiment, the waveguide extends throughout the length of the electrode from the upper end to the lower end. In an embodiment, the waveguide has an outer surface which is in contact with an inner wall of the internal duct.

[0014] In an embodiment, the electrode is a prebaked carbon electrode comprised of a plurality of segments joined together end-to-end. In an embodiment, the electrode is a Soderberg electrode formed by baking a carbon paste within an outer metal casing.

[0015] In an embodiment, the length parameter is selected from one or more of: the length of the electrode from its upper end to its lower end; the length of a portion of the electrode; and the position of the lower end of the electrode relative to a fixed point on the furnace. In an embodiment, the solid core comprises a plurality of segments joined together end-to-end; and the length parameter comprises the number of segments in the solid core.

[0016] In an embodiment, the at least one target comprises a tip of the solid core which is directly exposed to the molten bath at the lower end of the electrode. In an embodiment, the at least one target comprises one or more discontinuities located along a length of the solid core. In an embodiment, each of the one or more discontinuities comprises a notch or a joint.

[0017] In an embodiment, the solid core comprises a rigid, elongate bar or rod. In an embodiment, the material comprising the solid core is a ceramic. In an embodiment, the material comprising the solid core has a dielectric constant greater than the dielectric constant of air.

[0018] In an embodiment, the material comprising the solid core has a maximum use temperature with an upper limit at or below the temperature of the arc emitted by the electrode. In an embodiment, a lower limit of the maximum use temperature is about 300°C, or about 500°C.

[0019] In an embodiment, the emitted signal and the at least one return signal comprise electromagnetic radiation.

[0020] In another aspect, there is provided a method for determining a position of a slag/metal interface in a bath of an electric arc furnace relative to a fixed component of the furnace. The method comprises: (a) determining a length parameter of an electrode during operation of the electric arc furnace according to the method of any one of claims 1 to 21, wherein the length parameter is the length of the electrode from its upper end to its lower end; (b) with the lower end of the electrode located in the bath, raising or lowering the electrode; (c) monitoring one or more electrical parameters of the electrode as it is being raised or lowered; (d) continuing to raise or lower the electrode until the monitoring of the electrical parameters indicates that the lower end of the electrode has passed through the slag/metal interface; and (e) calculating the position of the slag/metal interface relative to the position of fixed component, based on the length of the electrode determined in step (a), the position of the slag/metal interface determined in step (d), and the known position of the fixed component.

[0021] In an embodiment, the fixed component of the furnace is the hearth.

[0022] In yet another aspect, there is provided an apparatus for measuring a length parameter of an electrode of an electric arc furnace. The electrode has an upper end situated outside the furnace, a lower end situated inside the furnace, a length defined from the upper end to the lower end, and an internal duct extending along the length of the electrode. The internal duct is open at the lower end of the electrode, and the apparatus comprises: (a) a waveguide having a first end, a second end, and a solid core, wherein the waveguide is adapted to be at least partly received in the internal duct of the electrode, wherein the solid core of the waveguide comprises a material having low dielectric strength and high temperature resistance, and wherein the solid core of the waveguide includes at least one target; (b) a wave generator adapted to emit an electromagnetic radiation signal into the solid core at the first end of the waveguide; and (c) a wave receiver adapted to receive an electromagnetic radiation signal from the solid core at the first end of the waveguide.

[0023] In an embodiment, the solid core comprises a plurality of segments joined together end-to-end. In an embodiment, the at least one target comprises a tip of the solid core or at least one discontinuity located along a length of the solid core. In an embodiment, the at least one discontinuity comprises at least one notch or at least one joint. In an embodiment, the solid core comprises a rigid, elongate bar or rod.

[0024] In an embodiment, the material comprising the solid core has a dielectric constant greater than the dielectric constant of air. In an embodiment, the material comprising the solid core has a maximum use temperature with an upper limit at or below the temperature of the arc emitted by the electrode. In an embodiment, a lower limit of the maximum use temperature is about 300°C.

[0025] In an embodiment, the signal comprises electromagnetic radiation and wherein the wave generator and the wave receiver are provided in a radar unit.

[0026] In an embodiment, the waveguide further comprises an outer layer surrounding the solid core, wherein the outer layer has an electrical resistivity which is greater than the electrical resistivity of the solid core.

[0027] In yet another aspect there is provided a waveguide for an apparatus for measuring a length parameter of an electrode of an electric arc furnace containing a bath. The waveguide comprises an elongate solid core comprising a material having low dielectric strength and high temperature resistance; wherein said high temperature resistance is defined as a maximum use temperature which has a lower limit of about 200°C below the temperature of the bath in the vicinity of the lower end of the electrode, and an upper limit at or below the temperature of the arc emitted by the electrode.

[0028] In an embodiment, the solid core comprises a plurality of segments joined together end-to-end. In an embodiment, the solid core comprises a rigid, elongate bar or rod. In an embodiment, the material comprising the solid core is a ceramic. In an embodiment, the material comprising the solid core has a dielectric constant greater than the dielectric constant of air.

[0029] In an embodiment, the waveguide further comprises an outer layer surrounding the solid core, wherein the outer layer has an electrical resistivity which is greater than the electrical resistivity of the solid core. In an embodiment, the solid core has a dielectric constant less than the dielectric constant of the surrounding outer layer. In an embodiment, the outer layer comprises a metal having a melting point of at least about 450°C.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] The invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

[0031] Figure 1 is a schematic cross-sectional view of a furnace incorporating an apparatus for measuring the length of an electrode according to an embodiment;

[0032] Figure 2 is a close-up of the circled area of Figure 1;

[0033] Figure 3 is a close-up view of the tip of the electrode of Figure 1;

[0034] Figure 4 is a schematic perspective view of a waveguide as described herein incorporated into a Soderberg electrode; and

[0035] Figure 5 is a cross-section along line 5-5' of Figure 4.

DETAILED DESCRIPTION

[0036] A method and an apparatus for determining a length parameter and thus tip position of an electrode during operation of an electric arc furnace are now described below with reference to the drawings.

[0037] Figure 1 is a simplified cross-sectional view of an electric arc furnace 10 for use in a melting or smelting operation. The furnace comprises a refractory-lined enclosure defined by a bottom wall or hearth 12, side walls 14 and a roof 16. An electrode 18 passes through a port 20 in the furnace roof 16, the electrode 18 having an upper end 22 situated outside (above) the furnace 10, a lower end 24 situated inside the furnace 10, a length L defined from the upper end 22 to the lower end 24, and an internal duct 26 extending along the length L of electrode 18. The electrode 18 has a central longitudinal axis A, which in the illustrated embodiment is a vertical axis. Although only one electrode 18 is shown in Figure 1, it will be appreciated that furnace 10 will typically include a plurality of electrodes 18.

[0038] Although not shown in Figure 1, the electrode 18 emits electricity from its lower end 24 to melt a solid charge material 25 that is then maintained as a quantity of molten material within the furnace. The contents of the furnace are referred to herein as the "bath", which will typically contain a quantity of molten metal 21 or alternatively matte, a quantity of slag 23 which may form a layer on top of the metal or matte and which will typically be molten at least in areas surrounding the electrodes, and a quantity of charge material 25 which may comprise a solid burden on top of the molten metal or matte and the slag. It will be appreciated that the composition of bath is highly variable, and that the materials making up the bath may not be separated into discrete layers as shown. Typically, the lower end 24 of electrode 18 will extend through any solid layer of charge material 25 above the bath and will contact the underlying molten material 21, 23. In most cases, the lower end 24 of electrode will be submerged in the molten slag 23 of the bath, and will typically extend about 1 to 3 metres below the upper level of the charge material 25. It is the presence of these "charge banks" 25 that severely limits the operator's ability to gauge electrode tip position. As the reaction progresses the charge banks 25 drop and are replenished, ensuring the electrode tips are always covered or hidden.

[0039] Electrode 18 shown in Figure 1 can be any type of carbon electrode for an electric arc furnace. In this specific embodiment, the electrode 18 is of the "Soderberg" type, comprising a mass of solidified "baked" carbon paste 30 surrounded by a structural metal casing 32. The furnace 10 is shown as being of the "submerged electrode" type, wherein the lower end 24 of electrode 18 is submerged in the molten slag 23. As will be discussed further below, the electrode 18 may instead be of the "prebaked" type, in which case the electrode 18 comprises a plurality of "prebaked" electrode sections in the form of solid blocks which are mechanically connected to one another.

[0040] During operation of furnace 10, the lower end 24 of electrode 18 is gradually and continuously consumed. To compensate for electrode consumption, the electrode 18 is fed downwardly into the furnace 10, while new sections are added to the top of the electrode 18, as will be further discussed below. Figure 1 schematically illustrates a lowering mechanism 34 to gradually lower the electrode 18 into the furnace 10.

[0041] The internal duct 26 extends along the length of electrode 18, and has an open lower end 36 which is located at the lower end 24 of electrode 18. Therefore, as shown in the close up view of Figure 3, the lower end 36 of duct 26 is open to, and in contact with, the contents of molten bath, typically either slag 23 or metal 21.

[0042] The electrode 18 is shown as having a tip 38 at its lower end 24, wherein the tip 38 may have become rounded or pointed, and may have a smaller diameter than other portions of the electrode 18. As shown, the tip 38 may be located along the central longitudinal axis A, although this is not necessarily the case.

[0043] In the embodiment of Figure 1 the internal duct 26 is substantially co-axial with the central longitudinal axis A, such that the lower open end of the internal duct 26 is located at the tip 38 of electrode 18. However, as explained below with reference to other embodiments, this is not necessarily the case. Rather, the internal duct 26 may be spaced from the central longitudinal axis A, such that the lower open end of the duct 26 is located somewhat above the tip 38, and/or in some embodiments the tip 28 may not be aligned with the central longitudinal axis A.

[0044] The embodiment of Figure 1 also includes a waveguide 40 having a first (upper) end 42, a second (lower) end 44 and a solid core 46. The waveguide 40 is at least partly received in the internal duct 26 of electrode 18 with its second end 44 located proximate to the lower end 24 of electrode 18. In the illustrated embodiment, the waveguide 40 extends throughout the length L of electrode 18 from the upper end 22 to the lower end 24. For example, as shown in the close-up of Figure 3, the solid core 46 has a tip 48 located at its second end 44, and the tip

48 may be located at the lower end 24 and/or tip 38 of electrode 18, and may be directly exposed to the molten slag 23 or metal 21 at the lower open end 36 of the internal duct 26.

[0045] The waveguide 40 is comprised of a solid core 46 having low dielectric constant (also known as "relative permittivity") and high temperature resistance wrapped in a conductive outer layer 62. As defined herein, the term "low dielectric constant" means that the waveguide is substantially non-conductive to electricity, while permitting transmission there through of electromagnetic radiation in the radio and/or microwave spectrum. For example, the solid core 46 may be comprised of a material having a dielectric constant (relative to air) which is greater than 1 but less than the dielectric constant of the surrounding outer layer.

[0046] The material comprising waveguide 40 also has a low loss tangent (tan δ), which is a parameter used to quantify the amount of energy lost by an electromagnetic wave propagating through the material.

[0047] In some embodiments, the material comprising the solid core 46 is a ceramic. Although the type of ceramic used for core 46 is variable, alumina-based ceramics are considered suitable according to some embodiments described herein.

[0048] As defined herein, the term "high temperature resistance" means that the material comprising the solid core 46 has a maximum use temperature such that the material located within the internal duct 26 will melt, dissolve or disintegrate by direct contact with molten slag 23 or metal 21 at the open lower end 36 of internal duct 26, while portions of the solid core 46 which are shielded from contact with molten slag 23 or metal 21 by the material of electrode 18 will remain substantially intact. A material having such a degree of high temperature resistance will result in a core 46 such as that shown in Figure 3, in which the tip 48 of core 46 will be located at the open lower end 36 of internal duct 26 which, depending upon the location of duct 26 within electrode 18, may be located at the tip 38 of electrode 18 or proximate thereto. Therefore, in the example of Figures 1 and 3, where the tip 48 of core 46 is located at the tip 38 of electrode 18, the length of core 46 will be substantially identical to the length L of electrode 18.

[0049] The inventors have found that forming the solid core 46 of waveguide 40 from a material having a maximum use temperature which is in close proximity to the temperature of slag 23 in the vicinity of the tip 38 of electrode 18 will ensure that the solid core 46 will melt, dissolve or disintegrate once it contacts the molten slag 23 at the lower end 36 of internal duct 26, but will not significantly melt, dissolve or disintegrate before this point. For example, the maximum use temperature above which the solid core 46 melts, dissolves or disintegrates will be greater than about 300°C, more typically greater than about 500°C.

[0050] Thus, the tip 48 of the solid core 46 of a waveguide 40 having a maximum use temperature as defined above will not significantly protrude beyond the lower end 36 of internal duct 26 into the molten slag 23, nor will the tip 48 be located a significant distance above the lower end 24 or tip 38 of electrode 18. This will ensure that the length of the solid core 46 of waveguide 40 is substantially the same as the length of the electrode 18, within an acceptable and constant margin of error.

[0051] Also shown in Figure 1 is a device 50 for emitting and receiving an electromagnetic radiation signal. Device 50 incorporates a wave generator adapted to emit an electromagnetic radiation signal (referred to herein as the "emitted signal") into the solid core 46 at the first end 42 of waveguide 40. Device 50 also incorporates a wave receiver adapted to receive an electromagnetic radiation signal (referred to herein as the "return signal") from the solid core 46 at the first end 42 of waveguide 40. The return signal is produced by reflection and/or diffraction of the emitted signal within the solid core 46 of waveguide 40, as will be further explained below. Therefore, the radiation device 50 is positioned above the first end 42 of waveguide 40, and may be connected thereto. According to some embodiments described herein, the electromagnetic radiation signal may comprise electromagnetic radiation within the radio or microwave spectrum, and the radiation device 50 comprises a radar unit.

[0052] The radiation device 50 includes a radiation source which emits the electromagnetic radiation signal into the first end 42 of waveguide 40, and the emitted signal is propagated through the solid core 46 from the first end 42 toward the second end 44 of waveguide 40.

[0053] The solid core 46 of waveguide 40 includes a target 52 for reflecting and/or diffracting the emitted signal to generate the return signal which is transmitted from the target 52 toward the first end 42 of waveguide 40. The return signal is received by the wave receiver of the radiation device 50.

[0054] The radiation device 50 may measure a time or frequency variation or difference between emission of the emitted signal and reception of the return signal, and this time or frequency difference is used to compute the length parameter of the electrode. This calculation may be performed by a length calculation device 54, such as a computer, which may be a separate component connected to radiation device 50 (as shown in Figure 1), or which may form part of the radiation device 50.

[0055] Depending on the selection of the target 52 within the solid core 46, the apparatus described herein is capable of measuring a number of different length parameters of electrode 18.

[0056] For example, a target 52 will be located at the tip 48 of core 46, due to the dissolution, melting and/or disintegration of the material of core 46. Thus, at least a portion of the emitted electromagnetic radiation signal transmitted from the first end 42 of waveguide 40 will reach the tip 48 of core 46, and be reflected and/or diffracted back to the first end 42 as a return signal. By measuring a time or frequency difference between the emitted signal emitted at the first end 42 and the return signal reflected and/or diffracted from the second end 44, the total length of the waveguide 40 may be calculated. Since the material of the core 46 of waveguide 40 is selected such that it has a maximum use temperature which is close to or slightly less than the temperature of the molten bath, the total length of the waveguide 40 will be closely related to the overall length of the electrode 18. Thus, according to the present embodiment, a measurement of the length of the core 46 of waveguide 40 will correspond to the length L of the electrode 18, within a reasonable margin of error.

[0057] In some embodiments, the core 46 may include one or more discontinuities between the first and second ends 42, 44 of waveguide 40. Each of these discontinuities may provide a target 52 which can be used to measure another length parameter of electrode 18.

[0058] For example, in some embodiments, the solid core 46 of waveguide 40 may comprise a plurality of segments 56 (see Figure 2) which may be joined end-to-end in a variety of ways. Where the segments are mechanically connected, there will necessarily be joints 58 between adjacent segments 56. A portion of the emitted electromagnetic radiation signal being transmitted through the core 46 of waveguide 40 will be diffracted and/or reflected back to the first end 42 by each of these joints 58 as a return signal, and the number of these return signals will be proportional to the number of joints 58, and therefore the number of segments 56 comprising the waveguide 40. This type of structure may be particularly useful in prebaked electrodes, in which prebaked electrode segments are added to the upper end 22 of electrode 18 as the lower end 24 is consumed. In this type of electrode structure, it may be advantageous to align the joints 58 of the waveguide segment 56 with the joints between adjacent electrode segments (e.g. as indicated by dotted lines 64 in Fig. 2), such that the number of joints 58 detected by the radiation device 50 will be closely related to the number of prebaked segments making up the electrode 18.

[0059] Alternatively, the targets 52 may comprise other types of discontinuities which will diffract and/or reflect a portion of the emitted electromagnetic radiation signal back toward the first end 42 of waveguide 40 as a return signal. For example, the core 46 may be provided with notches 60 (see Figure 2) spaced apart along its length, wherein the spacing of notches 60 may correspond to a known length within the electrode 18. The notches 60 can be located between segments of a prebaked electrode 18, or can indicate the length of a section of a Soderberg electrode 18, for example.

[0060] In some embodiments, the length parameter which can be measured is used to determine the relative position of the tip 38 with respect to any fixed component on the furnace 10. For example, in the context of a "sounding test", the fixed point of the furnace 10 may comprise the bottom hearth refractory 12 of the furnace 10. The measurement of the length of electrode 18 permits the location of the tip 38 of electrode 18 relative to the bottom hearth refractory 12 of furnace to be accurately determined. By monitoring of the electrical parameters of electrode 18 as it passes through the slag/metal interface, the exact location relative to the hearth 12, of the interface can be determined. In this way, the thicknesses of the metal or matte and slag layers can be accurately determined without the need for a separate "sounding test" apparatus.

[0061] The waveguide 40 may further comprise an outer layer 62 surrounding the solid core 46, as shown in Figure 2. The outer layer 62 is electrically conductive, with an electrical resistivity (measured in Ω.m) which is typically greater than the electrical resistivity of the core 46, and may be comprised of metal and/or graphite. The outer layer 62 may be present, for example, where the electrode 18 is a Soderberg type electrode, and serves to provide an electrically conductive sheath around the core 46 in the upper regions of the electrode 18 where the carbon paste is not yet fully baked and may not completely surround the waveguide 40. Since the paste reaches a fully baked condition at about 450°C, the outer layer 62 will only be required up to this temperature. Therefore, the outer layer 62 may comprise a relatively thin layer of metal such as steel, copper or aluminum, and may be in the form of a thin foil wrap.

[0062] Where the electrode 18 is a segmented, prebaked electrode, the waveguide will be closely received within the internal duct 26 (most likely drilled through the prebaked electrode), with the outer surface of the waveguide 40 being in tight contact with an inner wall of the duct 26. In this construction, the walls of the duct 26 can serve as a conductive enclosure for the waveguide 40, and no outer layer 62 may be required.

[0063] Figures 4 and 5 illustrate further detail regarding the incorporation of a waveguide 40 as described herein into an electrode 18 of the Soderberg type. As illustrated, the electrode 18 comprises a carbon paste 30 enclosed within a steel casing 32, both of which are consumed in the furnace 10 (not shown in Figure 4). The fully baked carbon paste is identified by reference numeral 66 in Figure 4, and is located in the area below dotted lines 68. Above dotted lines 68 is a region of soft paste, identified by reference numeral 70 in Figure 4, and above line 72 is a region in which the steel casing 32 is filled with cylinders or blocks of hard paste 74, which will become softened and baked as the electrode 18 is lowered into the furnace. Joints between segments of the steel casing 32 are identified in Figure 4 by reference numeral 76.

[0064] Figure 4 also shows a waveguide 40 having a core 46 as described above. The core 46 is segmented and adjacent segments 56 of core 46 are shown as being connected by couplings 78, which may comprise integrated ceramic sleeves having the same or similar composition as core 46. As shown, the segments 56 of waveguide core 46 may have the same or similar length as the segments of casing 32, and therefore measurement of the number of segments 56 making up waveguide core 46 will provide an accurate measurement of the number of segments making up the steel casing 32 of electrode 18.

[0065] From Figures 4 and 5 it can be seen that the waveguide 40 is parallel to the central longitudinal axis A, but is spaced from the axis A. Therefore, while the tip 48 of waveguide core 46 is located in the lower end 24 of electrode 18, it is not located at the tip 38 of electrode 18. However, since the lower end 24 of electrode 18 is proximate to the tip 38, and because the distance between the tip 48 of waveguide core 46 and the tip 38 of electrode 18 is known or can accurately be predicted, the provision of the waveguide 40 in an offset location relative to axis A does not significantly affect the accuracy of the length measurement of electrode 18.

[0066] Figure 5 also shows the offset location of the waveguide 40 in the electrode 18, and shows the locations of a number of other potential components of the electrode 18. In this regard, Figure 5 shows the fins 80 of casing 32, and also shows the locations of a Cavigli device 82 and a thermocouple 84, both of which may be installed in ducts extending along the length of electrode 18. In addition, Figure 5 shows that the waveguide 40 may be enclosed in a protective cage 86, which may be constructed of expanded metal mesh.

[0067] Although the invention has been described in connection with certain embodiments, it is not limited thereto. Rather, the invention includes all embodiments which may fall within the scope of the following claims.

What is claimed is:

1. A method for determining a length parameter of an electrode during operation of an electric arc furnace containing a bath, the method comprising:

(a) providing the electrode, wherein the electrode has an upper end situated outside the furnace, a lower end situated inside the furnace, a length defined from the upper end to the lower end, and an internal duct extending along the length of the electrode, wherein the internal duct is open at the lower end of the electrode;

(b) providing a waveguide having a first end, a second end and a solid core, wherein the waveguide is at least partly received in the internal duct of the electrode with its second end located at or proximate to the lower end of the electrode, wherein the solid core of the waveguide comprises a material having a low dielectric constant and high temperature resistance, and wherein the solid core of the waveguide includes at least one target;

(c) emitting an electromagnetic radiation signal, from a source and transmitting the emitted signal through the solid core from the first end toward the second end of the waveguide;

(d) diffracting and/or reflecting the emitted signal from the at least one target to produce at least one return signal and transmitting the at least one return signal through the solid core from the at least one target toward the first end of the waveguide;

(e) receiving the at least one return signal from the solid core at the first end of the waveguide;

(f) measuring a time or frequency difference between the emitted signal and the at least one return signal; and

(g) calculating the length parameter based on this difference.

2. The method according to claim 1, wherein the bath contains one or more molten materials selected from molten metal, molten matte, and molten slag.

3. The method according to claim 1 or 2, wherein the lower end of the electrode is in contact with the one or more molten materials in the bath.

4. The method according to any one of claims 1 to 3, wherein the lower end of the electrode has a tip, and wherein the internal duct is open at the tip of the electrode.

5. The method according to any one of claims 1 to 4, wherein the internal duct extends throughout the length of the electrode from the upper end to the lower end, and is open at the upper end of the electrode.

6. The method according to any one of claims 1 to 5, wherein the waveguide extends throughout the length of the electrode from the upper end to the lower end.

7. The method according to any one of claims 1 to 6, wherein the waveguide has an outer surface which is in contact with an inner wall of the internal duct.

8. The method according to any one of claims 1 to 7, wherein the electrode is a prebaked carbon electrode comprised of a plurality of segments joined together end-to-end.

9. The method according to any one of claims 1 to 7, wherein the electrode is a Soderberg electrode formed by baking a carbon paste within an outer metal casing.

10. The method according to any one of claims 1 to 9, wherein the length parameter is selected from one or more of: the length of the electrode from its

upper end to its lower end; the length of a portion of the electrode; and the position of the lower end of the electrode relative to a fixed point on the furnace.

11. The method according to any one of claims 1 to 9, wherein the solid core comprises a plurality of segments joined together end-to-end; and wherein the length parameter comprises the number of segments in the solid core.

12. The method according to any one of claims 1 to 11, wherein the at least one target comprises a tip of the solid core which is directly exposed to the molten bath at the lower end of the electrode.

13. The method according to any one of claims 1 to 12, wherein the at least one target comprises one or more discontinuities located along a length of the solid core.

14. The method according to claim 13, wherein each of the one or more discontinuities comprises a notch or a joint.

15. The method according to any one of claims 1 to 14, wherein the solid core comprises a rigid, elongate bar or rod.

16. The method according to any one of claims 1 to 15, wherein the material comprising the solid core is a ceramic.

17. The method according to any one of claims 1 to 16, wherein the material comprising the solid core has a dielectric constant greater than the dielectric constant of air.

18. The method according to any one of claims 1 to 17, wherein the material comprising the solid core has a maximum use temperature with an upper limit at or below the temperature of the arc emitted by the electrode.

19. The method according to claim 18, wherein a lower limit of the maximum use temperature is about 300°C.

20. The method according to claim 19, wherein the lower limit of the maximum use temperature is about 500°C.

21. The method according to any one of claims 1 to 20, wherein the emitted signal and the at least one return signal comprise electromagnetic radiation.

22. A method for determining a position of a slag/metal interface in a bath of an electric arc furnace relative to a fixed component of the furnace, the method comprising:

(a) determining a length parameter of an electrode during operation of the electric arc furnace according to the method of any one of claims 1 to 21, wherein the length parameter is the length of the electrode from its upper end to its lower end;

(b) with the lower end of the electrode located in the bath, raising or lowering the electrode;

(c) monitoring one or more electrical parameters of the electrode as it is being raised or lowered;

(d) continuing to raise or lower the electrode until the monitoring of the electrical parameters indicates that the lower end of the electrode has passed through the slag/metal interface; and

(e) calculating the position of the slag/metal interface relative to the position of fixed component, based on the length of the electrode determined in step (a), the position of the slag/metal interface determined in step (d), and the known position of the fixed component.

23. The method according to claim 22, wherein the fixed component of the furnace is the hearth.

24. An apparatus for measuring a length parameter of an electrode of an electric arc furnace, wherein the electrode has an upper end situated outside the furnace, a lower end situated inside the furnace, a length defined from the upper end to the lower end, and an internal duct extending along the length of the electrode, wherein the internal duct is open at the lower end of the electrode, the apparatus comprising:

(a) a waveguide having a first end, a second end, and a solid core, wherein the waveguide is adapted to be at least partly received in the internal duct of the electrode, wherein the solid core of the waveguide comprises a material having low dielectric strength and high temperature resistance, and wherein the solid core of the waveguide includes at least one target;

(b) a wave generator adapted to emit an electromagnetic radiation signal into the solid core at the first end of the waveguide; and

(c) a wave receiver adapted to receive an electromagnetic radiation signal from the solid core at the first end of the waveguide.

25. The apparatus according to claim 24, wherein the solid core comprises a plurality of segments joined together end-to-end.

26. The apparatus according to claim 24 or 25, wherein the at least one target comprises a tip of the solid core or at least one discontinuity located along a length of the solid core.

27. The apparatus according to any one of claims 24 to 26, wherein the at least one discontinuity comprises at least one notch or at least one joint.

28. The apparatus according to any one of claims 24 to 27, wherein the solid core comprises a rigid, elongate bar or rod.

29. The apparatus according to any one of claims 24 to 28, wherein the material comprising the solid core has a dielectric constant greater than the dielectric constant of air.

30. The apparatus according to any one of claims 24 to 29, wherein the material comprising the solid core has a maximum use temperature with an upper limit at or below the temperature of the arc emitted by the electrode.

31. The apparatus according to claim 30, wherein a lower limit of the maximum use temperature is about 300°C.

32. The apparatus according to any one of claims 24 to 31, wherein the signal comprises electromagnetic radiation and wherein the wave generator and the wave receiver are provided in a radar unit.

33. The apparatus according to any one of claims 24 to 32, wherein the waveguide further comprises an outer layer surrounding the solid core, wherein the outer layer has an electrical resistivity which is greater than the electrical resistivity of the solid core.

34. A waveguide for an apparatus for measuring a length parameter of an electrode of an electric arc furnace containing a bath;

the waveguide comprising an elongate solid core comprising a material having low dielectric strength and high temperature resistance;

wherein said high temperature resistance is defined as a maximum use temperature which has a lower limit of about 200°C below the temperature of the bath in the vicinity of the lower end of the electrode, and an upper limit at or below the temperature of the arc emitted by the electrode.

35. The waveguide according to claim 34, wherein the solid core comprises a plurality of segments joined together end-to-end.

36. The waveguide according to claim 34 or 35, wherein the solid core comprises a rigid, elongate bar or rod.

37. The waveguide according to any one of claims 34 to 36, wherein the material comprising the solid core is a ceramic.

38. The waveguide according to any one of claims 34 to 37, wherein the material comprising the solid core has a dielectric constant greater than the dielectric constant of air.

39. The waveguide according to any one of claims 34 to 38, further comprising an outer layer surrounding the solid core, wherein the outer layer has an electrical resistivity which is greater than the electrical resistivity of the solid core.

40. The waveguide according to claim 39, wherein the solid core has a dielectric constant less than the dielectric constant of the surrounding outer layer.

41. The waveguide according to claim 39 or 40, wherein the outer layer comprises a metal having a melting point of at least about 450°C.

Fig. 1

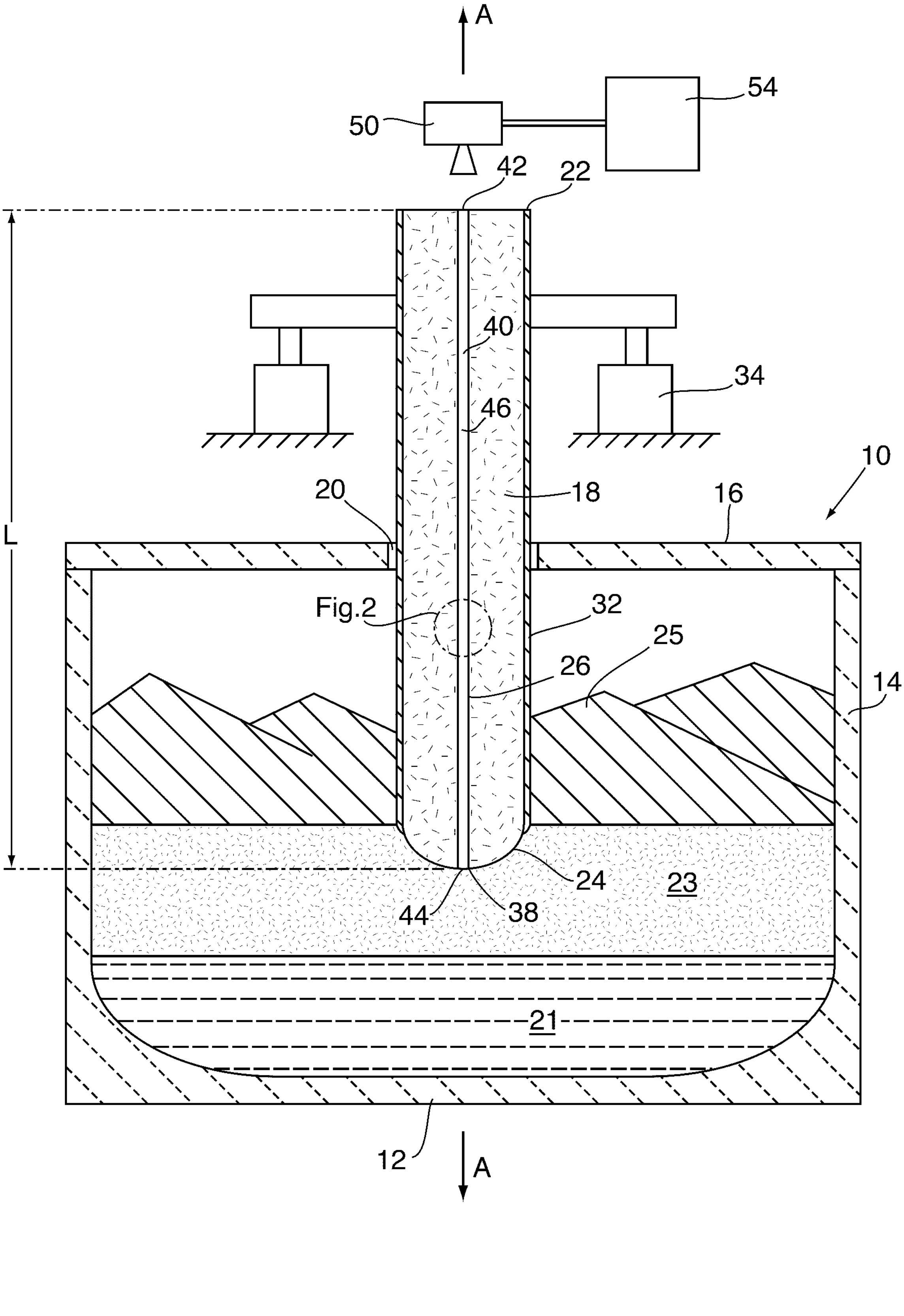

Fig. 2

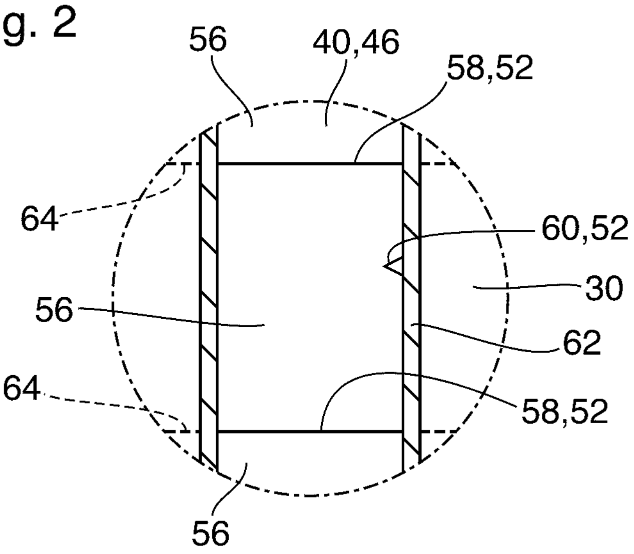
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Fig. 3

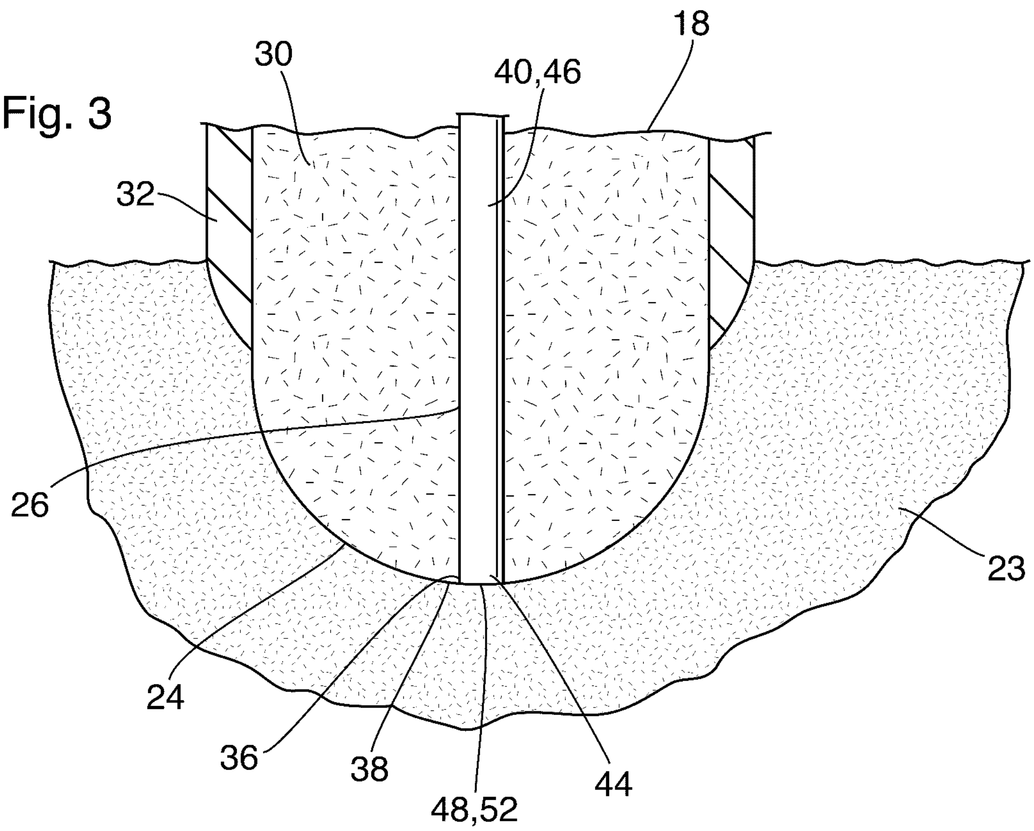
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Fig. 4

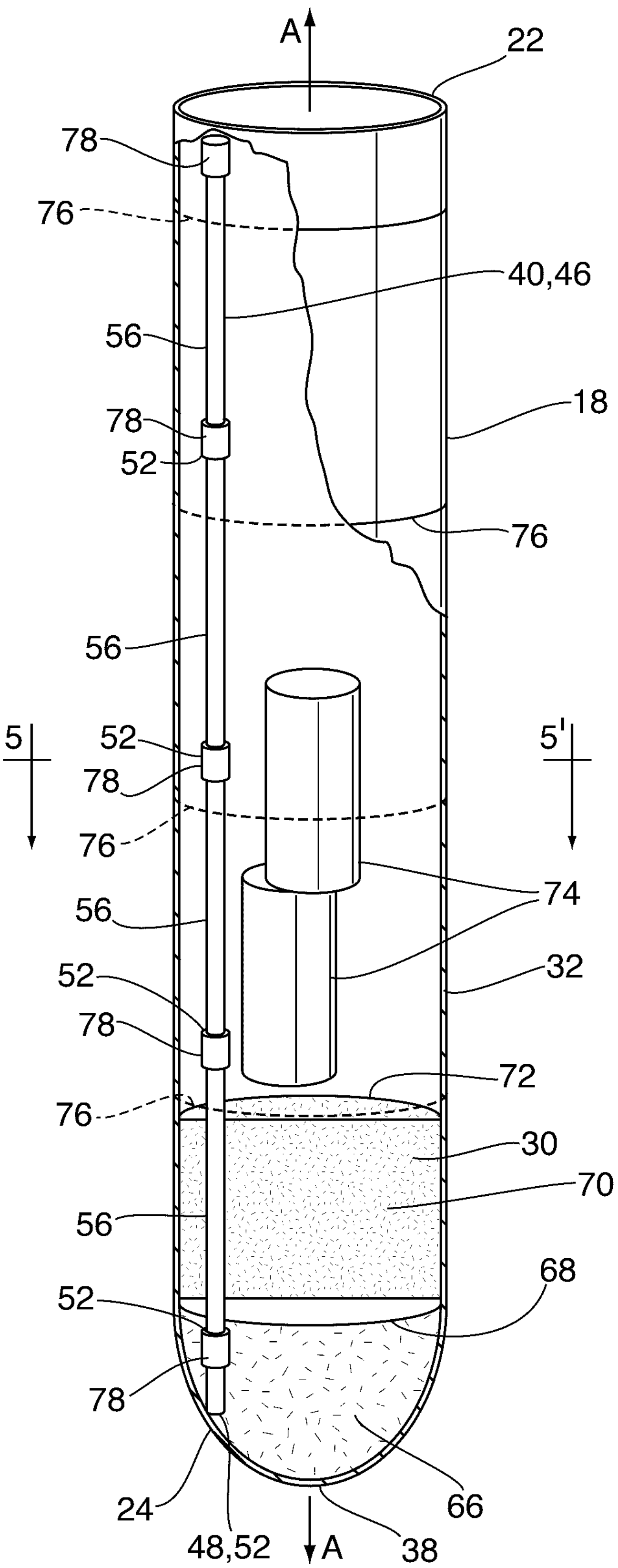
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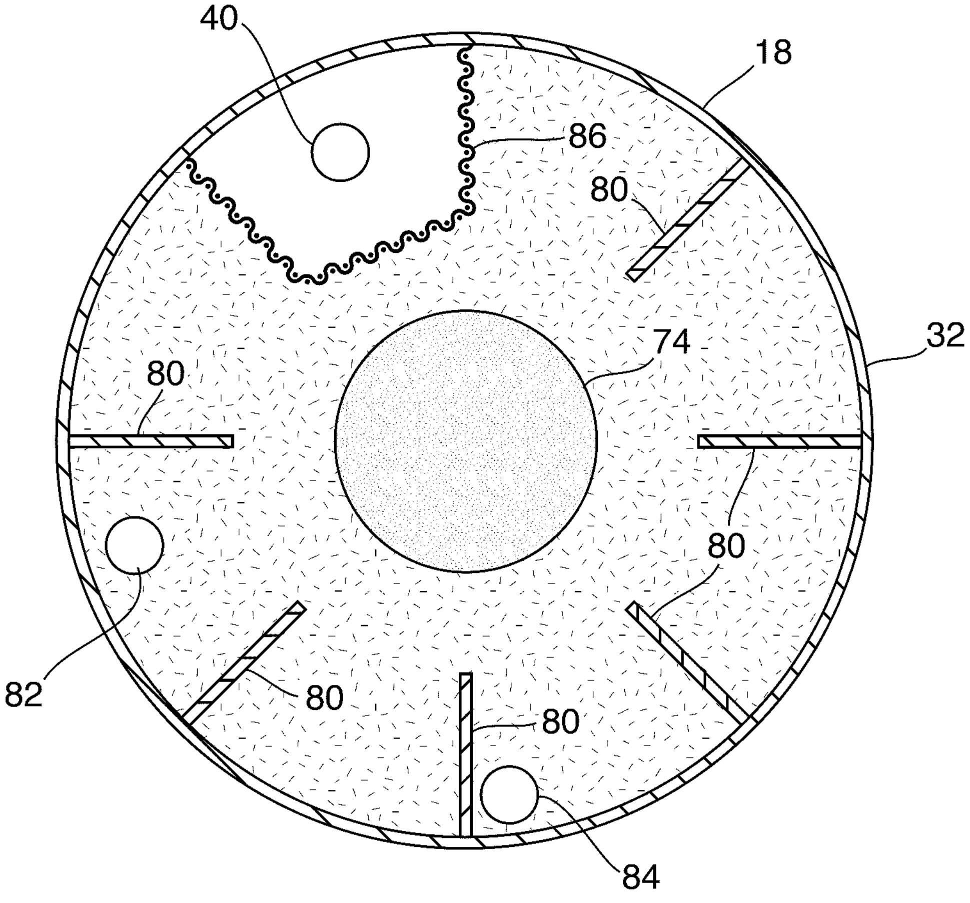
Fig. 5



INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2016/050550

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***G01S 13/08*** (2006.01) , ***C21D 1/38*** (2006.01) , ***C22B 9/21*** (2006.01) , ***F27B 3/08*** (2006.01) , ***F27D 21/00*** (2006.01) , ***G01F 23/284*** (2006.01) (more IPCs on the last page)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
IPC: ***G01S**** (2006.01), ***C21D**** (2006.01), ***C22B**** (2006.01) , ***F27B**** (2006.01), ***F27D**** (2006.01), ***G01F**** (2006.01)

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Databases: TotalPatent, Canadian Patent Database, IEEExplore, World Wide Web
Keywords: arc furnace, electrode, tip position, length, parameter, consumable, waveguide, solid core, electromagnetic radiation, transmitter, receiver

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013/0127653 A1 (DIENENTHAL et al.), 23 May 2013 (23-05-2013) **see entire document	1-41
A	WO 2014/002192 A1 (KAYANO), 3 January 2014 (03-01-2014) **see entire document	1-41
A	Ballard, Norman *Electrode Length Measurement in Electric Arc Furnaces.* MSc Dissertation. Department of Electrical Engineering, University of Cape Town, 26 April 1995 (26-04-1995), pages 1-68. **see pages 9-10 and 12-14	1-41

☐ Further documents are listed in the continuation of Box C.   ☑ See patent family annex.

* Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than	"&" document member of the same patent family

Date of the actual completion of the international search 28 June 2016 (28-06-2016)	Date of mailing of the international search report 26 July 2016 (26-07-2016)
Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 819-953-2476	Authorized officer Jamie Hayami (819) 639-4735

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		RU2550453C2	10 May 2015 (10-05-2015)
		WO2011151256A1	08 December 2011 (08-12-2011)
WO2014002192A1	03 January 2014 (03-01-2014)	None	

G01S 13/88 (2006.01)