United States Patent

Herff

[15] **3,701,518**

[45] **Oct. 31, 1972**

[54] **OXYGEN LANCE CONTROL ARRANGEMENT FOR BASIC OXYGEN FURNACE**

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[73] Assignee: **Berry Metal Company,** Harmony, Pa.

[22] Filed: **Oct. 3, 1969**

[21] Appl. No.: **863,609**

[52] **U.S. Cl.** ....**266/34 LM**
[51] **Int. Cl.** **C21c 7/00**
[58] **Field of Search** ....266/34 R, 34 L, 34 LM, 34 T, 266/41; 75/59, 60

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Primary Examiner—Gerald A. Dost
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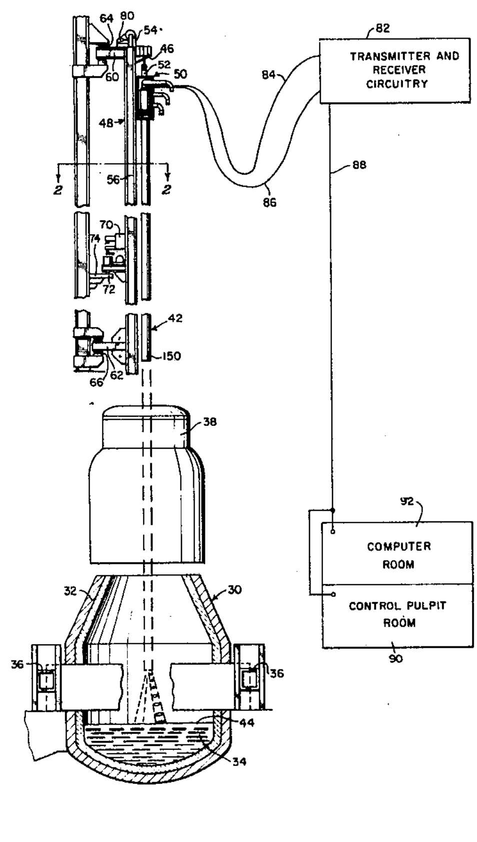
[57] **ABSTRACT**

A ranging radar system is employed in combination with the oxygen blowing lance of a basic oxygen furnace to make an absolute measurement of the distance between the lance and the level of molten material within the furnace vessel. This measurement may be made while the level of molten material is quiescent, i.e., before the oxygen blowing operation is started, and may be used either to calibrate the existing lance drum indicator or directly as a measurement of lance height in the overall computer control of the furnace. In the alternative, the measurement of lance height from the molten surface may be made during the oxygen blowing operation and may be employed for accurate lance positioning during blow or the accurate repositioning of the lance in the event a reblow operation is required to obtain a desired quality of steel for a particular heat.

16 Claims, 25 Drawing Figures



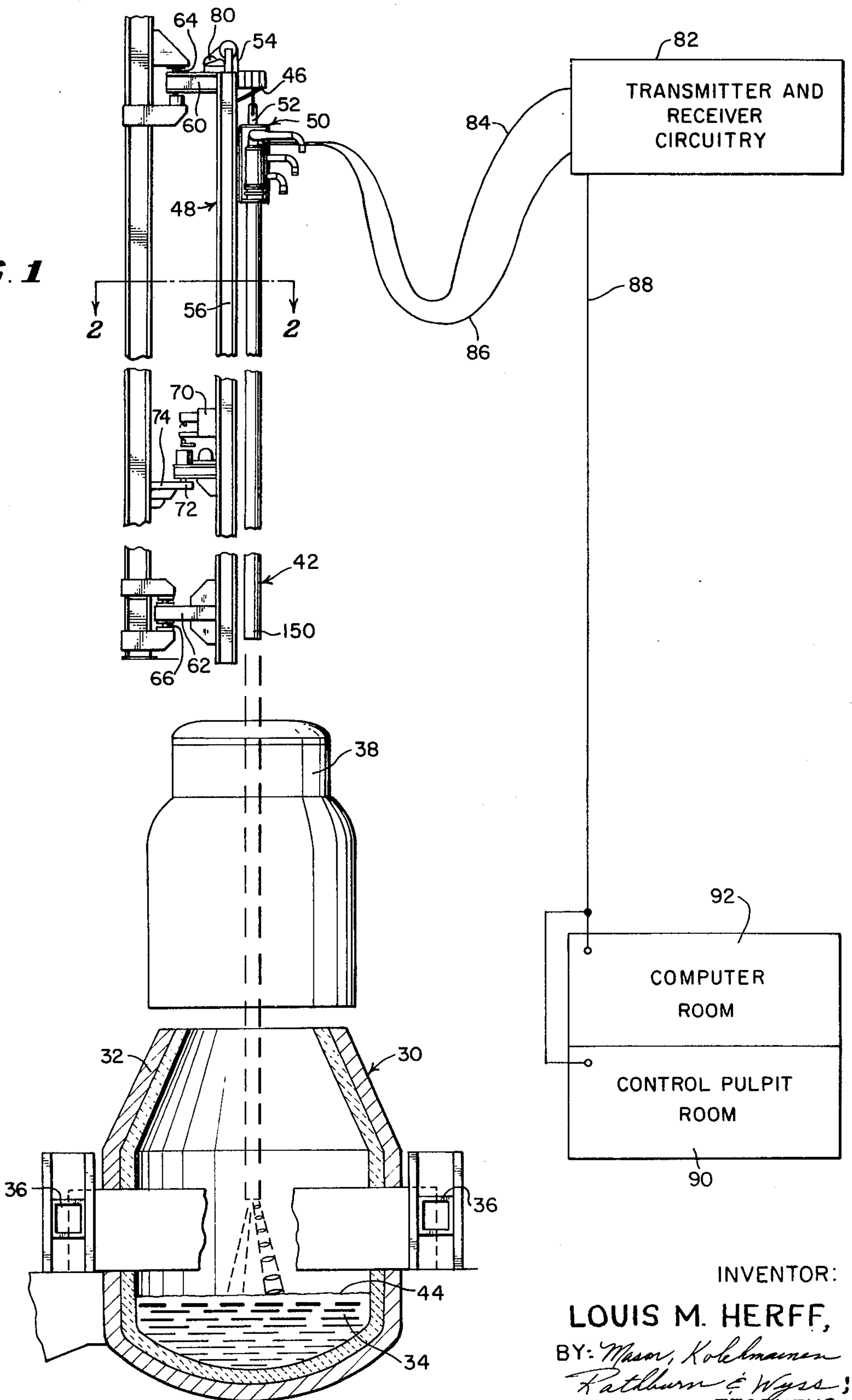


FIG. 1

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BY: Mason, Kolehmainen, Rathburn & Wyss;
ATTORNEYS.

FIG. 2

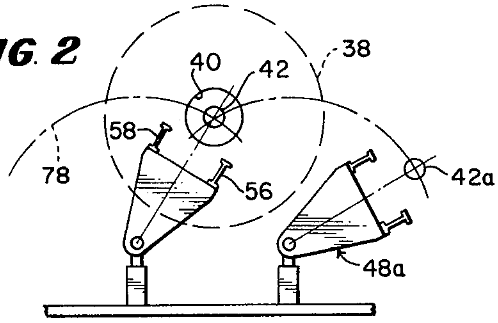


FIG. 6

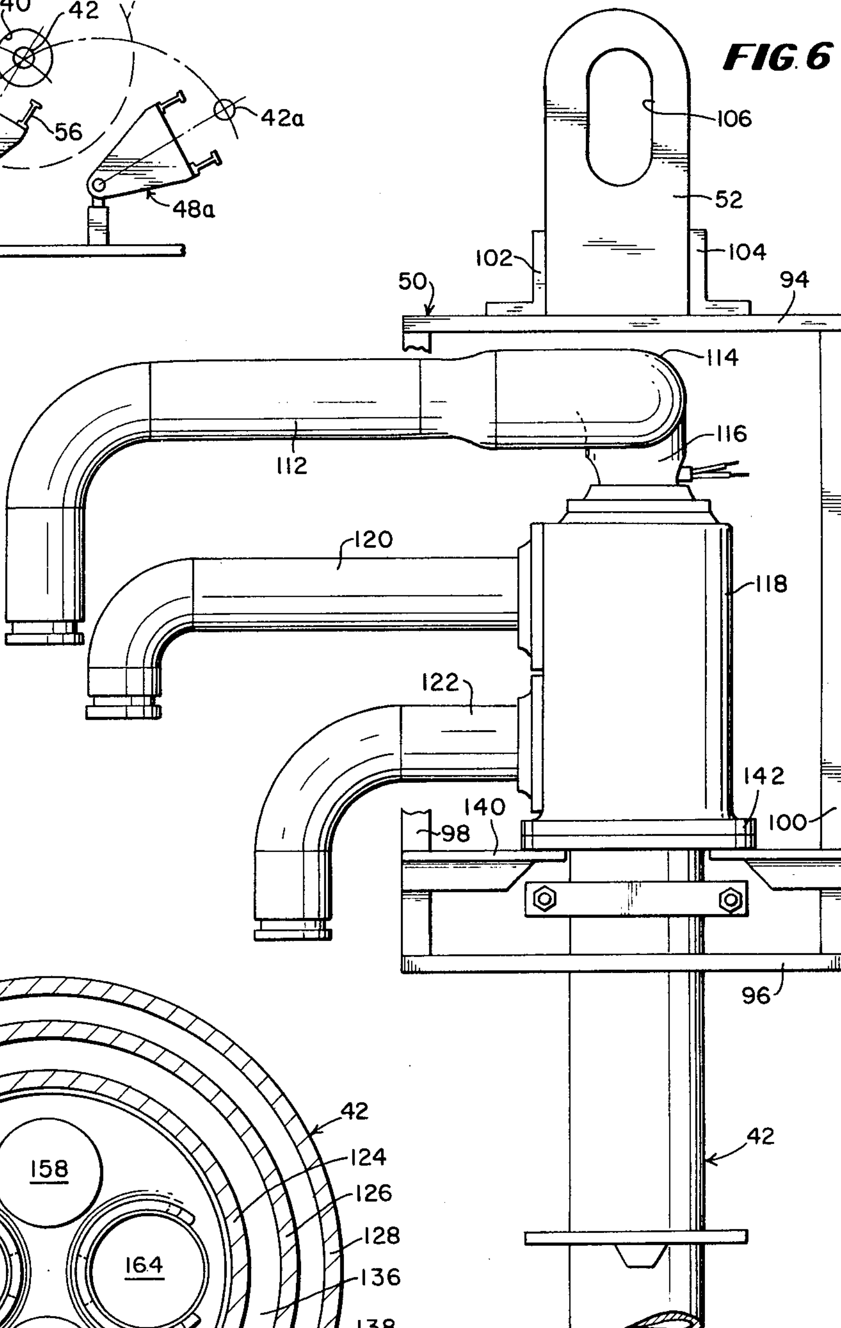


FIG. 5

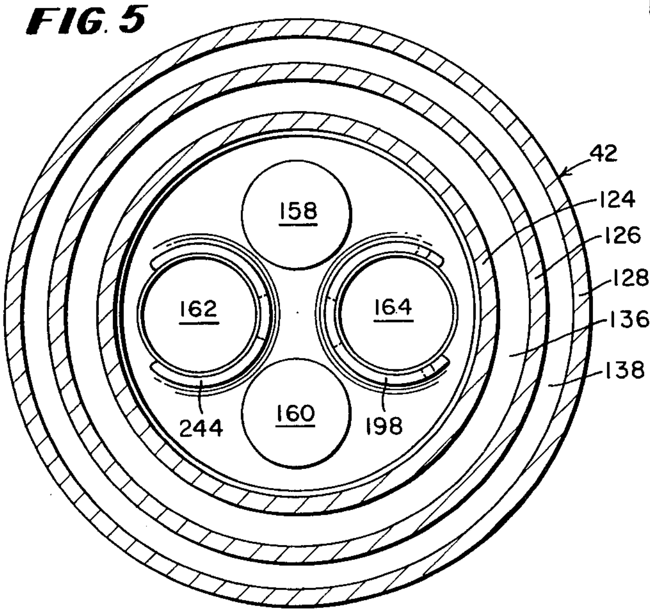
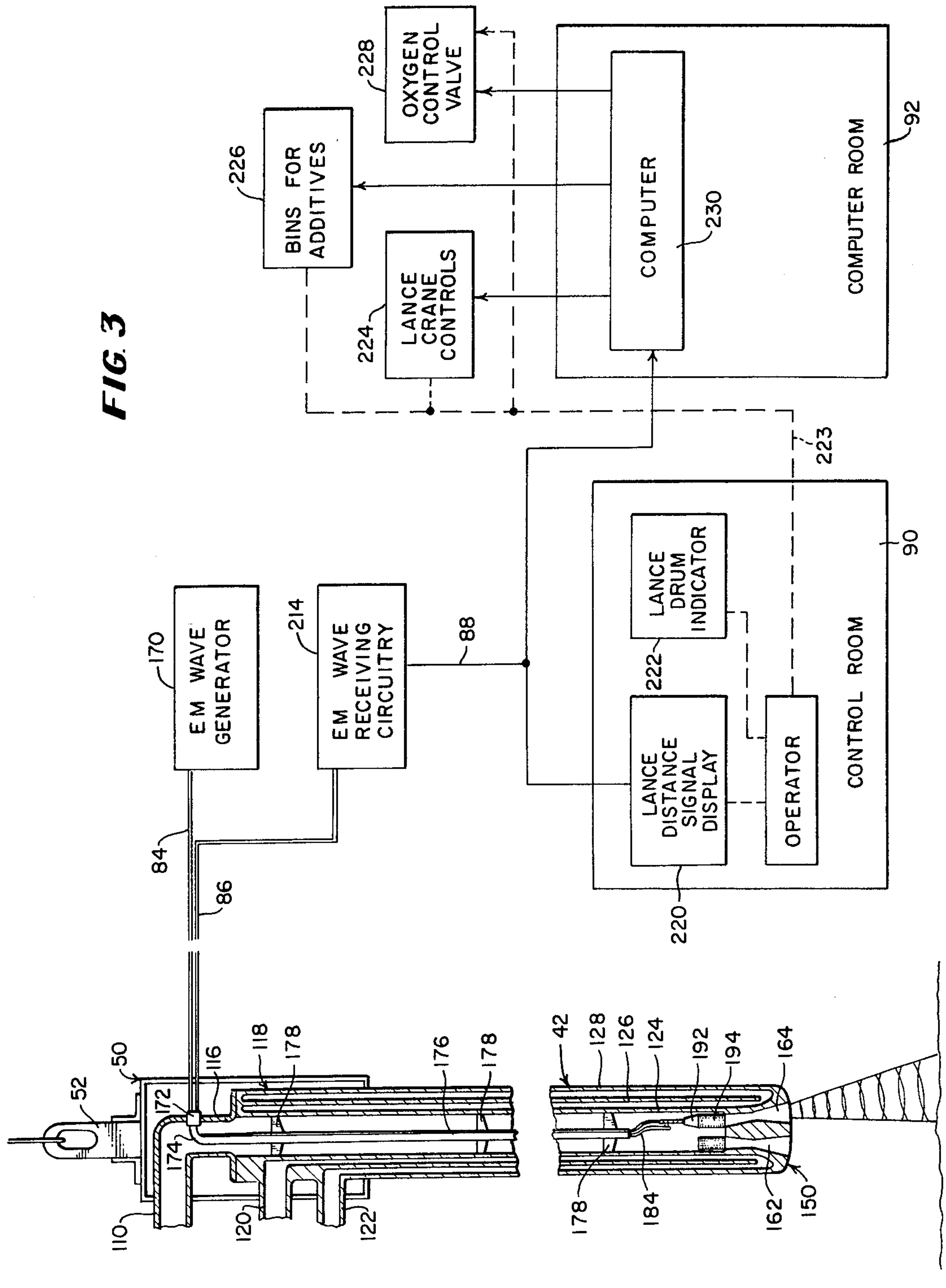


FIG. 3


EM WAVE GENERATOR
EM WAVE RECEIVING CIRCUITRY
BINS FOR ADDITIVES
OXYGEN CONTROL VALVE
LANCE CRANE CONTROLS
COMPUTER
COMPUTER ROOM
LANCE DRUM INDICATOR
LANCE DISTANCE SIGNAL DISPLAY
OPERATOR
CONTROL ROOM
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50
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176
84
86
170
214
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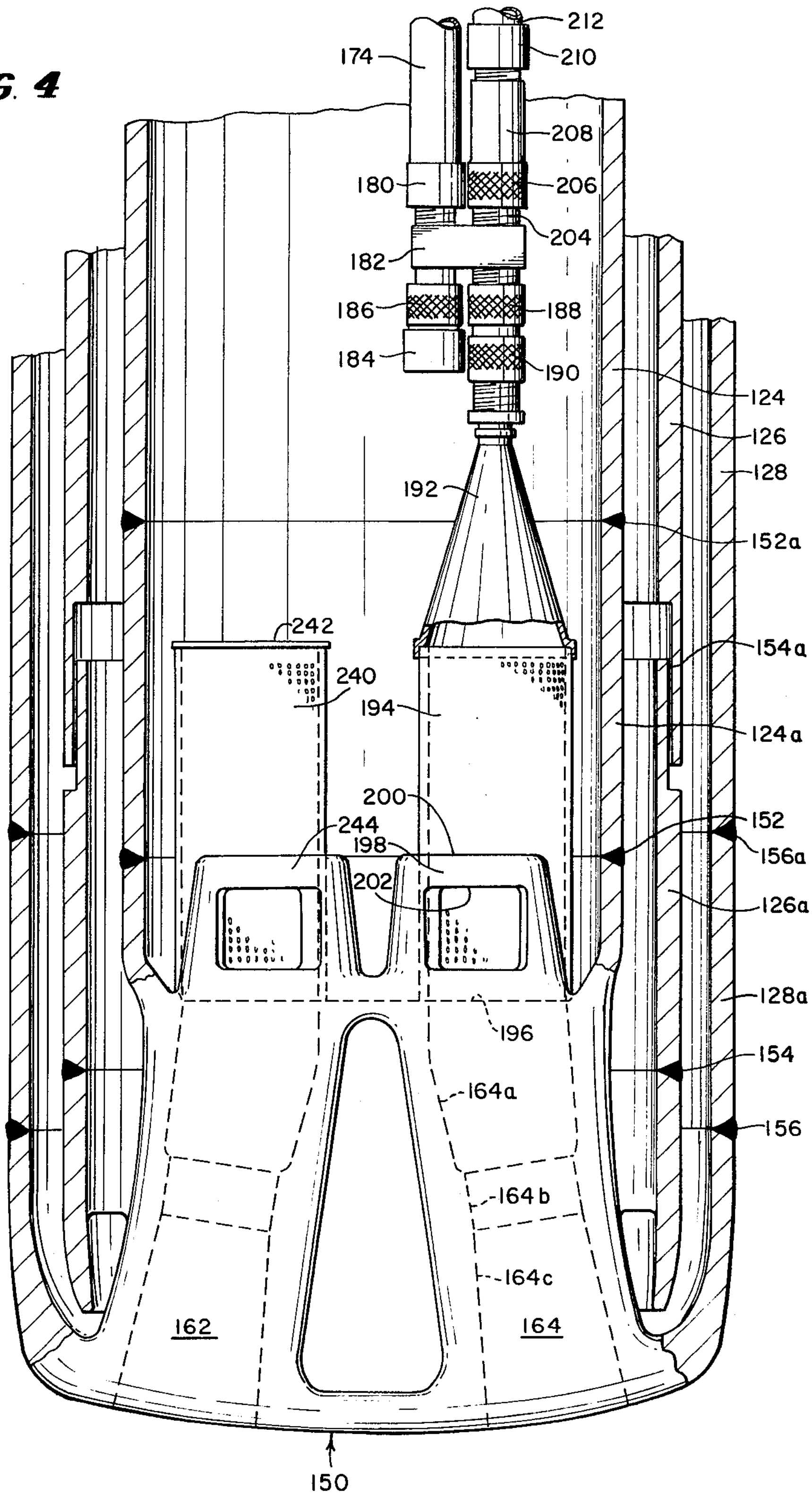
FIG. 4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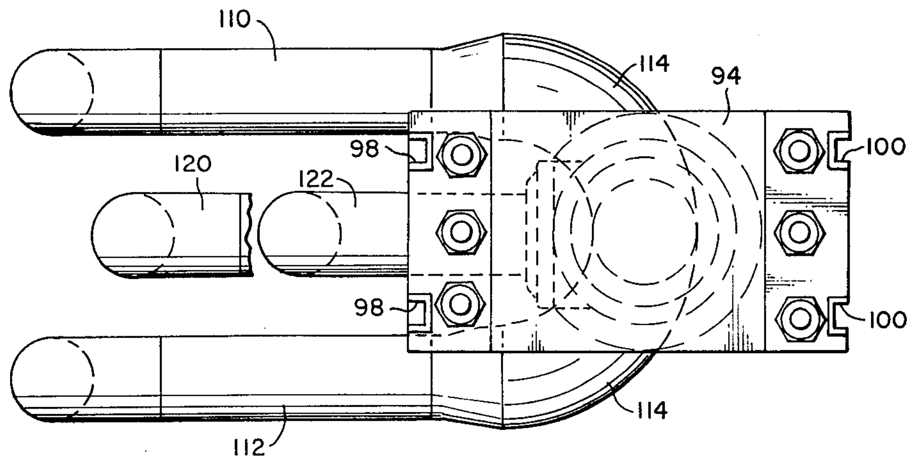
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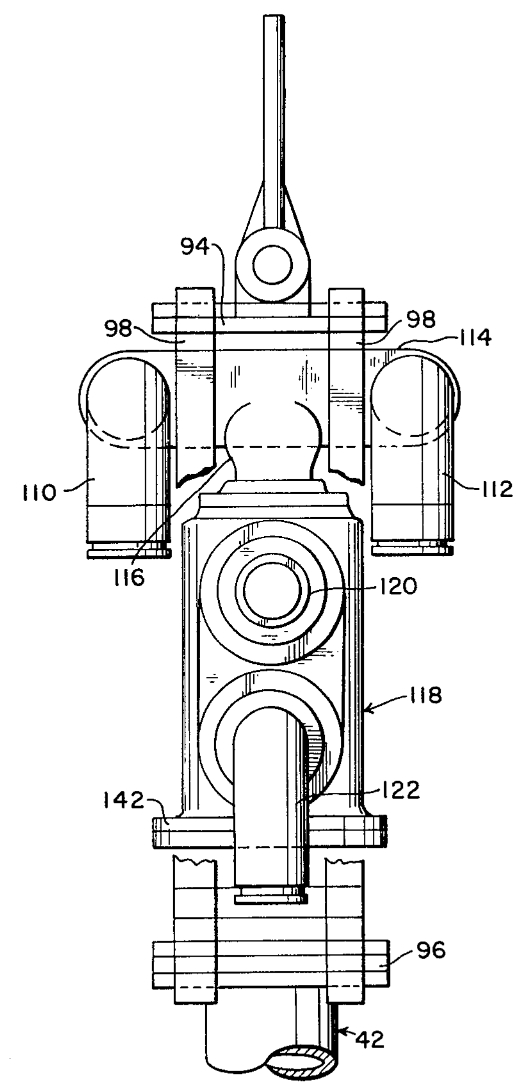
FIG. 7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142
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FIG. 8

FIG. 10

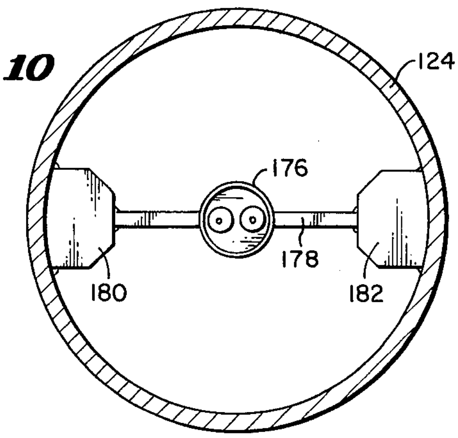
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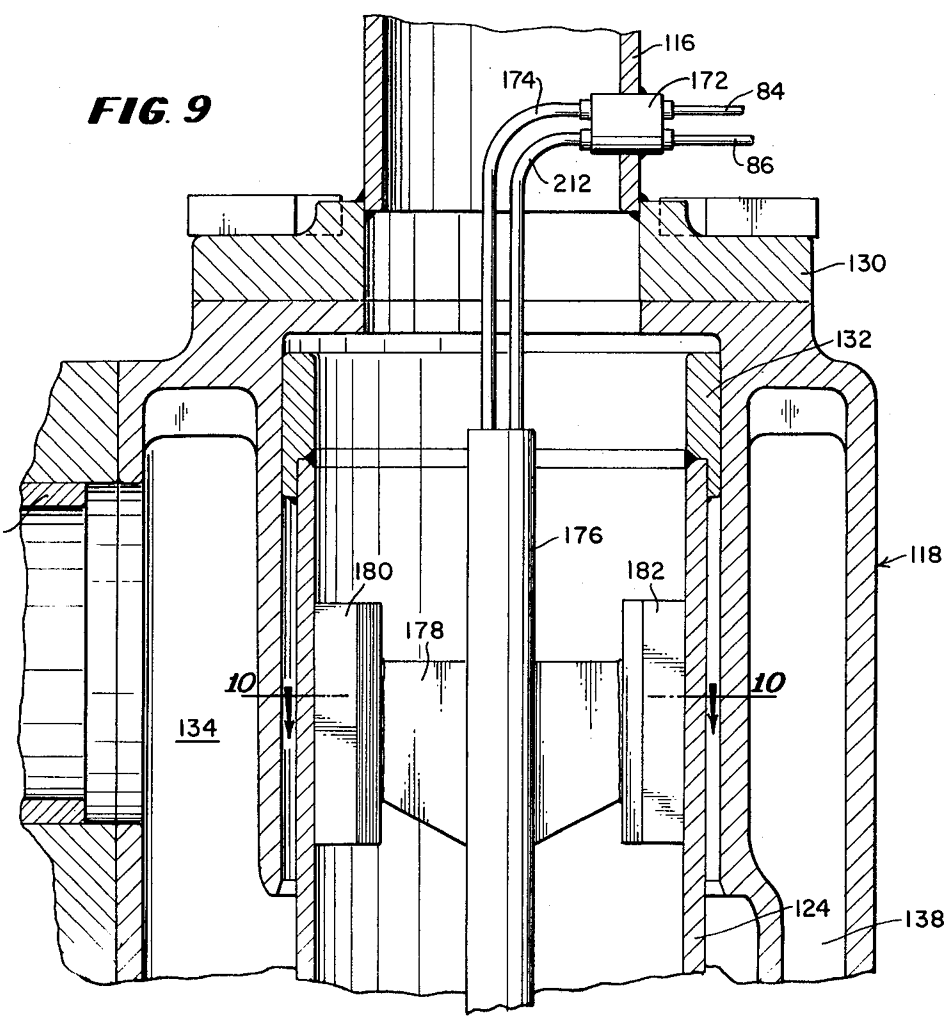
FIG. 9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212
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FIG. 11

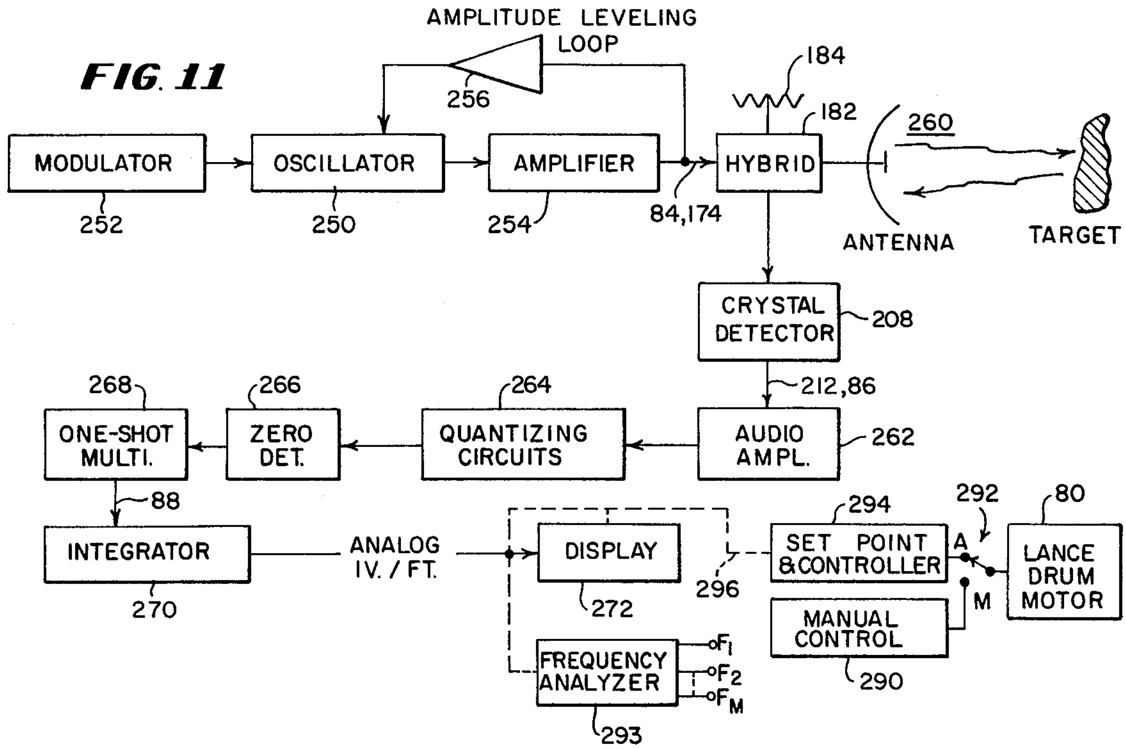


FIG. 12a

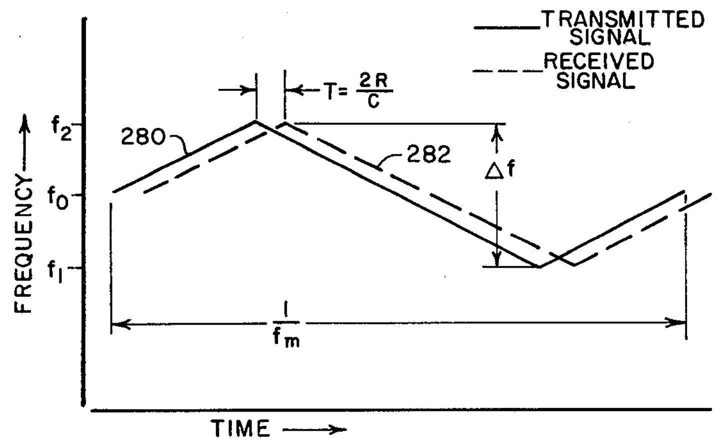


FIG. 12b

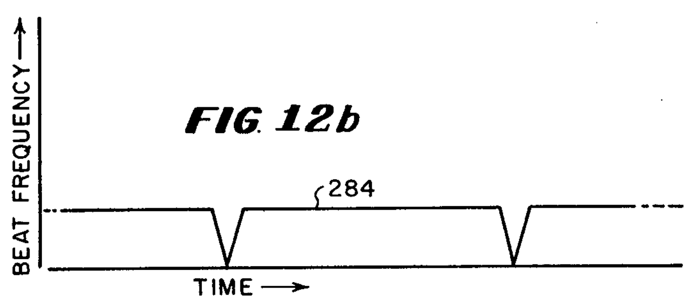
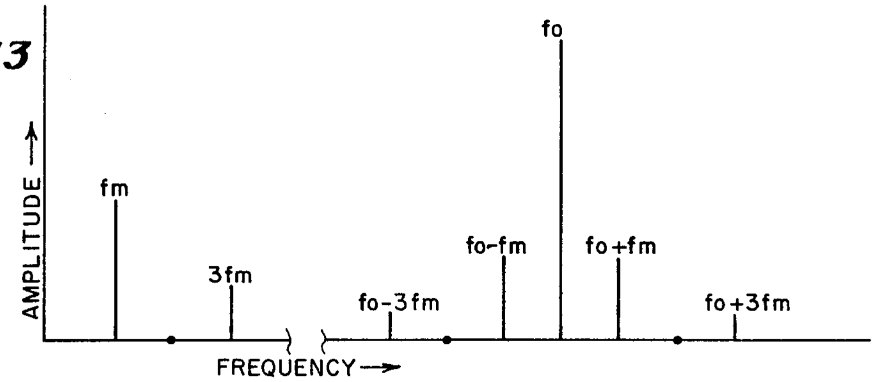
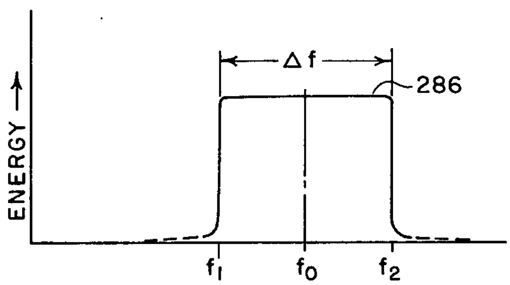


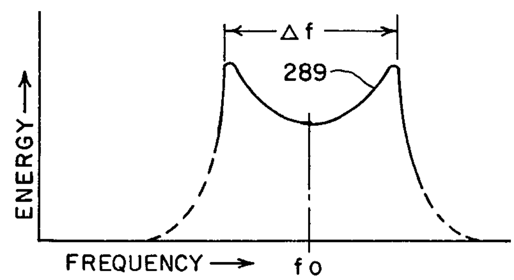
FIG. 13





LINEAR MODULATION

FIG. 15a



SINUSOIDAL MODULATION

FIG. 15b

FIG. 14a

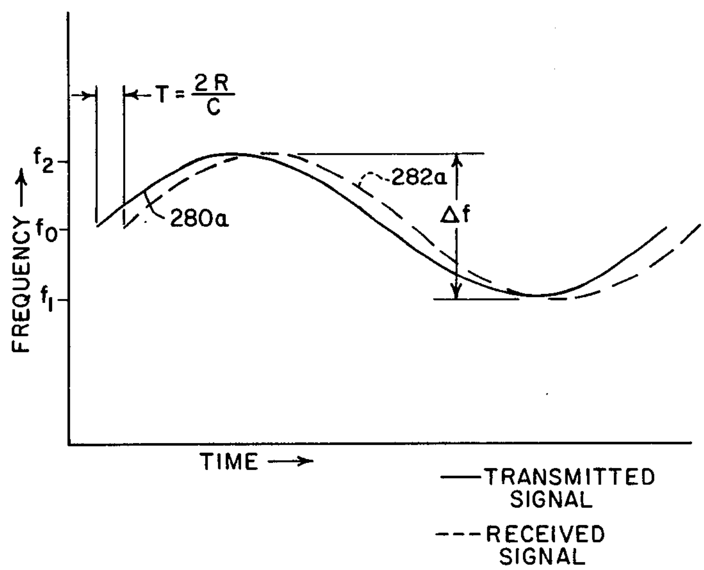
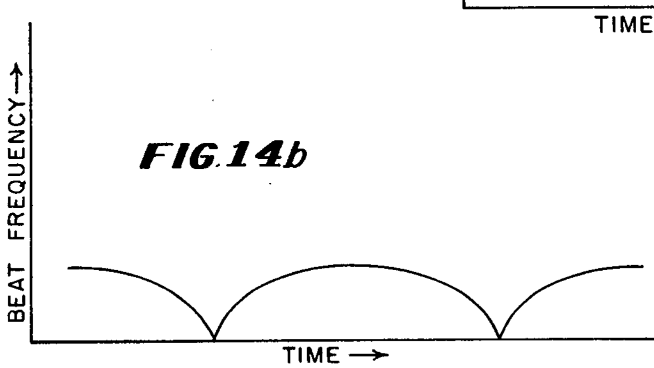
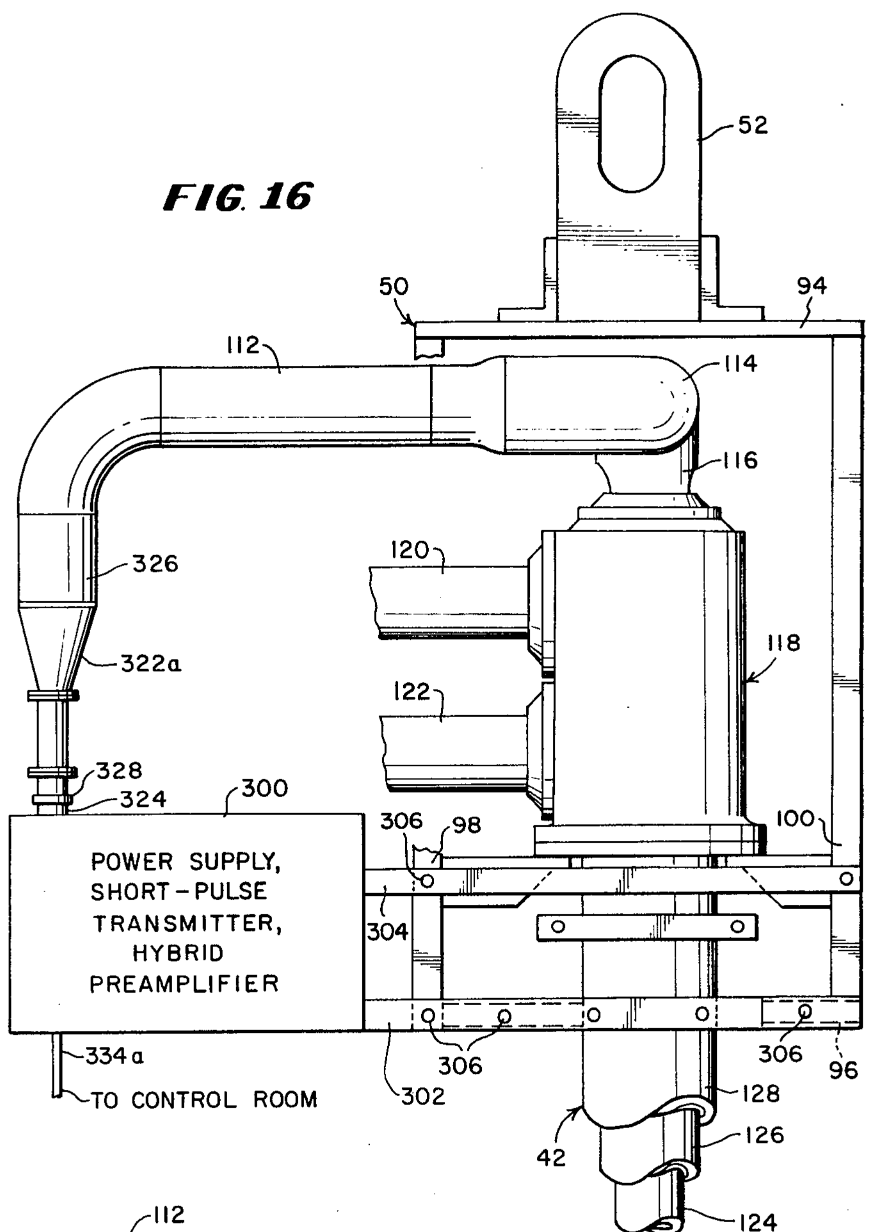


FIG. 14b



CW RANGING RADAR WITH SINUSOIDAL MODULATION

FIG. 16


52
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POWER SUPPLY,
SHORT-PULSE
TRANSMITTER,
HYBRID
PREAMPLIFIER
304
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TO CONTROL ROOM
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FIG. 17

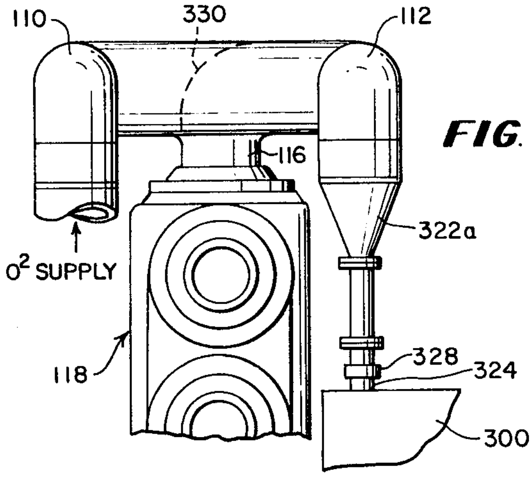
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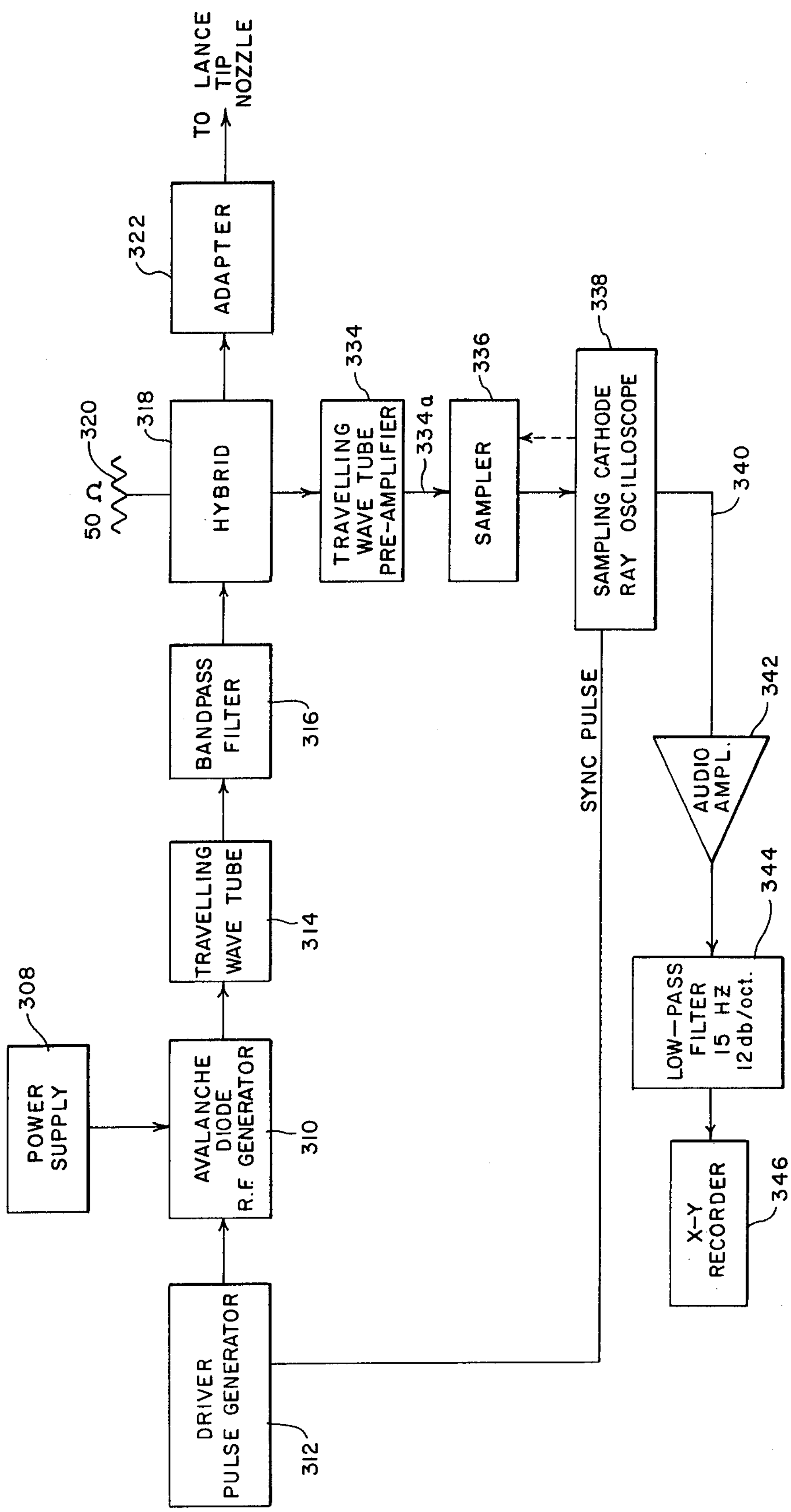
FIG 18


TO LANCE TIP NOZZLE
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TRAVELLING WAVE TUBE PRE-AMPLIFIER
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SAMPLER
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SAMPLING CATHODE RAY OSCILLOSCOPE
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320
318
50 Ω
HYBRID
BANDPASS FILTER
316
TRAVELLING WAVE TUBE
314
308
POWER SUPPLY
AVALANCHE DIODE R.F. GENERATOR
310
DRIVER PULSE GENERATOR
312
SYNC PULSE
342
AUDIO AMPL.
344
LOW—PASS FILTER 15 HZ 12 db/oct.
X-Y RECORDER
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FIG. 19

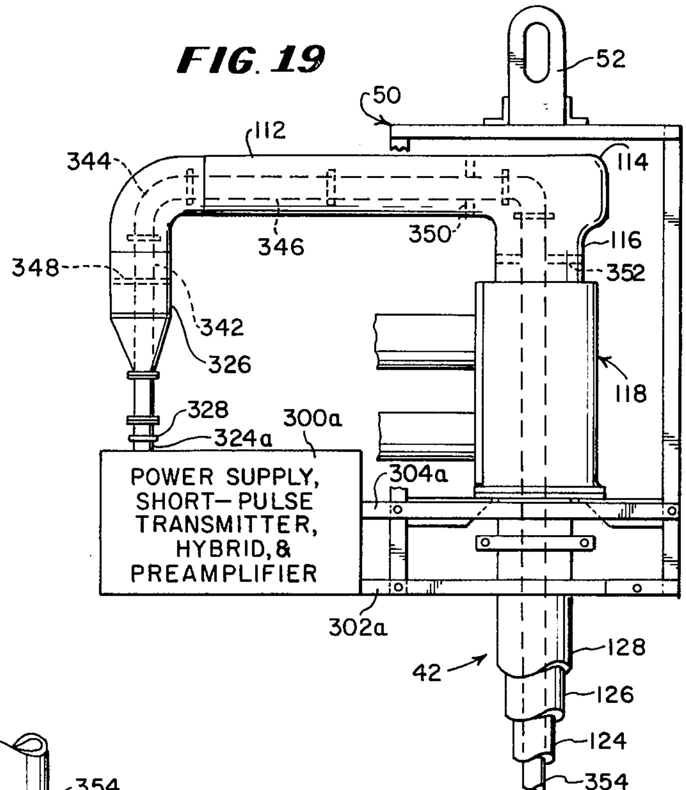
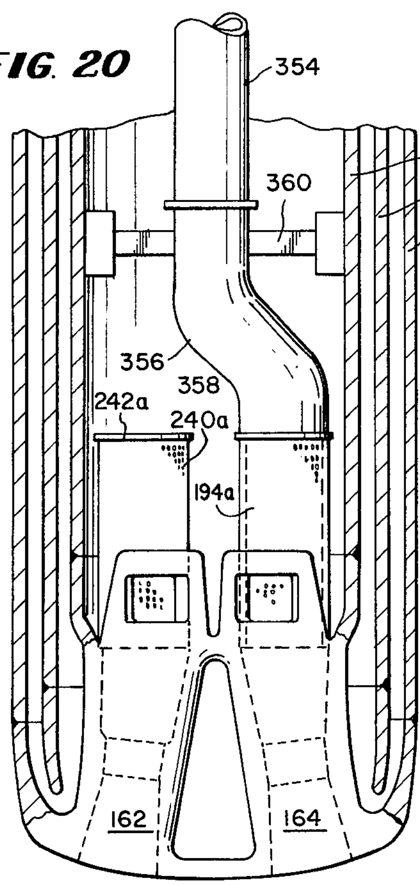


FIG. 20



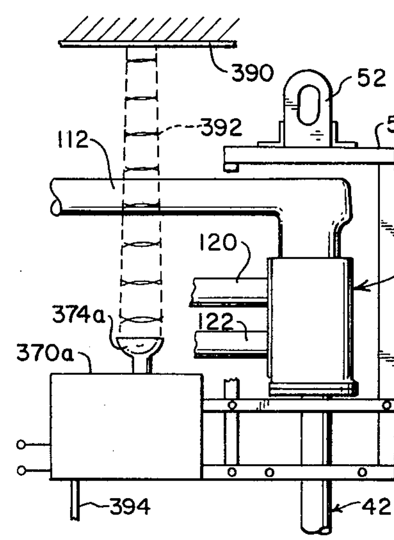
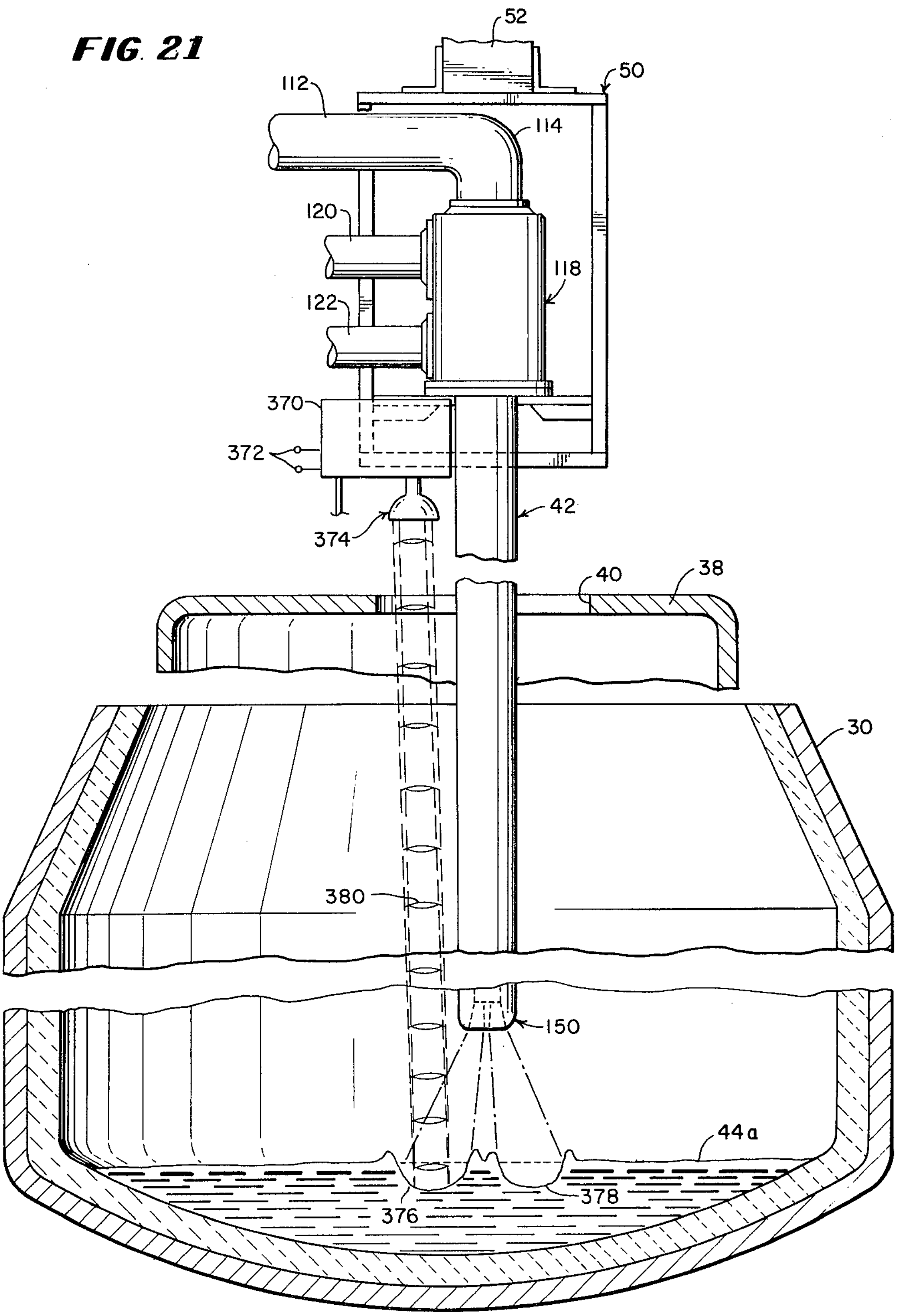


FIG. 22

FIG. 21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OXYGEN LANCE CONTROL ARRANGEMENT FOR BASIC OXYGEN FURNACE

The present invention relates to a top blown oxygen steelmaking converter such as the basic oxygen furnace, and, more particularly to a system and method for measuring and controlling the position of the oxygen blowing lance relative to the surface of the molten material within the converter in such manner as to optimize the efficient production of steel in such a converter.

In a conventional steelmaking converter of the top blowing type, commonly known as a basic oxygen furnace, a fire brick lined vessel open only at the top is employed into which is first loaded up to 30 percent of scrap iron. Molten iron which has been reduced from iron ore to iron in a blast furnace by removing impurities, is then moved directly from the blast furnace to the converter and is dumped into the top of the vessel. Various other ingredients called additives, which are necessary for proper slag formation and chemical conversion of the iron, are also added to the molten material in the vessel. A hollow pipe, called an oxygen lance, is then lowered through the upright top of the vessel to a position such that the tip of the lance is near the surface of the molten material. Pure oxygen is then supplied to the top end of the lance and issues from the lance tip in the form of one or more downwardly directed high velocity jets of oxygen which impinge upon the surface of the molten material with such force as to produce craters or cavities in the molten metal. This direct supply of oxygen is employed without any source of heat other than the heat created from the chemical reaction of the pure oxygen with the hot iron, to produce steel. While a complete steelmaking cycle may last as long as 40 minutes, oxygen is blown only over a short portion of this cycle and may last as little as 12 to 18 minutes. When oxygen is blowing, the vessel itself is filled with fumes, sparks and dust to the extent that there is no visibility within the vessel. In addition, the air space around the vessel is often filled with flying sparks rendering it difficult or impossible to approach the vessel from the sides. The operations of the vessel are controlled from a platform, aptly known as the pulpit, which is related to the top or open end of the vessel and to the side thereof so as to be out of the way of a hood which is positioned above the upright vessel and acts as a fume catcher to divert the fumes up a smokestack.

According to conventional practice, the oxygen lance is controlled by an operator who decides at what level the lance tip should be positioned and energizes a motor control system which actuates a lance crane comprising a suitable cable and drum arrangement the drum being rotated to lower the lance into the open top of the vessel. A lance height indicator, which may be controlled from a slide wire transmitter driven from the lance drum, is employed to provide an indication of the position of the lance tip. However, since the lance may be as long as 70 feet, is quite heavy and must be raised and lowered a distance of many feet during each steelmaking heat cycle, the lance drum indicator does not give an accurate indication of the position of the lance tip due to stretching of the crane cables during the raising and lowering operations. Also, since the oxygen lance is subjected to relatively high temperatures during the blowing operation, it may expand as much as 4 or 5 inches in length, thus rendering any initial measurement of lance tip position considerably in error.

Furthermore, and most importantly, the lance operator has no way of accurately determining the position of the lance tip relative to the level of the molten material within the vessel. This is because the level of the molten iron within the vessel will vary from heat to heat, depending upon the amount of scrap iron and molten iron which is supplied from the blast furnace. Furthermore, as the refractory lining of the vessel is worn away the level of the molten bath, even assuming that identical amounts of iron are added during each heat, correspondingly decreases. Also, when the refractory lining is coated with lime to seal the cracks between bricks the lime tends to collect in the bottom of the vessel and is not removed when the vessel is emptied. This buildup of lime may become as much as a foot or more in the bottom of the vessel and may greatly change the level of the molten material which is dumped in on top of the buildup of lime in the vessel.

At the present time, the actual distance between lance tip and molten material can be measured only by attaching a steel rod to the lance, lowering the lance until the tip of the rod is immersed in the liquid steel, letting the immersed portion of the rod melt in the liquid steel, and then moving the lance vertically out of the vessel and the hood and measuring the remaining rod length. In some plants such a measurement is made every day, while in others, such a measurement is made every shift. However, the refractory wear and subsequent lowering of the molten iron level between these measurements is neglected. Furthermore, such a measurement is made when no oxygen is blown and, of course, does not provide any indication of the dynamic operation of the basic oxygen furnace. Thus, at the present time, there exists no control arrangement by means of which the lance operator may accurately position the lance tip relative to the level of the molten material in the vessel.

It is, therefore, a primary object of the present invention to provide a new and improved control arrangement for positioning an oxygen lance relative to the surface of the molten material within the vessel of a top blowing oxygen converter.

It is another object of the present invention to provide a new and improved control arrangement for indicating and/or positioning an oxygen lance relative to the molten material within the vessel wherein reflection of an electromagnetic wave transmitted downwardly from the lance is employed to determine the distance between the lance tip and the level of the molten material within the vessel.

It is a further object of the present invention to provide a new and improved oxygen lance positioning system wherein an electromagnetic wave is generated and is transmitted downwardly through one of the nozzles in the lance tip and is reflected back through said nozzle to a receiver, a signal proportional to the elapsed time between transmitted and reflected waves being employed as a control parameter in either an open loop or a closed loop control system.

It is a still further object of the present invention to provide a new and improved oxygen lance position indicator system wherein inaccuracies due to elongation of the cable employed to lower the lance into the vessel are eliminated.

It is another object of the present invention to provide a new and improved oxygen lance positioning system wherein at least one of the nozzles in the lance tip which is employed to form a high velocity oxygen jet during the oxygen blowing period of the process, also acts as a transmitting and receiving antenna for an electromagnetic wave transmitted downwardly through the nozzle and reflected upwardly therethrough from the surface of the molten material in the vessel.

It is a further object of the present invention to provide a new and improved arrangement by means of which the conventional lance drum indicator may be accurately calibrated prior to the initiation of the oxygen blowing operation, so that this indicator may be employed during subsequent portions of the process to provide accurate positioning or repositioning of the lance tip as desired.

While it is desirable initially to position the oxygen lance accurately with respect to the molten metal at the start of the oxygen blowing operation, it is also necessary to reposition the oxygen lance tip to a different position during later periods of the blowing operation. Thus, the lance tip is originally positioned relatively far away from the level of the molten material, at a distance of from say 80 to 120 inches, during the so-called pre-ignition portion of the oxygen blowing process in which silicon is preferentially oxidized. Once the silicon in the melt has been substantially completely oxidized, the lance tip must be moved substantially closer to the level of the molten material in the vessel in order to provide the proper spacing between lance tip and metal bath for most efficient mixing action with the melt and carbon removal. However, once the oxygen blowing operation is initiated the surface of the melt becomes violently heaving and oscillatory so that the level of the molten metal relative to the lance tip is constantly changing during the oxygen blowing operation. Under present operating procedures, the lance operator can merely make a hopefully educated guess as to the distance between the lance tip and the violently heaving liquid metal within the vessel and lower the lance tip to a point which he believes will give the desired carbon removal. Also, if a reblow is required after the main oxygen blowing operation is completed, it is necessary to reposition the lance either at a high level for heating the steel without further decarbonization or at a lower level for decarbonization within increased heating of the steel.

While certain arrangements have been heretofore proposed for the dynamic control of a basic oxygen furnace these arrangements have not made any attempt to measure the constantly varying distance between the lance tip and the heaving surface of the molten material in the vessel nor have these arrangements attempted to employ such a measurement as a control parameter useful in the dynamic control of the basic oxygen furnace during the oxygen blowing operation. In general, these prior art process control arrangements have attempted to determine the rate of decarbonization or carbon removal during the early phases of the oxygen blowing operation by analyzing the gases given off during the oxygen blowing operation so as to determine the carbon content of such gases. One such arrangement measures the carbon and oxygen compounds in the waste gases for a given period of time together with the amount of oxygen blown during the same period of time and calculates from these measurements a carbon oxidation rate.

A set of characteristic decarbonization curve is thus derived empirically. At some point during the middle of latter phases of the blowing operation, the temperature of the molten bath is obtained by lowering a sinker thermocouple into the molten metal so as to determine an actual point on the temperature curve. This information is then employed to correct the blowing operation, primarily by changing the amount of oxygen which is being blown, so that the desired carbon end point and the desired end point temperature will be achieved to provide the desired quality of steel.

Such arrangements for dynamic control of the basic oxygen furnace are necessarily approximations since they depend upon attempted correlations of the actual furnace operation with a set of ideal curves rather than relying upon an actual measurement of what is going on in the furnace during the blowing operation. Furthermore, a considerable amount of time is required to analyze the exhaust gases and determine carbon content so that the resulting control parameter lags considerably behind the actual events taking place in the furnace and cannot be used for the direct dynamic control of the oxygen blowing operation.

It is, therefore, a further object of the present invention to provide a new and improved control arrangement for a basic oxygen furnace wherein the actual distance between the lance tip and the surface of the molten material in the vessel during the oxygen blowing operation may be employed as a control parameter.

It is another object of the present invention to provide a new and improved control arrangement for a basic oxygen furnace wherein an indication is provided during the oxygen blowing operation of the constantly varying distance between the lance tip and the heating surface of the molten material in the vessel, said indication being useful in the dynamic control of the oxygen blowing operation.

It is still another object of the present invention to provide a new and improved control arrangement for a basic oxygen furnace whereby the oxygen blowing lance may be positioned to different points relative to the heaving surface of the molten material during the oxygen blowing operation to provide optimum operating conditions for the furnace.

It is a further object of the present invention to provide a new and improved arrangement for measuring the amount of heaving of the molten metal surface during the oxygen blowing operation so that maximum efficiency during pre-ignition and carbon removal stages of the process may be achieved without causing an excessively unstable condition to arise which could produce sparking and furnace ejections such as slopping.

It is another object of the present invention to provide a new and improved dynamic control arrangement for a basic oxygen furnace wherein the motion of the heaving surface molten material in the vessel during the oxygen blowing operation is analyzed to provide information which can be used to control lance height and oxygen blowing rate to provide optimum conversion of iron into steel.

Briefly, in accordance with one aspect of the present invention, a radar system, which may be of the pulsed, FM/CW or phase modulation type, is provided which includes an electromagnetic wave generator arranged to transmit an electromagnetic wave through one of the nozzles in the lance tip which is also employed to form a high velocity oxygen jet during the oxygen blowing operation. The electromagnetic wave which is transmitted downwardly to the surface of the molten material in the vessel and is reflected back through said nozzle to a suitable receiving means, which may also be positioned within the lance. The elapsed time between transmitted and reflected waves is then employed to determine the actual distance between the lance tip and the surface of the molten material in the vessel. An output signal which may be in either analog or digital form, is then provided which accurately indicates the actual distance between the lance tip and the surface of the molten metal in the vessel. This distance signal may be employed in any one of several ways. First, as the oxygen lance is initially lowered into the open top of the vessel before the oxygen blowing operation is started, an indication of lance tip distance from the quiescent level of the melt may be provided at a selected point. The lance operator is thus informed of the actual distance to the quiescent level of the melt and may position the lance tip accurately at the desired location for the start of oxygen blowing. Furthermore, he can at the same time calibrate his existing lance drum indicator so that the lance drum indicator may thereafter be used for subsequent re-positioning of the lance tip to different levels during the oxygen blowing operation and reblow.

The above described lance separation signal may also be continuously employed to provide an indication of the frequency and amplitude characteristics of the heaving surface of the molten material during the actual oxygen blowing operation. With this information, either the lance height or oxygen blowing rate, or both, may be controlled either manually or by automatic process control means, which may include a computer, so as to set up a desired amplitude of standing wave in the molten liquid during various portions of the oxygen blowing operation to provide optimum efficiency of the conversion process. For example, the lance separation signal may be employed to position the lance during the pre-ignition period for optimum removal of silicon without loss of energy due to mixing of the steel which would be experienced if the lance were too close to the level of the liquid. Also, as slag is formed during the initial stages of the oxygen blowing operation the lance separation signal may be employed to determine and control the maximum amplitude of heaving of the molten material so that sparking and slopping does not occur. After the pre-ignition period, the lance may be accurately lowered to the desired point at which optimum carbon removal is achieved while limiting the instability of the heaving liquid within the vessel. Finally, if a reblow is necessary after the initial blowing operation has been completed, the lance separation signal may be employed to position the lance tip relatively far from the level of the liquid if additional heat is required or relatively close to the surface of the liquid if additional mixing and carbon removal is required to achieve the desired carbon end point and temperature end point for a desired quality of steel.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in connection with the accompanying drawings in which:

FIG. **1** is a side elevational view, partly in section, of a basic oxygen furnace employing an oxygen lance positioning system in accordance with the present invention;

FIG. **2** is a sectional view taken along the lines **2—2** of FIG. **1**;

FIG. **3** is a block diagram of the major electronic components of the positioning and control system of the present invention shown in conjunction with a diagrammatic representation of the oxygen lance;

FIG. **4** is a sectional view of the tip of the oxygen blowing lance of FIG. **3** but taken on a somewhat larger scale and illustrating the manner in which electromagnetic waves are transmitted and received through one of the nozzles of the lance tip;

FIG. **5** is a sectional view taken along the lines **5—5** of FIG. **4**;

FIG. **6** is a side elevational view of the lance top adaptor unit provided at the upper end of the oxygen blowing lance in the system of FIG. **1**;

FIG. **7** is a plan view of the lance top adaptor of FIG. **6**;

FIG. **8** is a left-side view of the lance adaptor portion of FIG. **6**;

FIG. **9** is a cross sectional view of the lance top adaptor of FIG. **6**, taken on a somewhat larger scale, and illustrating the manner in which the transmitted and received electromagnetic signals are supplied to the upper end of the lance;

FIG. **10** is a sectional view taken along the lines **10—10** of FIG. **9**;

FIG. **11** is a detailed block diagram of the major components of one type of transmitting and receiving radar system which may be employed to determine the separation of the lance tip from the surface of the molten material in the vessel of the basic oxygen furnace;

FIG. **12*a*** is a timing diagram showing the relationship between transmitted and received signals when linear modulation is used in the system of FIG. **11**;

FIG. **12*b*** is a timing diagram of the beat frequency characteristic when linear modulation is used as shown in FIG. **12*a*;**

FIG. **13** is a frequency component diagram illustrating the various beat frequency components of the received signal in the system of FIG. **11**;

FIG. **14*a*** is a timing diagram showing the relationship between transmitted and received signals when sinusoidal modulation is employed in the system of FIG. **11**;

FIG. **14*b*** is a timing diagram of the beat frequency obtained with sinusoidal modulation as in FIG. **14*a*;**

FIG. **15*a*** is an energy-frequency characteristic of a typical received spectrum when linear modulation is used in FIG. **11**;

FIG. **15*b*** is an energy-frequency characteristic of the received signal when sinusoidal modulation is employed in the system of FIG. **11**;

FIG. **16** is a side elevational view of a lance top adaptor arrangement wherein an alternative embodiment is employed for transmitting electromagnetic waves to the lance tip;

FIG. 17 is a lefthand side view of the arrangement of FIG. 16;

FIG. 18 is a block diagram of the major system components employed in a short-pulse ranging radar system which may be used in the arrangement of FIGS. 16 and 17;

FIG. 19 is a side elevational view of a lance top adaptor portion of an alternative embodiment of the invention wherein a further alternative arrangement for transmitting electromagnetic waves to the lance tip is employed;

FIG. 20 is a sectional side elevational view of the lance tip portion of the arrangement of FIG. 19, shown on a somewhat larger scale, and illustrating the manner in which electromagnetic waves are transmitted through one of the nozzles of the lance tip;

FIG. 21 is a side elevational view, partly in section, of a further alternative embodiment of the invention wherein a ranging radar system is provided outside the oxygen blowing lance to measure the distance to the molten material within the vessel of the basic oxygen furnace; and

FIG. 22 is a side elevational view of a still further embodiment of the invention wherein a ranging radar system is employed to provide an indication of lance height with respect to a fixed reference plane, this indication being usable in place of the conventional lance drum indicator.

Referring now to the drawings, and more particularly to FIGS. 1 and 2 thereof, the oxygen lance positioning system of the present invention is shown therein in connection with a basic oxygen furnace which includes an open top vessel indicated generally at 30 which is lined with some 2 to 3 feet of refractory material 32 and is adapted to receive scrap iron and molten iron directly from the blast furnace, as indicated generally at 34.

Conventionally, the vessel 30 is provided with trunion pins 36 which are journaled in suitable bearings, one of these pins being arranged to be driven so that the vessel may be tilted for the loading and emptying operations. A hood 38 is provided above the open mouth of the vessel 30 when this vessel is positioned vertically, and is adapted to carry off the fumes and exhaust gases produced during the steelmaking operation. The top of the hood 38 is provided with a central opening 40 (FIG. 2) through which an oxygen blowing lance, indicated generally at 42, may be lowered downwardly through the entire hood 38 and into the open top of the vessel 30 until the lance 42 is positioned somewhat above the surface 44 of the molten material 34 within the vessel 30. Since the vessel 30 may have a height of some 35 to 40 feet and the hood 38 is likewise of substantial height, the lance 42 conventionally has a length of about 70 feet in order to extend through the hood 38 and into the vessel 30 to a position a few feet above the surface of the molten material within the vessel 30. Accordingly, the oxygen blowing lance 42 is arranged to be suspended from a carriage 46 which is movably mounted on a vertically extending frame indicated generally at 48, and is suspended on the end of a cable 54. To this end, the lance top adaptor portion 50 is provided with an eye 52 which is arranged to be connected to a hook secured to the carriage 46. The frame 48 comprises a pair of vertically extending I beam members 56 and 58 (FIG. 2) which are connected together at the top and bottom ends thereof by means of triangularly shaped end plates 60 and 62, these end plates being journaled for rotation about a vertical axis by means of the bearings 64 and 66.

In order to swing the frame 48 about the vertical axis of the bearings 64, 66, a lance slewing motor 70 is mounted on the frame 48 and is arranged to drive a pinion gear 72 which is in engagement with a fixed segment gear 74 so that the oxygen blowing lance 42 may be swung in the arc of a circle as indicated at 76 in FIG. 2. Normally, a second oxygen blowing lance 42*a* is mounted on an associated frame 48*a* and may be used alternately with the lance 42. When one of the oxygen blowing lances is not being used it is swung to a parked position as indicated in FIG. 2 by the position of the lance 42*a*. The active oxygen blowing lance 42 is swung to an operative position over the opening 40 in the hood 38. When the lance is properly positioned with respect to the hood opening 40, a hoist drive motor 80 is energized so that the cable 54 is paid out and the lance 42 is lowered through the hood 38 and into the top of the vessel 30.

In accordance with the present invention, a microwave transmitter, indicated generally at 82, is arranged to develop an electromagnetic wave which is conveyed by means of a flexible coaxial cable 84 to the lance top adaptor portion 50. This electromagnetic wave is conveyed through the inside of the lance 42 to the tip portion thereof and issues from one of the nozzles provided in the lance tip for developing high velocity jets of oxygen which impinge upon the surface 44 of the molten material 34 in the vessel 30. A suitable crystal detector is provided within the lance tip portion or at the receiver circuitry 82, and is adapted to receive the reflected wave which bounces back from the reflective surface 44 within the vessel 30 as well as a small portion of the transmitted signal. Beat frequency components resulting from these transmitted and reflected signals are supplied by way of a flexible coaxial cable 86 to suitable receiver circuitry within the unit 82 and the resultant lance distance signal is supplied by way of the conductor 88 to the control pulpit room 90 and the computer room 92 which normally house the control facilities for operating the basic oxygen furnace.

Referring now to FIGS. 3 to 15, inclusive, wherein the details of the lance positioning system described generally heretofore are shown, the top adaptor portion 50 of the lance 42 is illustrated as comprising a frame consisting of top and bottom members 94 and 96 (FIG. 6) and side members 98 and 100, the eye 52 being secured to the top member 94 by means of the right angle brackets 102 and 104. The eye plate 52 is preferably pivotally mounted to the brackets 102 and 104 so as to permit the lance 42 to hang directly downwardly and the center line of the opening 106 provided in the eye 52 is offset from the center line of the lance 42 to achieve a plumb attitude when the lance is suspended from a hook placed within the opening 106, as will be readily understood by those skilled in the art.

Oxygen may be introduced through either arm 110 or arm 112 of a Y-shaped oxygen header 114 which opens downwardly by means of a common offset central pipe 116 into the top of a housing 118 into which the water inlet pipe 120 and the water outlet pipe 122 are connected. The oxygen lance 42 comprises a central pipe **124** which is usually eight inches in diameter, an intermediate concentric pipe **126** which is usually 10 inches in diameter and an outer pipe **128** which is concentric with the pipes **124** and **126** and is usually 12 inches in diameter.

As best illustrated in FIG. **9**, the central portion **116** of the Y-shaped header **114** is secured to a collar **130** which is positioned on the upper end of the housing **118** and the central oxygen pipe **124** is secured to an annular ring **132** positioned within the housing **118** so that oxygen supplied to either of the inlet pipes **110** or **112** is supplied directly to the interior of the central pipe **124**.

In order to cool the oxygen blowing lance **42**, and particularly the tip portion thereof, cooling water is introduced from the pipe **120** into the chamber **134** of the housing **118** and is supplied to the space **136** between the pipes **124** and **126**. The cooling water travels downwardly adjacent the central oxygen pipe **124** to the lance tip and is forced upwardly through the space **138** between the pipes **126** and **128** to the water outlet pipe **122**. The housing **118** is preferably seated on a platform **140** which extends between the side members **98** and **100** of the top adaptor frame, the housing **118** being provided with a bottom flange **142** which is adapted to seat on the platform **140**. The lance tip portion, indicated generally at **150**, is preferably cast as an integral unit from substantially pure copper and is secured to the bottom ends of intermediate pipe sections **124*a***, **126*a***, and **128*a*** by means of the welds **152**, **154** and **156** (FIG. **4**). The pipe sections **124*a*** and **128*a*** are in turn connected to the pipes **124** and **128** by means of the steel-to-steel welds **152*a*** and **156*a*** and the pipe section **126*a*** is connected to the pipe **126** through an expansion joint **154*a***. In the illustrated embodiment the lance tip **150** is provided with four oxygen jet forming nozzles **158**, **160**, **162** and **164**, each of these nozzles comprising a converging portion such as the portion **164*a*** of the nozzle **164**, a throat portion **164*b*** and a diverging portion **164*c***. Conventionally, oxygen supplied to the upper end of the central pipe **124** issues from all four of the nozzles **158**, **160**, **162** and **164** in the form of high velocity jets of oxygen, traveling at approximately twice the local speed of sound and having sufficient force to form craters or cavities in the surface **44** of the molten material within the vessel **30**.

In accordance with an important feature of the present invention, one of these nozzles, such as the nozzle **164**, is employed as a microwave antenna to which an electromagnetic wave is supplied from the interior of the pipe **124**. This electromagnetic wave which issues from the nozzle **164** travels downwardly from the lance tip **150** until it strikes the surface of the molten material **44** in the vessel **30** and is then reflected back through the nozzle **164** which now acts as a microwave receiving antenna and is utilized to determine the spacing or separation between the lance tip **150** and the reflecting surface **44**. More particularly, an electromagnetic wave is developed by the generator **170** (FIG. **3**) and is supplied by way of the flexible coaxial cable **84** to a coaxial cable fitting **172** which is mounted in the wall of the central vertically extending oxygen pipe section **116**. A coaxial cable **174** is connected to the coaxial connector **172** internally of the pipe **116** and extends downwardly through the center of the oxygen pipe **124** within a small pipe **176** which is mounted within the pipe **124** by means of brackets **178** which are spaced along the length of the pipe **124** and are secured to the inside of this pipe by means of the mounting brackets **180** and **182**.

Somewhat below the end of the pipe **176**, the coaxial cable **174** is connected through a type N coax fitting **180** to a microwave hybrid unit **182**, a dummy load **184** being connected to the hybrid **182** through the fitting **186**. The transmitted electromagnetic wave is then supplied through the fittings **188** and **190** to a coaxial cable-to-2.25 inch circular wave guide transition member or antenna **192**. The flared transition member or directive antenna **192** is seated on and secured to the upper end of a perforated metal cylinder **194** the bottom edge of which rests on the inner bottom wall **196** of the lance tip **150**. The cylinder **194** acts as a short section of circular wave guide so as to transmit the electromagnetic wave downwardly from the end of the transition member **192** to the converging portion **164*a*** of the nozzle **164** and the interior of the cylinder **194** is preferably coated with a thin layer of conductive material such as copper, to reduce losses in transmission of the electromagnetic wave therethrough. The cylinder **194** is perforated so as to permit the entrance of oxygen into the cylinder **194** and hence to the nozzle **164**. However, the perforations in the cylinder **194** are of the proper diameter and spacing so as to contain the electromagnetic wave within the cylinder **194** so that it may be propagated downwardly to the converging portion **164*a***. For example, the perforations in the cylinder **194** may be 0.125 to 0.200 inch diameter holes. It should be noted that the cylinder **194** will necessarily introduce some pressure drop since it will provide some obstruction to the flow of oxygen to the nozzle which flow may be in the order of 6,000 standard cu. ft. per min. Accordingly, the cylinder **194** must be strong enough to withstand this pressure drop and the highest pressure is on the outside of the cylinder **194** and tends to crush the cylinder. The cylinder **194** may be of steel and have a wall thickness of 0.125 in., the perforations in the cylinder wall being formed by drilling holes of a suitable diameter to accomplish the above-described objectives or, alternatively, the holes may be more economically provided by punching. If the holes are punched they can be square holes with sides oriented vertically so that better streamlining and less pressure drop is produced than with round holes. In the alternative, the cylinder **194** may be made of a material consisting of a porous matrix of small metallic shot material bonded together by suitable sintering techniques to provide a mesh-like cylinder having about 10 percent of its surface area consisting of voids through which oxygen can flow. Such a material has a smooth internal surface for transmission of the electromagnetic wave without dissipating energy in higher order modes while at the same time being less expensive and easier to fabricate than a steel cylinder. The length of the cylinder **194** is chosen so that sufficient oxygen can be admitted through the openings in the cylinder **194** to provide the required flow of oxygen to the entrance of the nozzle **164** with an acceptable pressure drop. For example, the cylinder **194** may be of steel and have a perforated length of 8 in. in which 960 holes of 0.125 in. diameter are symmetrically arranged. However, it will be understood that other ratios of length to number of holes can be used so long as the area of the holes is at least four times the area of the throat **164*b*** of the nozzle **164**. The cylinder **194** is preferably supported within the lance tip **150** by means of an arcuate upstanding boss portion **198** which extends upwardly from the bottom surface **196** of the tip portion **150**, the cylinder **194** being secured as by welding or brazing to the boss **198** as indicated at **200**. Preferably the boss **198** is provided with openings **202** so as to permit the maximum amount of oxygen to be admitted to the interior of the cylinder **194**.

Since the perforated cylinder **194** necessarily offers some impediment to oxygen flow to the nozzle **164**, if only one of the four nozzles of the lance tip **150** were so impeded, the lance jets would tend to energize preferentially the lowest unsymmetrical mode of oscillation of the liquid pool **34** within the vessel **30** which in turn would tend to produce undesired slopping. In addition, if only one of the four nozzles is impeded, a force would be developed tending to move the lance sidewise away from the center of the vessel, due to the fact that the force of the oxygen jet through the unimpeded nozzles would be greater than the force through the nozzle **164** and since these nozzles are directed at an angle to the vertical center line of the lance **42**, a sidewise component of thrust would thus be developed. In order to overcome these difficulties, the nozzle **162** which is diametrically opposite the nozzle **164** is also provided with a perforated metal cylinder **240** of the same length as the cylinder **194**, the cylinder **240** being closed at its upper end by means of a cover plate **242**. The bottom end of the cylinder **240** is seated on the surface **196** of the tip **150** and an arcuate boss **244**, similar to the boss **198** is provided for support of the cylinder **240**. The cylinder **240** is perforated in the same manner as the cylinder **194** so that oxygen issuing from the nozzle **162** has exactly the same force as the oxygen jet emitted from the nozzle **164**. The other two nozzles **158** and **160** are balanced with respect to the nozzles **162** and **164**, and hence do not require matching cylinders such as the cylinders **194** and **240**. If an oxygen blowing lance having three nozzles is used then all three nozzles should preferably be balanced.

The electromagnetic wave which is transmitted downwardly through the wave guide section **194** is propagated downwardly through the converging, throat and diverging portions of the nozzle **164** and is emitted in the form of a directed microwave signal from the bottom end of the lance tip **105** in the direction of the longitudinal axis of the nozzle **164**. The transmitted wave is reflected back from the surface **44** of the molten material in the vessel **30** and re-enters the nozzle **164**, is propagated upwardly through the diverging and converging portions of this nozzle and the wave guide section **194** to the flared transition member **192** so that a received signal is developed at the output **204** of the hybrid **182**. This received signal, together with a small portion of the transmitted signal which appears at the output **204** of the hybrid **182** due to leakage within the hybrid, is supplied by way of the fitting **206** to a crystal detector **208**. The output from the crystal **208** is supplied by way of the fitting **210** to a coaxial cable **212** and the cable **212** extends upwardly through the pipe **176** within the lance **42** to the other input of the coaxial cable connector **172** in the top adaptor portion **50**. The cable **212** is connected through the connector **172** to the flexible receiver coaxial cable **86** outside the pipe section **116** and the cable **86** is connected to the electromagnetic wave receiving circuitry indicated generally at **214** in FIG. **3**. As mentioned heretofore, the crystal detector **208** may be located adjacent the receiver circuitry **214** and the transmitted and reflected signals developed in the output **204** of the hybrid **182** may, if desired, be transmitted directly over the cables **212** and **86** to this crystal. Such an arrangement has the advantage that spurious signals which may appear in the hybrid output will be attenuated in transmission to the receiving crystal.

In the receiving circuitry **214** the signal transmitted over the cable **86** is processed to develop an output signal proportional to the distance of the lance tip **150** from the reflecting surface **44** within the vessel **30**, as will be described in more detail hereinafter in connection with the detailed circuit diagram and timing wave forms shown in FIGS. **11** to **15**, inclusive. This output signal is transmitted over the conductor **88** to a lance distance signal display unit **220** in the control room **90**. A lance drum indicator **222** is provided in the control room **90** and indicates the position of the lance drum as the lance **42** is lowered by means of the driving motor **80**.

Conventionally, the lance drum indicator **222** is energized from a slide wire transmitter driven from the lance drum and indicates the position of this drum to the operator within the control room **90**. However, as indicated heretofore, the reading of the drum indicator **222** is under current practice, in error due to stretching of the supporting cable **54** and also due to thermal elongation of the oxygen blowing lance **42** when it is heated up. Furthermore, and most importantly, the distance between the lance tip **150** and the surface of the molten material in the vessel **30** is not given by the drum indicator **222** because this level may vary with many factors such as the amount and character of the scrap iron used in the heat, the thickness of the refractory lining **32**, and the buildup of lime in the bottom of the vessel **30**. The lance distance signal display unit **220** does, however, in accordance with the present invention, provide a true indication of the distance between the lance tip and the reflecting surface of the molten material in the vessel **30**.

The lance distance signal displayed on the unit **220** may be used in several different ways. First, this distance signal may be used to make a quiescent measurement of the distance between the lance tip **150** and the reflecting surface within the vessel **30** before oxygen blowing is begun and hence before the surface of the molten material becomes violently heaving and churning as it does when oxygen is being blown. This quiescent measurement is made as the oxygen lance **42** is being lowered into the vessel **30** as it approaches the point where the lance is to be stopped and oxygen blowing started for the pre-ignition process. When the lance **42** reaches the desired distance above the surface **44**, as indicated on the unit **220**, the operator can use the distance signal thus displayed to calibrate the reading of the lance drum indicator **222** at this same point. Thus, the operator is informed that whereas the conventional lance drum indicator indicates, for example, that the lance tip **150** is positioned 120 in. above the surface **44**, this lance tip is actually positioned 108 in. from the surface **44**, due to the above-discussed factors which influence lance tip position and the level of the molten material in the vessel **30**. Once this calibration is made for the drum indicator **222**, the indicator **222** may then be used during the actual oxygen blowing operation to re-position the lance tip **150**, as required during the various operations during the heat, including the re-positioning of the lance tip at the proper height if a re-blow operation is necessary. Under these conditions, the operator manually controls the lance crane controls **224**, i.e., the lance driving motor **80**, the controls for releasing additives from the bins **226** into the vessel **30** at the proper times during the heat, and the oxygen control valve **228** for controlling the flow of oxygen to the pipe **110**, all as indicated by the dotted line **223** in FIG. 3.

It is also contemplated that the lance distance signal, which is obtained before the oxygen blowing operation is started, may be fed to a computer **230** where it is stored and utilized during the oxygen blowing operation in place of the signal conventionally generated by the lance drum transmitter. The computer **230** may, for example, be of the type described in the article entitled "Dynamic Control of Basic Oxygen Steel Process" by Keenan, Carlson and Martz appearing in Instruments and Control Systems for May 1967 pages 139 to 144, inclusive. The computer control system described in said article is intended to function with data derived from the chemical analysis of the exhaust gases from the vessel **30** and measurement of the bath temperature with a sinker thermocouple and controls lance position and oxygen flow to obtain the desired temperature and carbon content end points, for a desired quality of steel. As indicated generally heretofore, such a computer control arrangement is relatively slow acting because it depends upon gas analysis of the carbon removal rate in the initial stages of the heat and other on-line data. However, by employing the accurate lance distance signal developed by the ranging radar system of the present invention, the computer **230** is able to control the process more accurately and closer duplication of results with different heats is made possible.

It is also contemplated that the lance distance signal developed by the display unit **220** may be employed during the actual oxygen blowing operation and while the molten material within the vessel **30** is heaving and churning. Furthermore, since the oxygen jet emitted from the nozzle **164** produces a crater or cavity in the surface **44** of the molten material, this dynamic lance distance signal will be a measure of the actual distance between lance tip **150** and the bottom of the crater or cavity thus formed.

During the oxygen blowing operation the basic oxygen furnace may be considered as a process which includes the oxygen jets, the molten material, or melt, within the vessel, which may be considered as a body of liquid capable of various modes of oscillatory motion, and the interaction between the jets and the melt. When the oxygen jets strike the melt they produce a curtain or spray of droplets of steel and/or slag from each crater and part of these droplets are entrained and driven back into the melt by so-called jet pumping. As a result, energy is periodically added to the melt by the oxygen jets which results in oscillatory motion of the melt within the vessel **30**. This oscillatory motion may be made up of many modes, both diametral and circumferential, depending upon many factors including the shape of the vessel **30**, the mass, viscosity, slag-iron ratio, or slag composition of the melt, etc. Furthermore, depending upon the jet coupling to the melt the amplitude of this oscillatory motion may become so large as to cause the system to become unstable and cause sparking or slopping of the molten material out of the top of the vessel. Also, under certain conditions of acoustical feedback within the jet its pressure may drop abruptly thus causing a marked decrease in the amplitude of oscillation of the melt.

It will thus be seen that while the basic oxygen furnace is affected by many factors which cannot be detected directly, the direct dynamic measurement of variations in the level of the melt in the vicinity of the jet craters, by means of the above-described lance distance signal provides a new control parameter which may be used to correct other process parameters which cannot themselves be measured and thereby provide for the more efficient production of steel by means of the basic oxygen process. In this connection, it will be understood that the dynamic lance distance signal will contain frequency components corresponding to each of the modes of oscillation of the melt within the vessel **30** and the amplitudes of these various frequency components may be correlated and compared to provide an indication of optimum performance at various times during the oxygen blowing operation. Furthermore, by controlling oxygen flow to the lance the amplitude of oscillatory motion of the melt may be maintained at a high level to provide optimum mixing and shorten the overall process, without introducing instability of the melt which causes sparking or slopping. If the amplitude of the standing waves becomes excessive, the oxygen pressure may be reduced or the lance **42** may be raised to avoid instability. Also, under some conditions of incipient instability, the lance **42** may be moved sidewise within the opening **90** in the hood **38**, by controlling the slewing motor **70**, so that the mass of the melt is excited at a different point and less inphase energy is supplied to this oscillating mass by the oxygen jets.

Variation in power distribution between the various frequency components of the lance distance signal may also be employed to control the process. For example, at the beginning of the heat most of the energy may be concentrated in the lowest frequency of oscillation of the melt, because the scrap tends to damp higher frequency components, so that the melt may have a tendency to slop around. As the scrap melts and slag is formed, some energy is transferred to the higher frequency components. By analyzing the relative amplitudes of the frequency components of the lance distance signal and changes in these amplitudes during the process, information is thus obtained about the process which could not be obtained directly.

Considering now in more detail the electronic circuits employed to develop the above-described electromagnetic wave and to process the received or reflected signal to recover information indicating the distance between the lance tip and the reflecting surface in the vessel **30**, it will be understood that any suitable type of ranging radar system may be employed insofar as the basic principles of the invention are concerned. However, in a preferred embodiment of the invention, an FM/CW ranging radar system is employed, the circuit components of such a system being shown in FIG. **11**, and timing wave forms relative to such system being shown in FIGS. **12** to **15**, inclusive. Referring to these figures, it is first pointed out that in the arrangement of FIGS. **1** to **10**, inclusive, wherein the electromagnetic wave is transmitted through one of the nozzles **164** in the lance tip **150** and the diverging portion of this nozzle **164*c*** acts as a horn antenna, the frequency of the generated electromagnetic wave is limited by the minimum diameter of the nozzle **164**, i.e., the diameter of the throat portion **164*b*** of this nozzle, to a frequency somewhat above the cutoff frequency of this throat portion. For example, assuming that the throat **164*b*** has an inside diameter of 2 inches, in order to transmit a TE_{11} wave through this section considered as a circular wave guide section, a cutoff frequency of 3.45 GHz. is obtained and the transmitting frequency of the FM/CW ranging radar system must be somewhat above this frequency. For example, the frequency of the transmitted electromagnetic wave which is passed through the nozzle **164** may have, in the example given, a frequency of from 4 to 6 GHz. In this example, the frequency of the transmitted signal is preferably not appreciably above 6 GHz. since the coaxial cable **84** between the circuitry **82** and the lance top adaptor **50**, and the coaxial cable **174**, within the lance **42**, are necessarily of substantial length due to the length of the lance **42** itself and the fact that this lance must be lowered a relatively large distance from its rest position above the hood **38**, and the attenuation per foot of these coaxial cables, which may be of the type Z220–RGB–11, increases rapidly as the frequency of the transmitted signal is raised.

Considering now the circuit components which may be employed in an FM/CW ranging radar system to accomplish the purposes of the present invention, reference may be made to FIG. **11** wherein the electromagnetic wave to be transmitted is generated by an oscillator **250** which is modulated by means of a modulator **252**, the output of the oscillator **250** being amplified in an amplifier **254**. The oscillator **250** may comprise any suitable high frequency generator capable of developing an electromagnetic wave in the frequency range of 4–6 GHz. For example, the oscillator **250** may comprise a BWO (backward wave oscillator) or a semiconductor Gunn type diode designed to accomplish a one-step conversion from D.C.-to-microwave energy without employing complex circuitry, the frequency of this oscillator diode being variable over the desired frequency range by the modulator **252**, as will be described in more detail hereinafter in connection with FIG. **12*a***. However, it will be understood that any other suitable type of microwave generator capable of generating a microwave signal in the indicated frequency range which can be varied over the desired bandwidth, i.e., Δf may be employed insofar as the present invention is concerned. Since semiconductor diode oscillators are of relatively low power, an amplifier **254**, which may comprise, for example, a traveling wave tube, is employed to amplify the output of the oscillator **250** to the output level necessary to provide a reflected signal of usable amplitude in the above described arrangement of the present invention. However, it will be understood that the amplifier **254** may be omitted if a sufficiently high power generator is employed as the modulated oscillator **250**.

In order to maintain the power output level of the continuous wave transmitted signal substantially constant, an amplitude leveling loop including a feedback amplifier **256**, is employed to control the power output level of the power oscillator **250** so that the level of the electromagnetic wave signal appearing on the coaxial cable **84** remains substantially constant and undesired amplitude fluctuations which would interfere with the desired range measurement are not produced.

As discussed generally heretofore, the signal appearing on the cable **84** is transmitted over the cable **174** within the lance **42** to the hybrid unit **182** (FIG. **11**) to which is connected the dummy load **184**. The hybrid **182** may, for example, comprise a model 754 hybrid manufactured by Sage Laboratories, Inc., or any other suitable hybrid arrangement which is designed to convey the electromagnetic wave to the antenna **260**, corresponding to the flared wave guide transition member **192**, member **194** and nozzle **164** of FIG. **4**. The reflected signal together with only a small amount of leakage of the transmitted signal should appear at the crystal detector **208** for optimum mixing with the reflected signal, as will be readily understood by those skilled in the art. The dummy load **184** may comprise a model 9210 unit manufactured by Sage Laboratories, Inc. and the crystal detector **208** may comprise a model 1026 element also manufactured by Sage Laboratories, Inc. The coaxial to circular wave guide transition member **192** may comprise any suitable arrangement for matching the coaxial line output of the hybrid **182** to the cylindrical wave guide section **194** and the nozzle **164** with minimum loss of energy, as will be readily understood by those skilled in the art.

As indicated generally heretofore in connection with FIG. **4**, the hybrid **182** is preferably mounted in close proximity to the flared transition member **192** and the antenna-nozzle. Furthermore, the crystal detector **208** is also mounted in close proximity to the hybrid **182**. A small amount of the transmitted signal is coupled by leakage in the hybrid **182** to the crystal detector **208** so that the reflected signal which is received back through the nozzle **164**, the cylinder **194** and the horn type transition member **192** to the crystal **208** is heterodyned or mixed with the transmitted signal for the generation of side bands which contain the desired range information. The difference in transmission path of the hybrid leakage and received signals is detected by the crystal **208**, i.e., from the hybrid **182** directly to the crystal **208** and from the hybrid **182** downwardly to the reflecting surface **44** and back to the crystal **208**, results in the generation of these side bands as beat frequency components. While the transmitted signal is illustrated as being compared with the reflected signal in the crystal **208** by normal hybrid leakage, it will be understood that the transmitted signal may be introduced into the crystal detector **208** by any other suitable means at the required level for optimum heterodyning action with the reflected signal. It will also be understood that an appropriate correction must be made for the resulting fixed error in range from the crystal **208** to the lance tip **150**.

The beat frequency components in the output of the crystal detector **208** are transmitted by way of the coaxial cables **212** and **86** to an audio amplifier indicated generally at **262** in FIG. **11**. The audio amplifier **262** is employed for the purpose of increasing the level of the difference frequency that contains the information desired for range measurement. This amplifier may contain a band pass filter to reject unwanted signals such as amplifier $1/f$ noise, microphonics and 60-cycle power line interference. The amplifier **262** may also include suitable automatic amplitude control circuits or multiple limiters so as to control the signal amplitude of the desired beat frequency components.

The selected beat frequency components developed in the output of the audio amplifier **262** are supplied to quantizing circuits **264** which are provided for the purpose of converting the analog signal output of the audio amplifier **262** into a corresponding digital signal. The unit **264** comprises suitable circuits for detecting the cross over points of the selected beat frequency signal during a modulation cycle of the modulator **252**.

The particular point at which the quantized output from the quantizing circuits **264** is detected, is determined by a zero detector **266** connected to the output of the quantizing circuits **264**, this zero detector also being arranged to prevent the transmission of signals when the output from the audio amplifier **262** is of insufficient amplitude to operate the quantizing circuits in a reliable manner, as will be readily understood by those skilled in the art. The output from the zero detector **266** is supplied to a one-shot multivibrator **268** which develops pulses of identical amplitude and width corresponding to each transition produced in the output of the zero detector **266**. The quantizing circuits **264**, zero detector **260** and multivibrator **268** are provided for the purpose of transmitting range information over the relatively long cable **88** to the control room **90**, without substantial deterioration, as would be the case if an analog signal were used. The output of the one-shot multivibrator **268** is thus conveyed by means of the cable **88** to an integrator **270** which forms a part of the lance distance signal display unit **220** in the control room **90**. In this connection it is pointed out that the units **262, 264, 266** and **268** comprise the receiver circuitry indicated generally at **82** in FIG. **1** and these circuit components, together with the transmitter components **250, 252** and **254**, are preferably positioned as close as possible to the lance top adaptor **50** commensurate with the requirement that the cables **84** and **86** be of sufficient length to permit lowering of the lance **52** into the vessel **30**. By thus positioning the transmitter and receiver components relatively close to the lance **42** and employing digital signals for transmission to the control room **90**, the development and transmission of range information without signal degradation is improved. However, it will be understood that if a suitably high-powered transmitter and sensitive receiver is employed, which are sufficient to overcome the loss in the coaxial cables referred to, the circuitry **82** may be positioned in the control room **90**, as will be readily understood by those skilled in the art.

The integrator **270** is provided for the purpose of averaging the pulse information supplied thereto over the cable **88** and converts the pulses developed by the one-shot multivibrator **268** into an equivalent D.C. analog signal. The time constant of the integrator **270** is determined by the difference frequency range to be covered, i.e., the unambiguous range of the FM/CW ranging radar system, and the allowable response time for the ranging system. The integrator **270** also tends to smooth out the effects of range cell stepping due to the inherent range resolution limitation of the radar system, as will be readily understood by those skilled in the art.

The output of the integrator **270** is supplied to a display unit **272** which may be a meter or other suitable display device for indicating the lance distance as determined by the frequency of the selected beat frequency component transmitted through the band pass filter in the audio amplifier **262**. In the alternative, the analog signal supplied to the display unit **272** may be quantized and displayed, as by a conventional digital volt meter.

As discussed generally heretofore, the modulator **252** develops a suitable wave form for controlling the frequency of the oscillator **250**. Thus, the modulator **252** may develop a triangularly shaped modulating wave, as shown in FIG. **12***a*, wherein the transmitted signal is indicated by the solid line **280** and the reflected or received signal is indicated by the dotted line **282**. The transmitted and received signals **280** and **282** are spaced apart by an amount T proportional to the difference in transmission paths of the leakage transmitter signal and the reflected signal to the crystal detector **208**, as discussed heretofore. The center frequency of the oscillator **250** is indicated as f_o and the amplitude of the triangularly shaped modulating wave output of the modulator **252** i.e., Δf, is chosen so as to provide the necessary bandwidth to measure a minimum range increment. If the quantizing circuits **264** are arranged to develop two counts per cycle of the selected beat frequency, i.e., to detect both cross over points of each cycle of this beat frequency, the bandwidth (Δf) of the modulating wave may, for example, be in the order of 0.6 MHz, this figure representing the total theoretical bandwidth required for the linear modulation FM/CW system shown in FIG. **12***a*. If the output of the modulator **252** is of a sinusoidal wave form, as shown in FIG. **14***a* by the transmitted and received signals **280***a* and **282***a*, respectively, the bandwidth Δf required to measure the same minimum range increment will be about the same, as will be readily understood by those skilled in the art. The modulating frequency, i.e., the frequency of occurrence of one complete cycle of the triangularly shaped modulating wave shown in FIG. **12***a*, or one complete cycle of the sinusoidal modulating wave as shown in FIG. **14***a*, is preferably chosen to be quite low and will be considerably lower then the beat frequency component selected in the audio amplifier **262** for range measurement. For example, with a modulating frequency f_m of 100 Hz, a Δf of 0.6 MHz and a range of 6.5 feet, a beat frequency component of 1,640 HZ is obtained. The band pass filter in the amplifier **262** may be centered about this beat frequency component with its modulating frequency side bands occurring at intervals of plus and minus f_m. When a triangularly shaped modulating wave is used, i.e., a linear frequency change with time, the beat frequency components of the system appear as shown in FIG. **13** wherein the major sidebands for f_m are shown. Since a linear frequency modulation system is employed in FIG. **12***a*, each beat frequency component appears as a discrete line in the audio spectrum. Also, the value of this beat frequency component will remain at a constant value as indicated at **284** in FIG. **12***b*, except near the cross over points of the transmitted and received signals **280** and **282**, and the energy distribution over the RF band is substantially uniform, as indicated by the portion **286** of the energy-frequency characteristic of FIG. **15***a*. On the other hand, when sinusoidal modulation is used (FIG. **14***a*) the beat frequency component varies continuously, as shown by the characteristic **288** in FIG. **14***b*, and the energy distribution over the RF band is not uniform, as shown by the curve **289** in FIG. **15***b*. The required bandwidth is the same with either triangular or sinusoidal modulation and the integration interval of the integrator **270** for smoothing the system output should in either instance be much greater than approximately 10 milliseconds with the above-indicated system values.

Since the system resolution is not increased by using a modulating frequency greater than the selected beat frequency component, the beat frequency spectrum can be shifted out of the low audio frequency range by using a modulating frequency which is much less than the beat frequency, as illustrated by the above example of a modulating frequency of 100 cycles per second and a beat frequency component of 1,640 Hz. However, it will be understood that the above values are given merely by way of illustration and any other suitable choice of modulating frequency and selected beat frequency component which will give suitable range information may be employed insofar as the present invention is concerned.

As discussed generally heretofore, the lance distance signal displayed by the unit **272** may be visually inspected by the operator who may then operate a manual control **290** which controls the lance drum motor **80** through a manual-automatic switch **292**. In the alternative, the operator may simply use the distance signal displayed on the unit **272** to calibrate the conventional lance drum indicator **222** (FIG. **3**) and thereafter refer to the lance drum indicator **222** when operating the manual control **290** to move the lance **42** to any desired position either before or during the oxygen blowing operation. In a further alternative arrangement the signal supplied to the display unit **272** may also be supplied to a set point and controller unit **294**, as indicated by the dotted line **296** (FIG. **11**), the set point and controller operating from the output of the integrator **270** in a manner similar to the conventional control of the lance drum from a slide wire transmitter, it being understood that the set point and controller **292** would be employed when the switch **292** is in the automatic position. Finally, the output of the integrator **270** may be supplied to the computer **230** in place of the conventional lance height signal.

As discussed generally heretofore, the lance distance signal may be developed during the oxygen blowing operation to develop a dynamically changing signal indicative of changes in the level of the melt within the vessel **30** due to oscillatory movement thereof. To such end, the output of the integrator **270** may be supplied to a frequency analyzer **293** having a number of different channel outputs identified as F_1, F_2 to F_n corresponding to the fundamental and harmonic components of the distance signal being analyzed. Depending upon the frequency of the particular mode of oscillation being examined, the time constant of the integrator **270** should be adjusted to a value somewhat less than the selected component to permit this component to appear in the integrator output, as will be readily understood by those skilled in the art.

Referring now to FIGS. **16** to **18**, inclusive, an alternative arrangement of the present invention is therein shown in which a pulse type radar system, as distinguished from the FM/CW system employed in the arrangement of FIGS. **1** to **15**, inclusive, is used. In the arrangement of FIGS. **16** to **18**, inclusive, the oxygen pipe **124** is itself employed as a wave guide to transmit electromagnetic energy developed by a suitable short-pulse transmitter, to the oxygen nozzle, this electromagnetic energy issuing from the nozzle in the lance tip and being reflected back through the nozzle and the oxygen pipe to a pulse type receiver. More particularly, the electronic equipment for the pulse-type radar system is contained in a housing **300** which is mounted on the bottom of the lance top adaptor **50** by means of the support members **302** and **304** which are secured to the top adaptor frame by means of the bolts **306**. The housing **300** contains a suitable power supply **308** (FIG. **18**), a short pulse transmitter which may comprise an avalanche diode generator **310** (FIG. **18**) operated in the LSA mode and energized from the power supply **308**, and driver pulse generator **312** which drives the solid state diode **310** at the desired transmitter pulse repetition rate. For example, the generator **312** may generate a driver pulse having a width of **6** nanoseconds and a repetition frequency of 60 Hz. The pulse output of the RF generator **310** may be further amplified in a traveling wave tube **314** to obtain the desired power level and the pulse signal is passed through a band pass filter **316** to a hybrid **318** to which is connected a dummy load **320**. The transmitter pulse is supplied from the hybrid **318** to an adaptor or directive antenna **322**. In the arrangement of FIG. **16**, the hybrid **318** may be arranged to feed a wave guide output section **324** to which is connected a horn type adaptor **322***a* capable of matching the wave guide section **324** to the right angle end section **326** of the 6 in. diameter pipe **112** which forms one arm of the Y-shaped oxygen header **114**. However, it will be understood that the output of the hybrid **318** may be a coaxial cable in which case a flared transition member or horn type antenna, similar to the transition member **192** of FIG. **4**, may be employed to couple energy to the end of the pipe section **326**.

Oxygen is supplied to the other arm **110** of the Y-shaped oxygen header **114** and flows downwardly through the central portion **116** of this header and the oxygen pipe **124**. In order to prevent the flow of oxygen into the wave guide section **324**, a pressure seal **328**, which is transparent to electromagnetic waves, is provided in the wave guide section **324**. Also, in order to direct the electromagnetic wave energy supplied to the pipe section **112** downwardly into the oxygen pipe **124**, an arcuate perforated metal section indicated generally at **330** is provided within the header **114**, the section **330** being of sufficient strength to withstand the pressure drop across it due to the flow of oxygen to the pipe **124** from the pipe **110** while providing an electrically continuous downwardly directing surface for the electromagnetic energy which is supplied to the upper end of the oxygen pipe **124**. The pipe sections **326**, **112** and **124** thus act as a wave guide for electromagnetic energy supplied from the adaptor **322*a***. In order to reduce losses in transmission through these pipe sections their interior is preferably coated with a very thin layer of a good conductor such as copper or zinc, or pipe sections constructed of one of these metals may be used. This copper coating need only be as thick as the skin depth penetration of the microwave signal and will reduce the losses in these pipe sections by a factor of **10**.

The transmitter pulse which is thus supplied to the top end of the oxygen pipe **124** is transmitted downwardly through this pipe and issues out of the oxygen jet forming nozzles in the tip portion of the oxygen blowing lance. The echo pulse which is reflected back from the surface **44** within the vessel **30** is transmitted back through the nozzles, up the pipe **124** and through the horn type adaptor section **322*a*** to the hybrid **318** to which is connected a traveling wave tube pre-amplifier **334**. The amplified echo pulse in the output of the pre-amplifier **334** is supplied to a sampler **336** which operates in conjunction with a sampling cathode ray oscillograph **338**. The sampling cathode ray oscillograph **338** functions in conjunction with the sampler **336** to reconstruct the echo pulse wave form from samples taken during many recurrences of the wave form, thereby circumventing the bandwidth limitations of a conventional amplifier. In reconstructing the pulse wave form, the sampling unit **336** turns on the sampling circuit for an extremely short interval and the wave form voltage at that instant is measured. The next sample is taken during a subsequent cycle at a slightly later point on the input wave form and the complete wave form is thus plotted out point by point. With such an arrangement, a relatively high level echo pulse is reconstructed from the output of the pre-amplifier **334**. However, it will be understood that other suitable arrangements may be employed for obtaining a pulse output signal of the required level.

The reconstructed pulse output of the oscilloscope **338** which is now of relatively low frequency, is supplied by way of the conductor **340** to an audio amplifier **342** wherein the signal is further amplified, the output of the amplifier **342** being supplied through a low pass filter **344**, which removes the 60 Hz component of the reconstructed pulse, to a suitable indicator or recorder unit **346**. In the alternative, the output from the sampling oscilloscope **338** may be applied to a suitable signal processor, consisting of suitable flip flop circuits with threshold setting, and applied to an electronic counter for providing a digital range indication. If analog range information is desired the signal processor output may be applied to a suitable rectifier circuit.

When the microwave pulse which is transmitted down the oxygen pipe **124** reaches the surface **196** in the lance tip **150** adjacent the entrance of the oxygen nozzles, a mismatch is encountered and a portion of the signal is reflected back to the receiver **334** by way of the hybrid **318**. The remainder of the signal is propagated out of the nozzles of the lance and is reflected back through these nozzles and the oxygen pipe **124** and the adaptor **322** to the hybrid **318** and amplifier **334**. If desired, only one of the nozzles can be used as a microwave antenna and a wire mesh or perforated plate placed over the entrance to the other nozzles which will reflect electromagnetic waves but will not interfere with the flow of oxygen out of these other nozzles.

The delay between this first reflection, i.e., the mismatch at the lance nozzle tip and the second reflection from the molten material in the vessel **30** indicates the position of the lance relative to the level of the molten material and may be viewed on the viewing screen of the cathode ray oscilloscope **338**. In the alternative, a permanent record of the reconstructed pulse spectrum may be obtained on the recorder **346**. The operator may then employ the range information obtained from the oscilloscope **338** or the recorder **346** either to calibrate the existing lance drum indicator or utilize this information directly to control the lance drum motor **80** so that the lance **42** is positioned at the desired point relative to the reflective surface **44**.

In FIGS. **19** and **20** of the drawings, there is shown a further alternative embodiment of the invention, wherein a wave guide transmission system is employed which minimizes the discontinuities and loss of power due to pulse dispersion and multiple propagation which may be encountered in the system of FIGS. **16** and **17**. Referring to these figures, a housing **300*a*** is mounted on the bottom portion of the lance top adaptor **50** by means of the members **302*a*** and **304*a***, the housing **300*a*** including a power supply, short pulse transmitter, hybrid and pre-amplifier similar to those units described in connection with the arrangement of FIGS. **16** to **18**, inclusive. However, the wave guide output beyond the pressure seal **328** in the wave guide **324*a***, is supplied to the interior of the end pipe section **326** through a closure member **340** and wave guide sections **342**, **344** and **346**, etc., are employed within the pipe section **112** which are of the same diameter as the output section **324*a*** and the adaptor or transition unit **322*a*** of FIGS. **16** and **17** is eliminated.

In the arrangement of FIGS. **19** and **20**, the wave guide sections, which may be of cylindrical cross section are suitable to transmit any desired type of electromagnetic wave with minimum loss of energy. These sections are continued through the header portion **114**, downwardly through the section **116** into the upper end of the oxygen pipe **124** and downwardly at the center of this pipe to the lance tip. The wave guide sections may be supported by any suitable means, such as the brackets **348** and **350** shown within the pipe section **112**, the bracket **352** within the header section **116** and the brackets **360** within the pipe **124**, and should include a telescopic section to accommodate thermal expansion of the lance **42**.

Near the lance tip portion, the wave guide section **354** is connected to an offset portion **356**, which is supported on the upper end of a perforated cylinder **194*a*** which may be similar to the perforated cylinder **194** shown in FIG. **4** and described in detail heretofore. A similar perforated cylinder **240*a*** is provided in association with the oxygen nozzle **162** so as to provide a balanced thrust from the nozzles **162** and **164**, as described heretofore in connection with FIG. 4. The electromagnetic energy transmitted through the wave guide section 354 is transmitted through a closure member 358 on the end of the section 356 which is transparent to electromagnetic waves but seals off the upper end of the cylinder 194a so that oxygen cannot be transmitted upwardly through the central wave guide sections 356 and 354. Oxygen is admitted through the cylinders 194a and 240a in the same manner as described in detail heretofore in connection with FIG. 4 and the electromagnetic wave energy is also transmitted through the cylinder 194a and the nozzle 164 is reflected back to the preamplifier in the housing 300a.

While the wave guide arrangement of FIGS. 19 and 20 is shown in connection with a lance tip having four oxygen nozzles it will be understood that such an arrangement may be employed with a lance tip having a single oxygen nozzle at the center of the lance tip, in which case the offset portion 356 may be eliminated and the wave guide section 354 carried directly downward without offset to a single perforated cylinder corresponding to the cylinder 194a and positioned centrally of the lance tip portion over the single oxygen nozzle. Such an arrangement has the advantage that all of the electromagnetic energy developed by the transmitter is emitted by the single nozzle-antenna without loss of energy due to reflection by the bottom wall, such as the wall 196, of the hollow lance tip. Furthermore, the range measured by such a system would be the distance, or elapsed time, between the transmitter and the received echo which is conveyed back to the housing 300a, a distance of over twice the length of the lance 42. The problems of measuring an extremely short elapsed time interval are thus avoided with a single nozzle, perforated cylinder and wave guide arrangement such as shown in FIGS. 19 and 20. While some lengthening of the pulse will be experienced in transmitting the same over the relatively long wave guide section in FIGS. 19 and 20, a wider pulse may still be utilized where the pulses are not extremely close together, as for example, by measuring to the leading edge of the pulse, as will be readily understood by those skilled in the art. In this connection, it should be noted that a continuous wave FM system, such as described in detail heretofore in connection with FIGS. 1 to 15, inclusive, may equally well be employed in the alternative arrangement of FIGS. 16 to 18, inclusive, or the alternative arrangement of FIGS. 19 and 20. Such a continuous wave system avoids the pulse lengthening effect just mentioned, although a higher power transmitter signal will probably be required to obtain a usable level of reflected signal at the crystal detector at the end of the wave guide run. Such a single nozzle lance tip portion may also be employed in connection with any of the other embodiments of the invention such as those disclosed in FIGS. 1 to 15, inclusive, and FIGS. 16 to 18, inclusive, as will be readily understood by those skilled in the art.

In FIG. 21 there is shown a further alternative embodiment of the present invention wherein a ranging radar system is provided in association with the lance top adaptor 50 but exteriorly of the oxygen blowing lance 42, electromagnetic wave energy from this ranging radar system being directed downwardly through the hood 38 and alongside the lance 42 to the reflective surface 44a of the molten material within the vessel 30. More particularly, a ranging radar system indicated generally at 370 in FIG. 21 is mounted on the frame of the lance top adaptor 50 and is energized from a suitable A.C. source indicated by the terminals 372. The radar system 370 comprises suitable transmitter and receiver portions, the electromagnetic wave energy developed by such system being applied to a high directive antenna system indicated generally at 374 which is directed downwardly from the bottom of the lance top adaptor 50. The ranging radar system 370 may comprise any suitable low power radar system, such as an FM/CW system similar to that described in detail heretofore in connection with FIGS. 1 to 15, inclusive, or a pulse echo type ranging radar system such as described in connection with FIGS. 16 to 18, inclusive.

The electromagnetic wave energy radiated by the antenna system 374 travels downwardly through the opening 40 provided in the hood 38 for insertion of the lance 42, and in a direction parallel to the lance 42, until it strikes the reflective surface 44a of the molten material within the vessel 30, where it is reflected back to the antenna system 374 and to the receiver circuitry within the radar system 370. Since the radar system 370 measures the actual distance between the lance top adaptor 50 and the reflective surface 44a within the vessel 30, the range indication provided by such system takes into account all of the above-described factors which affect the level of the molten material within the vessel 30 and the elongation of the cable used to lower the lance 42. The only factor which the radar system 370 will not measure is the actual thermal expansion of the oxygen lance 42 itself when it heats up after it is admitted into the vessel 30. However, in those situations where the thermal expansion is known or can be reasonably predicted, a correction factor for temperature expansion may be added to the range indication provided by the radar system 370. Furthermore, the arrangement of FIG. 21 has the advantage that the frequency of the radar system 370 is not limited to a value above the cutoff frequency of one of the oxygen nozzles within the lance tip 150, as it is in the other embodiments of the invention described heretofore. Accordingly, a relatively low frequency transmitter signal may be developed at relatively high power and at lower cost which is employed in the arrangement of FIG. 21 together with a highly directive antenna system which will concentrate the electromagnetic energy into a narrow beam more efficiently than one of the oxygen nozzles, such as the oxygen nozzle 164 described heretofore. Also, the range measured by the radar system 370 is many times greater than the distance between the lance tip and the reflective surface within the vessel so that the problems inherent in extremely short range measurements are largely avoided. The arrangement of FIG. 21 has the further advantage that all of the components of the radar system, including the directive antenna 374, are not subjected to the intense heat within the vessel 30.

The system of FIG. 21 may be used to detect the quiescent level of the molten material within the vessel 30 and will provide compensation for the above-described factors affecting a lance height measurement, as described in detail heretofore. When the radar system **370** is employed to make a lance height measurement during the oxygen blowing operation, it is expected that the craters **376** and **378** which are formed in the surface of the molten material by the force of the oxygen jets issuing from the lance tip **150** will produce a spray or curtain of steel and slag droplets which will be thrown upwardly out of the edges of the cavities **376, 378** and across the path of the electromagnetic beam **380** indicated diagrammatically as being transmitted from the antenna system **374**. This curtain or spray of steel droplets will cause a relatively high background level for the received signal of the radar system **370** and this background level may vary with the shape of the cavities **376, 378** which will influence the angle at which the steel and slag droplets are thrown out of these cavities. Also, the background level due to the spray or curtain of droplets may vary depending upon the lance tip spacing and the force with which the oxygen jets strike the surface **44***a* of the molten material which factors in turn affect the depth and shape of the cavities **376** and **378**. Accordingly, if dynamic measurements are to be made, the ranging radar system **370** is preferably chosen to be of the type which is particularly designed to detect a reflected signal in the presence of a high background level. Thus, a pulsed doppler type of radar system may be employed which differs from the continuous wave FM system described heretofore only in the introduction of a pulsed coherent transmitter in place of the CW coherent transmitter and a duplexer which turns off the receiver during a pulse period and isolates the receiver from the transmitter between pulses. With such a pulsed doppler type of radar system, and proper selection of the deviation values of the transmitted signal, the doppler frequency components may be separated from the range frequency components so that the true range or distance from the antenna system **374** to the bottom of the crater **376** may be determined during the oxygen blowing operation and while the surface **44***a* of the molten material within the vessel **30** is heaving due to the oscillatory standing wave pattern set up within the vessel **30** by the interaction of the oxygen jets issuing from the lance tip **150** with the molten material within the vessel. With such an arrangement the range frequency components may be uniquely resolved so that the range signal provided by the system **370** will include frequency components corresponding to the various modes of oscillation of the molten material within the vessel **30** set up by interaction of the oxygen jets from the lance **42** therewith. These frequency components may then be analyzed as described in detail heretofore in connection with the FM/CW system of FIG. 11.

If desired, a range-gated pulsed doppler type of radar system may be employed as the system **370** to provide further sensitivity to the reflected signal in the presence of high background levels. In such a range-gated pulsed doppler system, range gating is employed in the receiver with suitable means for circumventing the inherent range ambiguities when a relatively wide range of distances is to be measured, as will be readily understood by those skilled in the art.

In FIG. **22** of the drawings, there is shown a further alternative embodiment of the invention wherein a ranging radar system is provided in association with the lance top adaptor **50** to provide an indication of the position of the lance **42** with respect to a fixed reference plane, this indication being used in place of a conventional lance drum indicator, such as the lance drum indicator **222** discussed heretofore in connection with FIG. **3**.

Referring to FIG. **22**, a ranging radar system **370***a*, is mounted on the frame of the lance top adaptor **50**, in a manner similar to that described above in connection with the ranging radar system **370** of FIG. **21**. However, in the system of FIG. **22**, the highly directive antenna system of the radar **370***a*, indicated generally at **374***a*, is arranged to direct a beam **392** upwardly so that the transmitted beam will strike a fixed reflective surface **390** which is mounted above the upper end of the lance top adaptor **50** when this adaptor is in its uppermost position. For example, the reflective surface **390** may comprise a sheet metal reflective surface mounted in the roof of the building which houses the basic oxygen furnace equipment. The radar system **370***a* in FIG. **22** takes the place of a conventional lance drum indicator and will provide an accurate indication, on its output cable **394**, of the distance from the lance top adaptor **50** to the fixed reflective surface **390**. This indication of lance position may then be used in place of the conventional lance drum position signal, as described in detail heretofore in connection with the lance distance signal display **220** (FIG. **4**).

If desired, the directive antenna system **374**a may be adjustable so that it can be directed downwardly in the manner of the antenna system **374** of FIG. **21** and an additional distance measurement may be obtained representing the distance between the lance top adaptor **50** and the reflective surface **44***a* of the material within the vessel **30** (FIG. **21**). In the alternative, a separate directional antenna system may be provided in association with the radar system **370***a* which is directed downwardly and a suitable switching arrangement may be employed to energize either one of the two directive antenna systems so that measurements may be alternately made, one directed upwardly to the reflective surface **390** and the other directed downwardly to the reflective surface **44***a*.

While various embodiments of the present invention have been here specifically disclosed, it will be apparent that many variations may be made therein, all within the true spirit and scope of the invention.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. In a basic oxygen furnace having a vessel adapted to contain molten material and including an oxygen lance movable to a position somewhat above the level of the material in said vessel and having nozzle means arranged to emit a stream of oxygen against the material in said vessel, the combination of an electromagnetic wave generator, means for modulating an electromagnetic wave developed by said electromagnetic wave generator, means for directing said modulated electromagnetic wave downwardly through said nozzle means in a substantially unobstructed manner such that said modulated wave strikes the surface of the material in said vessel and is continuously reflected back through said nozzle means, receiving means for receiving said continuously reflected modulated wave, and means utilizing the modulation components of said transmitted wave and said received wave to develop an output signal which is continuously proportional to the distance of said nozzle means from the material in said vessel.

2. In combination, a vessel for molten material, a tubular gas blowing lance adapted to be lowered into said vessel and having a tip portion including at least one nozzle adapted to form a high velocity jet when gas is supplied to the upper end of said lance, means for developing an electromagnetic wave, wave guide means positioned within said lance and spaced from the interior wall thereof, means for supplying said developed wave to said wave guide means, means connecting said wave guide means with said nozzle so that said electromagnetic wave is directed downwardly through said nozzle and is reflected back through said nozzle, and distance measuring means responsive at least in part to said reflected wave for developing an output signal continuously representing the distance from said lance tip to a reflecting surface within said vessel.

3. The combination of claim 2 wherein said vessel is adapted to receive molten iron and said gas supplied to said lance is oxygen.

4. The combination of claim 2, wherein said wave guide means is positioned adjacent said nozzle and is provided with openings therein for admitting oxygen to said nozzle from the interior of said lance.

5. The combination of claim 4, wherein said openings are of such dimensions and spacing as to contain said electromagnetic wave within said wave guide means while permitting the flow of oxygen to said nozzle.

6. The combination of claim 2, wherein said nozzle includes a divergent portion which acts as a horn antenna for said electromagnetic wave.

7. The combination of claim 6, wherein said divergent portion acts as a horn antenna both for transmitting said electromagnetic wave away from said lance tip and for receiving back said reflected wave.

8. In combination, a vessel for molten material, a tubular gas blowing lance adapted to be moved into said vessel and having a tip portion which includes at least one nozzle adapted to form a high velocity jet when gas is supplied to the upper end of said lance, said nozzle having a throat portion of restricted diameter which prevents the transmission of electromagnetic waves therethrough which have a frequency below a predetermined value, means for transmitting an electromagnetic wave having a frequency above said predetermined value downwardly through said nozzle, and means for receiving said electromagnetic wave after it has been reflected from a surface within said vessel.

9. The combination of claim 8, wherein said receiving means is positioned within said tubular lance.

10. The combination of claim 2, wherein said nozzle includes a convergent portion and said wave guide means is cylindrical and of substantially the same diameter as said convergent portion of said nozzle.

11. The combination of claim 1, which includes means for moving said lance up and down, and means responsive to said output signal for controlling said lance moving means.

12. The combination of claim 1, wherein said nozzle means is arranged so that oxygen supplied to the upper end of said lance issues from said nozzle means in the form of a high velocity jet which produces a cavity in the surface of the material in said vessel, and said output signal varies continuously in accordance with variations in the distance between said cavity and said lance.

13. The combination of claim 12 wherein the force of said high velocity jet which strikes the material in said vessel sets up wave-like motion in said material and said output signal includes frequency components corresponding to different modes of oscillatory movement of said material within said vessel.

14. The combination of claim 1, wherein said modulated electromagnetic wave is continuously developed and is frequency modulated in accordance with a predetermined modulation pattern, said output signal comprises a signal in the audible range, and the rate at which said modulation pattern is repeated is substantially lower than said output signal frequency.

15. The combination of claim 1, wherein said downwardly directed and reflected waves are in the form of pulse modulated electromagnetic waves of relatively short duration, and said output signal is derived by measuring the time interval between said downwardly directed pulses and said reflected pulse.

16. The combination of claim 1, wherein said nozzle means comprises at least two nozzles in the end of said lance, means for directing said modulated wave through one of said nozzles, said last named means partially obstructing the flow of oxygen through said one nozzle, and means positioned to partially obstruct the flow of oxygen through said other nozzle by an amount sufficient to balance the partially obstructed flow through said one nozzle.

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