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PATENT SPECIFICATION

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(54) MAGNETIC SENSOR

(71) We, NIPPON STEEL CORPORATION, a Japanese company, of No. 6—3, Otemachi 2-chome, Chiyoda-ku, Tokyo 100, Japan, and MISHIMA KOSAN CO., LTD., a Japanese company, of No. 1—15, 2-chome, Edamitsu, Yawata-ku, Kitakyushu-City, Fukuoka Prefecture, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a magnetic sensor for measuring the behaviour of a charge in a container. The invention is particularly applicable for use in shaft furnaces or the like in which the charge is iron ore.

According to the invention, there is provided a magnetic sensor comprising an outer casing having a cooling medium injecting pipe with a flow control valve therein and a cooling medium exhaust pipe with a flow control valve therein, a flange for mounting the sensor on the wall of a container to be tested, said flange extending from the outer peripheral surface of the outer casing at a predetermined position along the outer casing in one direction from the injecting pipe and the exhaust pipe, an inner core body consisting of a permanent magnet exciter for magnetizing a material in the container to be tested, a magnetic field sensing member positioned along the inner core body adjacent one end of the exciter for detecting an exciting magnetic field generated by said exciter, the magnetic field sensing member being on the same side of the exciter as the flange is positioned in relation to the injecting and exhaust pipes, a driving circuit positioned along the inner core body adjacent the other end of the exciter for driving said magnetic field sensing member, an inner casing in which the inner core body is contained, said inner casing being positioned in said outer casing and spaced from the interior surface of said outer casing, whereby the cooling medium is circulated through the space between the inner and outer casings to cool the inner core body.

Using the above apparatus, a charge such as iron ore in a furnace or the like is magnetized by means of the exciter, and changes of excitation and the magnetic field vector component in the direction of the magnetic field in the magnetic field sensing member may be detected as the charge level drops. In addition continuous cooling ensures that the behaviour of the charge may be precisely monitored without being disturbed by excessive heat from the furnace.

In order that the invention may be better understood, several embodiments thereof will now be described by way of example only and with reference to the accompanying drawings in which:—

Figure 1 is a cross-sectional front view of one embodiment of a magnetic sensor according to the present invention;

Figure 2 is a sectional elevation on an enlarged scale taken along the line II—II of Figure 1;

Figure 3 is a cross-sectional view showing the attachment of the magnetic sensor to a furnace;

Figure 4 is a view similar to Figure 2 showing another embodiment of the magnetic sensor according to the present invention;

Figures 5a to 5d are circuit diagrams of various alternative magnetic oscillation type magnetometers for use in the sensor according to the present invention; and

Figures 6a and 6b are circuit diagrams of further embodiments of the magnetometer.

Referring to Figure 1, there is shown under reference A one embodiment of a magnetic sensor having a cooling device according to the present invention. The magnetic sensor has an inner core body 1 which comprises a magnetic field sensing member 2, an exciter 3 and a drive circuit 4 for driving the magnetic field sensing member 2 arranged successively in series from the top (right hand) end.

The exciter 3 generates an exciting magnetic field to magnetize a charge in a shaft furnace (not shown). The exciter 3 may comprise, for example, an exciting coil or a combination of a magnetic core and an exciting coil (in both these cases, current flowing through the exciting coil for generating the exciting magnetic field may be a direct current or an alternating current). However, in the present embodiment the exciter comprises a permanent magnet which is simple in construction.

The magnetic field sensing member 2 is arranged at the top end of the inner core body 1 in front of the exciter 3 and is operable to detect a change of magnetic field caused by a drop of a charge in the shaft furnace. The magnetic field sensing member comprises, in combination with the drive circuit 4 arranged at the rear of the exciter 3, a magnetometer.

The magnetometer may comprise a flux gate magnetometer, Hall element, a semiconductor magnetic diode, a magnetic reluctance element, a search coil system, or any one of the known magnetic field detecting elements. However, in the present embodiment is used a magnetic multi-sensor which utilises a magnetic oscillation phenomenon produced by a transistor and a reactor. This is to be described in detail hereafter.

The inner core body 1 is formed with a recess portion (not shown) in which are mounted the magnetic field sensing member 2, the exciter 3 and the driving circuit 4 on a substrate 1a. At the rear portion of the inner core body 1 is provided a connector 21.

The inner core body 1 is accommodated in an inner casing 5 which is itself mounted within an outer casing 7 in such a way that a space 6 is interposed between the inner and outer casing 5 and 7. The casings 5 and 7 are made of a non-magnetic material, for example, stainless steel, copper or the like.

A plurality of pairs of fixed plates 8 are provided on the outer peripheral surface of the inner casing 5 in order to locate the inner casing 5 within the outer casing 7 and prevent any lateral movement of the inner casing 5 within the space 6.

A cooling medium injecting pipe 10 leads into a cooling medium injecting inlet 15 in the outer casing 7, and with the use of this pipe a cooling medium is supplied into the space 6 through a flow control valve 12. The cooling medium is exhausted by means of a cooling medium exhaust pipe 11 leading from a cooling medium exhaust outlet 16 in the outer casing 7 through a flow control valve 13. The cooling medium may comprise a known gaseous cooling medium such as air or nitrogen, or a liquid cooling medium such as water or oil, depending upon the furnace wall temperature and the ambient temperature.

Partition plates 9 (see Figure 2) are provided in the space 6 between the casings 5 and 7, each have the same length as the inner casing 5 so that the space 6 is divided into an upper and a lower portion. Thus, in order for the cooling medium to flow from the injection pipe 10 to the exhaust pipe 11, it is necessary for it to traverse the length of the casing 5 to the top end in order for it to pass from the lower portion to the upper portion of the space 6. In this manner the cooling medium cools the inner and outer casings 5 and 7.

In an embodiment of the invention, shown in Figure 4, the partition plate 9 is formed as a cylinder coaxial with and enclosing the inner casing 5. In this case, two sets of fixed plates 8 are used, arranged as shown in Figure 4.

A flange 14 is provided at a predetermined position in front of the cooling medium injecting pipe 10 and the exhaust pipe 11 on the outer peripheral surface of the outer casing 7, in order to secure the magnetic sensor A to the shaft furnace wall.

The inner and outer casings 5 and 7 are attached together by means of a pair of flanges 5a and 7a which are themselves bolted together. A packing material 20 is interposed between the flanges 5a and 7a. Further, as will be apparent from Figure 1, the inner core body 1 is fastened to the flange 5a of the inner casing 5 at an end portion 1b of the substrate 1a. The connector 21 is provided with a cover 22, and the electrical connections are made by means of a connecting lead 23.

A pair of connectors 24, 25 are provided respectively on upper and lower head portions of the magnetic sensor A and are connected to respective cooling medium temperature detecting elements 17 and 18 embedded at a predetermined position in the cooling medium exhaust pipe 11 and the cooling medium injection pipe 10 respectively.

Figure 3 shows the manner in which the magnetic sensor A is mounted in the shaft furnace wall. A hole 32 for receiving the sensor is drilled horizontally in the direction of the furnace centre into an outer layer 30 and a brick layer 31 which together form the shaft furnace wall. The sensor A is inserted into the hole 32 and fixed to the outer layer 30 by means of the flange 14.

Thus, changes in various properties of the charge, such as dropping speed, changes in layer thickness, changes in the distribution in the vertical and circumferential directions of the charge, such as iron ore, which change continuously during operation of the furnace, are all detectable by a change of the exciting magnetic field generated by the exciter 3, as measured by the magnetic field sensing member 2 and observed. Further, during measurement, the cooling medium is constantly supplied to the space 6 so as to prevent interruption of measurements by the excessive heat of the furnace and, in order to ensure uniform cooling, temperature detecting elements 17 and 18 are provided in both the injection and exhaust pipes 10 and 11.

Figures 5a to 5d, show various embodiments of the drive circuit 4 for use in the magnetic sensor A. In each case, the magnetometer comprises a single transistor Q1 or Q2, a reactor comprising a magnetic core 41 on which are wound coils 42, 43, and a D.C. supply source Ed. Hex represents an external magnetic field. Figure 5a is an embodiment using an NPN type transistor. One end of the coil 42 is connected to a resistor R_1 and the resistor R_1 is further connected to a negative terminal of the direct current supply source Ed. The other end of the coil 42 is connected to the base electrode of transistor Q_1 and to one end of a resistor R_2 connected to a positive terminal of the direct current supply source Ed. The coil 43 is inserted between a collector electrode of the transistor Q_1 and the positive terminal of the direct current supply source Ed. Further, between an emitter electrode of the transistor Q_1 and the negative terminal of the direct current supply source is inserted a resistor R_0, and an oscillation current caused to flow through this resistor R_0 is derived from an output voltage e_{01}. In addition, a d.c. mean valve of the oscillation current can be derived from the terminal voltage E_{01} of a capacitor C_0 inserted in parallel with the resistor R_0.

The operation of the circuit will now be explained. It is apparent that the external magnetic field H_{ex} defines a certain flux level in the magnetic core 41. Therefore, when the voltage of the supply source Ed is applied to the transistor Q_1, a current flows through the circuit comprising

$$Ed\oplus \rightarrow R_2 \rightarrow Q_1 \rightarrow R_0 \rightarrow Ed\ominus.$$

This current causes the collector current of Q_1 to flow and a positive feedback voltage is thus induced in the coil 42. As a result of this, the base current of Q_1 is increased which in turn causes a further rapid increase in the collector current of Q_1. The magnetic core 41 is a non-linear type having a saturable characteristic, so that as the collector current increases, so the rate of change of flux $d\phi/dt$ becomes smaller, and the induced voltage in the coil 42 becomes lower. As a result of this the base and hence collector current of Q_1 is gradually reduced and Q_1 eventually becomes non-conductive.

At this point, since collector current no longer flows, the flux level in the magnetic core 41 returns to its original level and the cycle repeats, thus generating a magnetic oscillation. In addition, it will be seen that the level of flux in the magnetic core 41 as defined by the external magnetic field H_{ex} dictates the ratio between the conducting period and the non-conducting period of the transistor Q_1.

Figures 5b and 5c are modified versions of the circuit of Figure 5a. Magnetic oscillation in Figures 5b and 5c is generated by a switching operation of the reactor and the transistor in the same manner as described above. The mode of operation will be clearly apparent to those skilled in the art, and further description is therefore omitted.

Figure 5d is a further modified version using a PNP type transistor Q_2. In this modification the resistor R_2 is inserted between the negative terminal of the supply source Ed and the base of the transistor Q_2 is omitted since the circuit oscillates in the absence of this resistor. The oscillatory operation of the circuit of Figure 5d is the same as described above.

Figures 6a and 6b show a magnetic multivibrator type magnetometer consisting of two transistors, a reactor comprising a magnetic core 41 on which are wound four coils 45, 46, 47 and 48, and a direct current supply source Ed. Figure 6a is a version using NPN type transistors Q_3 and Q_4. The operation in this circuit is as follows:—

At first, when the voltage of the supply source Ed is applied to the transistor Q_3, current flows along the path

$$Ed+ R_5\ Q_3\ R_0\ Ed-.$$

As a result, the collector current of Q_3 begins to flow through the coil 46 and the resistor R_0 and a feedback voltage is thus induced in the coil 45. This induced voltage tends to increase base current and hence collector current of Q_3. Thus transistor Q_3 is in the conducting condition. On the other hand, the voltage induced in the coil 48 by the collector current of Q_3 causes the base of transistor Q_4 to be negative with respect to the emitter, so that Q_4 is in the non-conducting condition. Because of the non-linear characteristic of the magnetic core 41, the value of $d\phi/dt$ in the reactor becomes smaller and, eventually, zero as described in the explanation of Figure 5a. When this happens the voltage induced in the coil 45 becomes zero, and as a result, the collector current of Q_3 is reduced and the flux level in the magnetic core 41 tries to return to the flux level defined by the external magnetic field H_{ex}. This fall in flux level induces a voltage having an opposite polarity in the coil 48, resulting in the base of transistor Q_4

becoming positive with respect to the emitter. Hence Q_4 is turned on, and its collector current flows to the coil 47 through the resistor R_0. In addition, the induced voltage generated in the coil 45 at this time causes Q_3 to revert to the non-conducting condition. This cycle of operation is repeated to generate magnetic oscillations.

Figure 6b is a modified version of Figure 6a and uses two PNP type transistors. This circuit corresponds to a configuration formed by using two of the circuits shown in Figure 5d, and operates in a similar manner.

As apparent from the above explanation the magnetic sensor operates by detecting the drop of the charge in the shaft furnace, which results in the exciting magnetic field generated by the exciter 3 being disturbed. This causes the exciting magnetic field vector component in the direction of the magnetic field in the magnetic field sensing member 2 to change and, as a result, the behaviour of the charge can be precisely measured.

In an alternative embodiment (not shown), two magnetic field sensing members 2 are arranged, one at each end of the exciter 3, i.e. the outer end of the inner core body 1 and at the outer portion of the drive circuit 4. If these two magnetic field sensing members 2 are driven by a single drive circuit 4, the same effect can be achieved, so that by removing a parallel magnetic field component applied from the periphery, the behaviour of only the charge in the shaft furnace near the furnace wall is detected by the magnetic field sensing member 2 arranged at the outer end of the inner core body.

In a still further embodiment a plurality of magnetic field sensing members 2 are provided at the outer end, the angles at which they are mounted being individually selected. In this way, a plurality of different signals can be measured at the same time as the same measuring point. For example, two magnetic field sensing members may be provided, the two members being respectively parallel and orthogonal to the centre axis of the exciter, or two parallel magnetic field sensing members may be arranged in differential relationship, thereby attaining the same effect.

The present invention is not limited to its use in shaft furnaces, but can be utilized in a wide industrial field, for example in storage tanks, raw material cutting hoppers, or chemical reaction tanks.

WHAT WE CLAIM IS:—

1. A magnetic sensor comprising an outer casing having a cooling medium injecting pipe with a flow control valve therein and a cooling medium exhaust pipe with a flow control valve therein, a flange for mounting the sensor on the wall of a container to be tested, said flange extending from the outer peripheral surface of the outer casing at a predetermined position along the outer casing in one direction from the injecting pipe and the exhaust pipe, an inner core body consisting of a permanent magnet exciter for magnetizing a material in the container to be tested, a magnetic field sensing member positioned along the inner core body adjacent one end of the exciter for detecting an exciting magnetic field generated by said exciter, the magnetic field sensing member being on the same side of the exciter as the flange is positioned in relation to the injecting and exhaust pipes, a driving circuit positioned along the inner core body adjacent the other end of the exciter for driving said magnetic field sensing member, an inner casing in which the inner core body is contained, said inner casing being positioned in said outer casing and spaced from the interior surface of said outer casing, whereby the cooling medium is circulated through the space between the inner and outer casings to cool the inner core body.

2. A magnetic sensor as claimed in Claim 1, wherein said magnetic field sensing member consists of a magnetic oscillation type magnetometer comprising a magnetic core, two windings wound on the core, one transistor having the electrodes connected to the windings, and a d.c. supply source connected between the transistor and the windings.

3. A magnetic sensor as claimed in Claim 1 wherein said magnetic field sensing member consists of a magnetic oscillation type magnetometer comprising a magnetic core, four windings wound on the core, two transistors having the electrodes connected to the windings, and a d.c. supply source connected between the transistors and the windings.

4. A magnetic sensor as claimed in any one of Claims 1 to 3, further comprising temperature detecting elements in the injecting pipe and the exhaust pipe of the

outer casing for detecting the temperature of the cooling medium at the inlet to and exhaust from said space.

5. A magnetic sensor substantially as hereinbefore described with reference to the accompanying drawings.

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1562315 COMPLETE SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

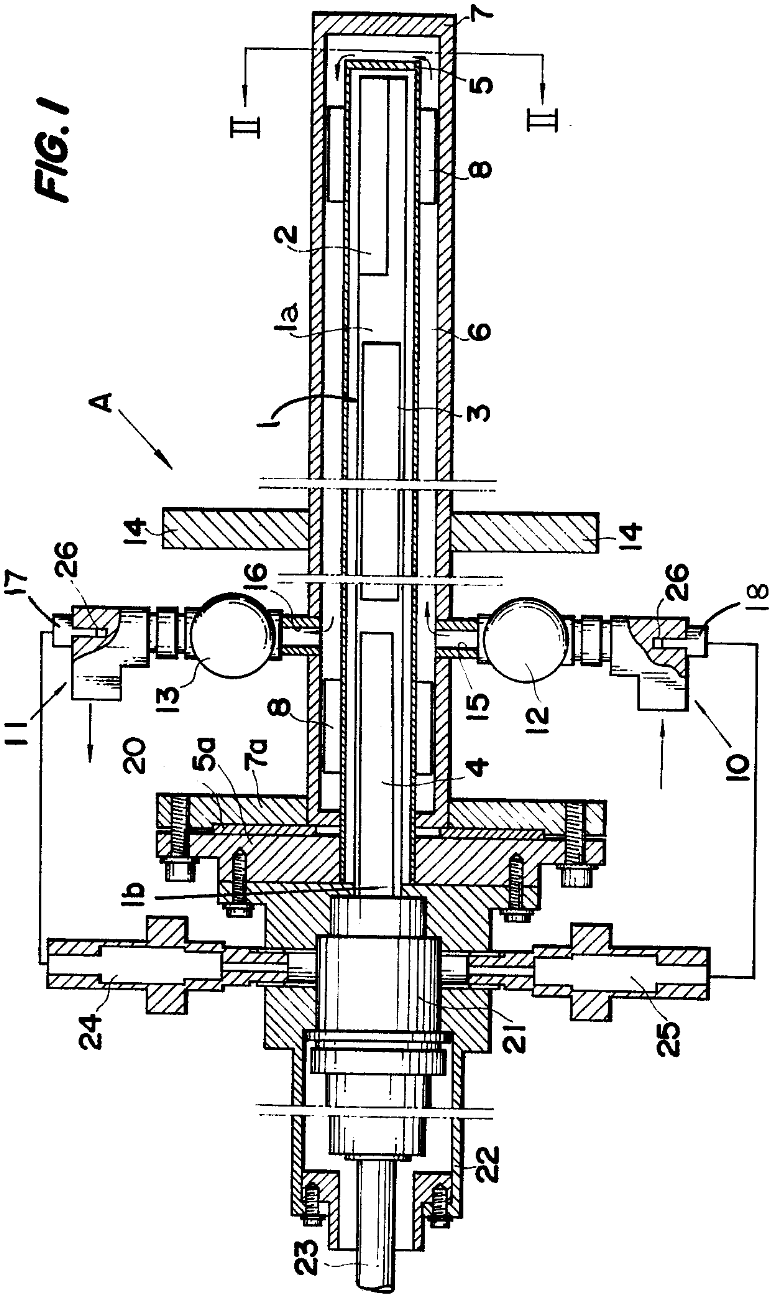

FIG. 1

FIG.2

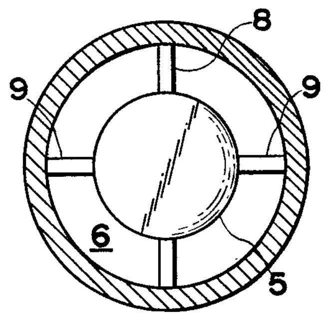

FIG.4

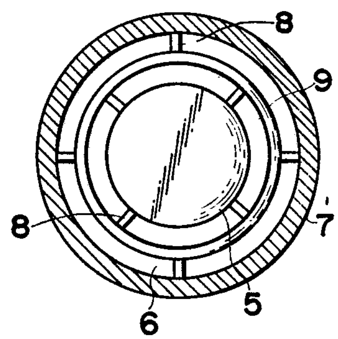

FIG.3

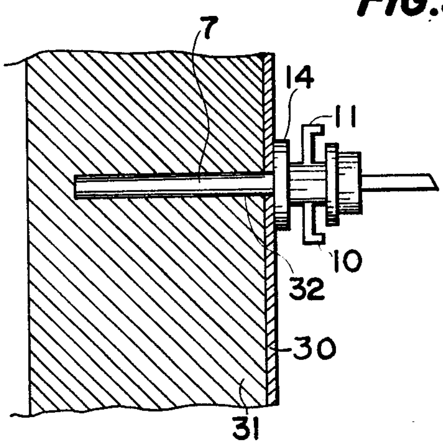

FIG. 5a

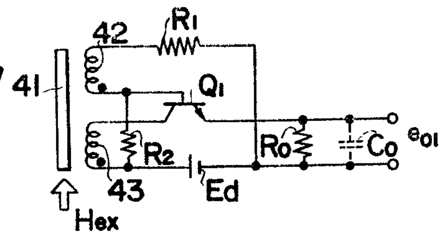

FIG. 5b

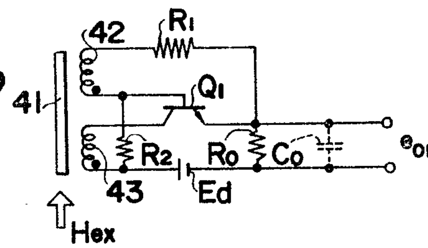

FIG. 5c

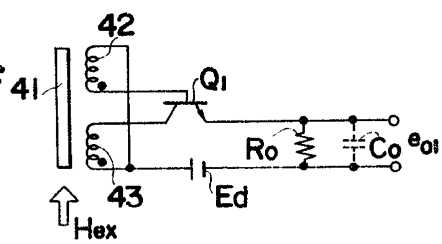

FIG. 5d

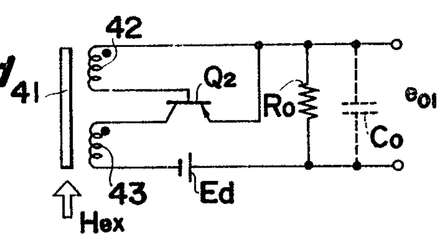

FIG.6a

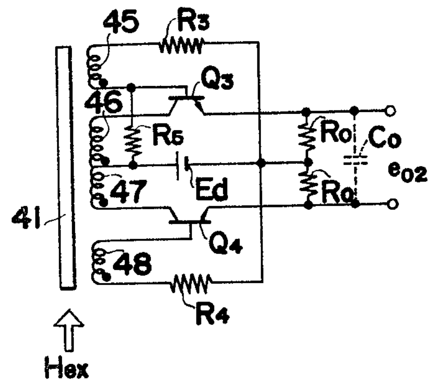
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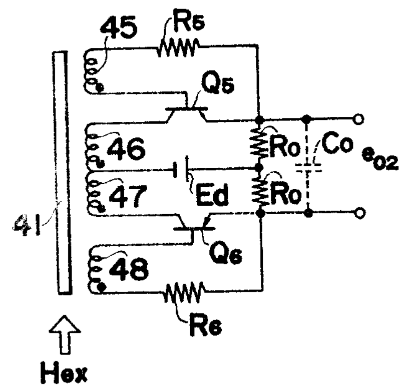
FIG.6b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Q6
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R6
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