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Application No. 77/3923
P7550

REPUBLIC OF SOUTH AFRICA

The Patents Act, 1952

COMPLETE SPECIFICATION

(a) Here insert title verbally agreeing with that in the application form.

(a) "THE CONTROL OF ELECTRICAL ARC FURNACES"

(b) Here insert (in full) name, address, and calling of applicant(s) as in application form.

(b) We, NATIONAL INSTITUTE FOR METALLURGY,
of, 200 Hans Strydom Avenue, Randburg,
Transvaal Province, Republic of
South Africa,

do hereby declare this invention, the manner in which and the method by which it is to be performed, to be particularly described and ascertained in and by the following statement:—

THIS INVENTION relates to the control of electrical arc furnaces and more particularly to the derivation of the conditions existing in the secondary (power) circuit of such a furnace to enable such control to be effected.

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The effective control of arc furnaces in an attempt to optimise their efficiency or production rate, possibly within limits dictated by surrounding circumstances, is often hampered by the difficulty in measuring the required currents and voltages on the secondary side of the transformers which are usually powered by a three-phase electrical power supply. This results

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in a difficulty in measuring the power distribution within the furnace.

Whereas this invention could be applied to, and is intended to include within its scope, any
5 "multi-electrode" furnaces, this description will refer to "three-electrode" furnaces which are the most common type. The "three-electrode" circuits can be considered as delta-star combinations wherein each part of the circuit can be represented by lumped parameters (inductance and
10 resistance) which need not necessarily be linear in their behaviour.

In a production furnace, the power is supplied through transformers with tap changers or other devices to enable the secondary voltages to be adjusted.
15 Usually the following measurements (inter alia) are provided for:-

- (a) Primary voltages, phase to phase
- (b) Primary currents (usually only the star currents but not always)
- 20 (c) Secondary star currents (derived from primary measurements and tap changer position)

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(d) Secondary phase to phase voltages from points anywhere on the transformer, busbars, electrodes or attached conductors

5 (e) Secondary phase to furnace-bath voltages

(f) Transformer tap position.

The secondary measurements are of doubtful accuracy for the following reasons. Any voltage measurements in the secondary circuit which involve a measuring lead
10 loop through which electromagnetic flux can pass will generally be erroneous as a result of magnetically induced voltages. It is possible to compensate for these induced error voltages if the secondary currents are known. This means that the secondary circuit electrical parameters,
15 namely the three resistances and three inductances, might be determined by measuring (i) voltages with respect to the electrode bath, and (ii) the secondary circuit currents, and then computing the results by either analogue or digital means. However, these methods involve a measurement
20 connection to the furnace bath which is not always possible and this connection is not necessarily the neutral point voltage. Thus, in most cases, it is impossible to measure or calculate accurately the resistances and inductances solely from the secondary measurements.

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The primary measurements are fundamentally more accurate than the secondary measurements. However, it is impossible to determine the secondary resistances and inductances from the primary measurements and transformer tap position without some other information.

It is one object of this invention to provide a method of controlling a furnace wherein the secondary circuit values are derived in a manner which will, in at least many cases, provide improved accuracy of results over the prior art methods referred to above, such values being used for controlling such a furnace.

Apart from the above described difficulty with prior art methods of controlling furnaces, such prior art methods have generally not provided means for limiting certain variables according to surrounding circumstances. It is in general desirable to place the following limits on the operation of a controller so that attempts are not made by the controller to cause a variable to pass such limits:-

(a) limit individual electrode currents to avoid damage thereto; or

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(b) limit the transformer current to avoid overheating thereof;

(c) limit the total power of the furnace.

5

This may be necessary where, even if the transformer is capable of higher power outputs, electrical power is supplied at a rate dependant upon the "maximum demand". The latter may not be relevant where power is cheap (for example hydro-electric power) and such a limit would only be imposed where necessary.

10

(d) A limit on the apparent power or MVA of the transformers to avoid overheating thereof.

15

(e) The transformer output voltage can only be selected from those corresponding to the tap changer positions provided.

(f) The effective resistance of the furnace must fall within certain limits otherwise the operation of the furnace may become difficult.

20

(g) Additional limits apply whilst an electrode is being "baked-in".

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In order to illustrate the possible effects of these limits in practice, Fig. 1 of the accompanying drawings gives a graphical illustration of how they apply to a hypothetical furnace.

5 In the graph, line 1 represents the line of maximum practical operating resistance of the furnace. Line 2 represents the line of minimum practical operating resistance thereof. Line 3 represents the electrode current limit and line 4 represents the transformer current
10 limit. Line 5 represents the apparent power (MVA) limit. The set of curves 6 of power versus current has each member of the set corresponding to one tap changer position of the transformer. The allowable or at least preferred operating area is shown as a shaded area.

15 Clearly in some cases, one or more of the limits may be irrelevant as in the above case where the upper three tap changer positions are unusable and the transformer current limit is totally irrelevant. The latter is so because the electrode current limit is to
20 the left of the transformer current limit in this example.

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It is thus a secondary object of the invention to provide a method and system for controlling a furnace wherein the relevant limits of the above described type are adhered to.

5 In accordance with this invention a method of operating a multi-phase arc furnace by controlling the required values in the secondary circuits comprises the measurement and computation of such values from selected primary and/or secondary circuit measurements excluding
10 secondary phase voltages measured with respect to the furnace bath, computing the desired values for effecting control of the furnace on the basis of an assumption that the behaviour of the inductances of the secondary circuits is predictable during other variations in the particular
15 furnace, and, applying such computed values to the furnace control means optionally subject to any desired limits.

The assumption concerning the inductances of the secondary circuits is that they behave according to a predetermined pattern but often, if not in almost all
20 cases, the assumption will be that the inductances remain equal to each other.

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The computation of the values will generally be effected by means of an on-line computer programmed to make the assumption set forth above and such a computer can be connected to effect the required control of the furnace or to indicate adjustments which should be made to provide the desired operation thereof. However, other computational aids could be employed in less sophisticated systems and the computation could be effected by hand calculator, although with difficulty. Also, depending on the predicted behaviour pattern of the inductances graphs may be capable of preparation to give values of the inductances according to changes in other variables in the furnace.

The invention thus also provides an electrical arc furnace control arrangement comprising means for detecting required values other than voltages relative to the furnace bath, computing means to which such required values are fed, said computing means being adapted to compute the required control values on the basis of an assumption that the inductances in the secondary circuits are predictable theoretically, and means for applying said control values to the furnace.

The inductances in the secondary or power circuits are governed mainly by the geometry of the current

paths. Thus, the inductances are sensitive to the overall construction of the furnace, the location of the conducting paths within the burden, and the position and length of the electrodes. This means that assumptions such as the following are feasible:-

L is the inductance of a particular circuit.

- (a) $L_i = f_i (L_1, L_2, L_3)$, $i = 1, 2, 3$
(or equivalent formulae, including $L_1=L_2=L_3$).
- (b) $L_i = f_i$ (star voltages), $i = 1, 2, 3$ (or equivalent formulae).
- (c) $L_i = f_i$ (electrode currents), $i = 1, 2, 3$, (or equivalent formulae).
- (d) $L_i = f_i$ (hoist positions), $i = 1, 2, 3$, (or equivalent formulae).
- (e) $L_i = f_i$ (lumped star resistances), $i = 1, 2, 3$ (or equivalent formulae).
- (f) $L_i = f_i$ (electrode lengths), $i = 1, 2, 3$.
- (g) Any combination of the above.

It is possible, therefore, to monitor or control the high power circuit and its associated equipment of a three-electrode open-arc or submerged-arc furnace for optimum production through a knowledge of the secondary circuit elements derived from primary or secondary

measurements or both by using the selected assumption about the inductances. In the case of secondary measurements it is not necessary to measure voltages with respect to the furnace bath and therefore errors associated with such a measurement are avoided.

In the drawings:-

Fig. 1 is as described above;

Fig. 2 shows a block diagram of the device as connected to a typical furnace;

Fig. 3 is a simplified diagram of a secondary circuit of a furnace;

Fig. 4 is a schematic sectional side elevation of a controller unit, and

Fig. 5 outlines the actual programme followed by a computer in the controller unit.

An example of the theory of the implementation of the invention will now be described with reference to the relevant accompanying diagrams. The device, which is computer based, measures certain variables from a three phase arc furnace 11 and its associated equipment; carries out the required computation based on these variables to determine the state of certain electrical variables, in a

controller unit 12; displays the state of these parameters
for monitoring purposes on a display panel 13 on the
controller unit, and issues commands to a normal control
console 14 to adjust the tap changer positions of the
5 transformer 15 and/or adjust individual electrode positions
by means of an actuator 16 so as to maintain the electrical
state of the furnace within certain desired limits and at
substantially optimum conditions within such limits. The
limits would be those described above and would simply
10 be fed into a computer or the like together with a programme
embodying the assumption about the inductances.

The computer is connected to the instruments
monitoring the furnace, and in this way, every control
cycle (say every 1.0 second), it obtains, in this instance,
15 the following measurements:

- (i) Transformer tap position, K
- (ii) Transformer primary current I_1', I_2', I_3' , which
can be scaled by the transformer ratio at
tap position K to give secondary currents
20 I_1, I_2, I_3 .
- (iii) Transformer primary voltages $V_{12}', V_{23}', V_{31}'$,
which can be scaled down by the transformer
ratio at tap position K to give secondary
voltages V_{12}, V_{23}, V_{31} .

- (iv) Total circuit power, P.
- (v) Electrode hoist positions h_1, h_2, h_3 .

The power circuit of the furnace can be written as a star with reactances and resistances in each limb, fed from a delta voltage supply as shown in Fig. 3.

In this figure, the three phasor quantities $\vec{V}_{12}, \vec{V}_{23}, \vec{V}_{31}$ and $\vec{I}_1, \vec{I}_2, \vec{I}_3$, are complex numbers. The measured quantities V_{12}, V_{23}, V_{31} and I_1, I_2, I_3 , are the magnitudes of these phasors, and are real numbers. In the following equations and discussion θ_{12}, θ_{23} and θ_{31} are the angles of the phasors $\vec{V}_{12}, \vec{V}_{23}, \vec{V}_{31}$ relative to a fixed datum. Thus by suitable choice of datum one of the angles θ may be chosen to be zero.

We can write: (wherein $i = \sqrt{-1}$)

$$\left. \begin{aligned} \vec{V}_{12} &= V_{12} \exp (i\theta_{12}) \\ \vec{V}_{23} &= V_{23} \exp (i\theta_{23}) \\ \vec{V}_{31} &= V_{31} \exp (i\theta_{31}) \end{aligned} \right\} \text{-- (1)}$$

Because the phasor voltages form a triangle, we can write:

$$\vec{V}_{12} + \vec{V}_{23} + \vec{V}_{31} = 0 \quad \text{-- (2)}$$

Through 2 , the θ angles in equations 1 are inter-related and only one θ may be independently specified. By choosing, say, θ_{12} to be zero degrees, we can then calculate actual values for θ_{23} and θ_{31} from the measurements of V_{12} , V_{23} , V_{31} , using the cosine rule for a triangle. From these angles, we can calculate the phasors \vec{V}_{12} , \vec{V}_{23} , \vec{V}_{31} .

In the following, the angle β is the angle of \vec{I}_1 relative to the same datum as used to determine the angles θ . The angles ϕ_2 and ϕ_3 are the angles between \vec{I}_2 and \vec{I}_1 , and between \vec{I}_3 and \vec{I}_1 respectively.

Thus with the currents, we may write:

$$\left. \begin{aligned} \vec{I}_1 &= I_1 \exp(i\beta) \\ \vec{I}_2 &= I_2 \exp(i(\beta + \phi_2)) \\ \vec{I}_3 &= I_3 \exp(i(\beta + \phi_3)) \end{aligned} \right\} \text{-- (3)}$$

and because the currents balance at the star point,

$$\vec{I}_1 + \vec{I}_2 + \vec{I}_3 = 0$$

Again the angles in equations (3) are inter-related. By writing the angles as shown in equations (3), ϕ_2 and ϕ_3 may be calculated from the measurements of I_1 , I_2 , I_3 , leaving β to be chosen independently.

The angle β is related to the angles θ_{12} , θ_{23} , θ_{31} through the power, P . From the two-wattmeter method of measuring power, we may write:

$$P = \vec{I}_2 \vec{V}_{12} + \vec{I}_3 \vec{V}_{13} = \vec{I}_2 \vec{V}_{12} - \vec{I}_3 \vec{V}_{31}$$

5 (negative sign results from reversing the direction of \vec{V}_{13} to \vec{V}_{31}) and therefore,

$$P = I_2 V_{12} \exp i(\theta_{12} + \beta + \phi_2) - I_3 V_{31} \exp i(\theta_{31} + \beta + \phi_3) \quad (5)$$

All the variables in equations (5) are known except β , and so β can be calculated. From this β , together with ϕ_2 and ϕ_3 , we can calculate the current phasors \vec{I}_1 , \vec{I}_2 , \vec{I}_3 .

Now the resistances and reactances in each limb of the furnace circuit may be combined into complex impedances

$$\left. \begin{aligned} Z_1 &= R_1 + iX_1 \\ Z_2 &= R_2 + iX_2 \\ Z_3 &= R_3 + iX_3 \end{aligned} \right\} \quad (6)$$

From the voltage balances in the circuit, we obtain

$$\left. \begin{aligned} \vec{I}_2 Z_2 - \vec{I}_1 Z_1 &= \vec{V}_{12} \\ \vec{I}_3 Z_3 - \vec{I}_2 Z_2 &= \vec{V}_{23} \\ \vec{I}_1 Z_1 - \vec{I}_3 Z_3 &= \vec{V}_{31} \end{aligned} \right\} \quad (7)$$

Using subscripts R for real term and I

for imaginary term

$$\vec{I}_1 = I_{1R} + iI_{1I} : \vec{I}_2 = I_{2R} + iI_{2I} : \vec{I}_3 = I_{3R} + iI_{3I}$$

$$\vec{V}_{12} = V_{12R} + iV_{12I} : \vec{V}_{23} = V_{23R} + iV_{23I} : \vec{V}_{31} = V_{31R} + iV_{31I}$$

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Expanding equations numbered (7) above into

real and imaginary parts we get:-

$$\left. \begin{aligned} (I_{2R} \times R_2 - I_{2I} \times X_2) - (I_{1R} \times R_1 - I_{1I} \times X_1) &= V_{12R} \\ (I_{2I} \times R_2 + I_{2R} \times X_2) - (I_{1I} \times R_1 + I_{1R} \times X_1) &= V_{12I} \end{aligned} \right\} \text{-- (8)}$$

$$\left. \begin{aligned} (I_{3R} \times R_3 - I_{3I} \times X_3) - (I_{2R} \times R_2 - I_{2I} \times X_2) &= V_{23R} \\ (I_{3I} \times R_3 + I_{3R} \times X_3) - (I_{2I} \times R_2 + I_{2R} \times X_2) &= V_{23I} \end{aligned} \right\} \text{-- (9)}$$

$$\left. \begin{aligned} (I_{1R} \times R_1 - I_{1I} \times X_1) - (I_{3R} \times R_3 - I_{3I} \times X_3) &= V_{31R} \\ (I_{1I} \times R_1 + I_{1R} \times X_1) - (I_{3I} \times R_3 + I_{3R} \times X_3) &= V_{31I} \end{aligned} \right\} \text{-- (10)}$$

In the above six equations there are six unknowns viz R_1, R_2, R_3, X_1, X_2 and X_3 . However, one pair of equations (eg. those numbered (10)) is in effect a combination of the other two (eg. those numbered (8) and (9)) using the fact that $\vec{V}_{12} + \vec{V}_{23} + \vec{V}_{31} = 0$. This leaves four equations with six unknowns. If an assumption is made about the interrelationship between the reactances the four equations can be solved. This could be done in a number of ways, viz. :

(i) assume $X_1 = X_2 = X_3 = X$. Although this assumption does not give a totally accurate solution it does give a vastly improved result over the alternative technique which uses measurements of electrode to furnace bath voltages. In this case the four unknowns are, therefore, R_1, R_2, R_3, X .

5

(ii) assume $X_1 = X + f (l_1)$
 $X_2 = X + g (l_2)$
 $X_3 = X + h (l_3)$

10

Here each reactance is assumed to have a common basic term plus a term dependant on the electrode lengths l_1, l_2, l_3 .

(iii) Other assumptions are possible based on inter-relationships stated above.

15

Having calculated the resistances as shown above, the controller then must decide whether an electrode should be moved or not, in order to achieve a desired resistance. Desired set points for the resistances

would have been entered previously into the controller.

To decide whether to move an electrode, the raw calculated resistances are first put through a digital filter to smooth them. If F is the filtered value of R_1 and α is a constant related to the time constant of the filter then the filter equation is:

$$F_n = \alpha F_o + (1-\alpha) R_1 \quad (8) \quad \text{where } F_n \text{ is the present value and } F_o \text{ is the immediately preceding value.}$$

This filtered value F is allowed to remain within a small deadband around the set point without any action being taken. Should the value of F go outside the deadband, then a pulse will be sent out to the actuating mechanism to cause the electrode to move up or down accordingly. The length of this pulse will be proportional to the difference between R_1 and the set point. Of course, it is necessary to check that pulses lie within a reasonable range, to prevent any abnormal behaviour.

At the same time as R_1 is being checked as explained above, so R_2 and R_3 are likewise checked and the corresponding action taken accordingly. In addition to the resistances, the limits of operation are also checked.

In the case of the limits of operation, the real power P , voltages V_{12} , V_{23} , V_{31} , currents I_1 , I_2 , I_3 , and the apparent power (including the reactive component) which may be easily calculated as part of the resistance calculations, are all compared against their limits. Of these variables, only the one nearest its limit is then examined further. The decision procedure is similar to the resistance decision procedure. The ratio of the highest variable to its limit is again filtered. If this filtered value goes outside the small deadband around 1.0 (note: when variable = limit, then ratio = 1.0), the transformer taps are raised or lowered accordingly.

We have thus described above how the controller performs the task of controlling the electrical side of the furnace. In addition to this, it can also display variables which it has measured or calculated, and also indicate its status such as which limit it is operating against. By watching whether an electrode has moved or not after sending out a pulse to move it, the controller can provide a warning if a hoist mechanism gets stuck. This type of check makes it safer for a furnace to be run completely automatically under the controller, as the controller can summon help when it is needed.

In the practical implementation of the invention the variables mentioned are measured and the computation, indicated above, performed. At present the determination of electrode length involves measuring the electrodes periodically and using the resulting computed powers for each electrode in an electrode erosion model to predict the erosion of the electrodes. By measuring electrode slipping as well, a reasonably accurate electrode length determination is possible.

In practice a computer of a suitable type, preferably, but not necessarily, connected on-line to a furnace will be used. A programme will be fed to the computer embodying the assumption concerning the inductances of the furnace. The programme also preferably embodies limits as above described to ensure that the furnace is not operated outside the predetermined range of the type shown by way of example in Fig. 1. Alternatively, the limits may be made to be variable, if required, and in such a case thumbwheel switches 40 can be provided in a control panel 41 for setting the required limits from time to time. Thumbwheel switches on the panel 41 can also be provided for selecting the information to be displayed on the display panel 13, if the latter is made to display only one value at a time per phase.

In addition to the above it is preferred to include in the programme an alternative set of varying limits to be used, in respect of any one electrode, whilst it is being "baked-in". Baking-in one or more electrodes can be done automatically with the controller. It is indeed preferable to "bake-in" under computer control, as manual control with a furnace imbalance, which accompanies "baking-in", often leads to a worse imbalance, and further trouble.

A "baking-in" schedule consists of starting off at a lower current than normal, and gradually increasing the current by raising transformer taps until the normal operating current is reached. During this "baking-in" the electrode must not be moved, for fear of a "green break". Selection of such a "baking-in" schedule would be made manually on the controller by a selector switch on the thumbwheel panel 41.

The computer controlling unit has outputs which are adapted to alter the tap changer positions and raise or lower the electrodes independantly as required. The output is preferably variable, in so far as the extent of the control action is concerned, in order to provide a correcting action in the settings of the furnace proportional to the deviation from the required values at a particular time.

The controlling unit preferably has either a print output or a display to enable an operator to determine exactly the condition of the furnace at any one time. The displayed information may be the electrode current, power, tap position, the limiting factor being operated against at a specific time, whether or not an electrode is on a "baking-in" programme and the like. The controller may thus be made to provide any required information at any desired time. Also, it may be adapted to detect a fault condition in the furnace, such as an electrode not moving as instructed, and give a descriptive warning.

The above operation of a computer controlled furnace will now be further described with reference specifically to Figures 4 and 5 of the accompanying drawings. Cables 42 to and from the instruments on the furnace are connected to a terminal strip 43 in the controller body 12 and the connections are then made to convertors 44 for converting the signals from the furnace to computer compatible signals. From the convertors the signals are then fed to the computer electronics 45. An output 46 from the computer electronics is fed to an interface circuitry panel 47 which controls relays 48 controlling the electrical power supply to the furnace control instruments.

The computer electronics have a further input 49

from the thumbwheel panel so that the values selected on the thumbwheel switches are fed to the computer electronics. A further output 50 from the computer electronics is connected to provide the required values on the display panel as required or designed.

The computer electronics are programmed to, in this case, repeat a sequence of steps every one second. The sequence of steps to be carried out by the computer are shown in Figure 5. The first step is for the computer to examine the readings of voltages, currents, power and hoist positions from the instruments on the furnace this operation being indicated at block 51 in Figure 5. At the same time the information entered on the thumbwheel switches is read and the resistances and other values required are calculated according to the afore-described method at step 52. The next step 53 is to check the variables against the limits and decide whether the transformer tap positions should be changed. It is at this step 53 that the deadband technique described above is applied to the readings in order to decide whether or not the transformer tap positions should be changed. If the tap positions are to be changed the computer sends a signal to raise or lower one or more of the transformer tap positions as necessary as indicated by block 54.

The next step is to check the calculated resistance against the set point of resistance and decide whether one or more electrodes should be raised or lowered. In fact each electrode is treated separately in rotation and therefore the repeat sequence is indicated by block 56 in Figure 5. If the results of this calculation indicate that one or more electrodes should be raised or lowered the computer sends signals to the furnace control to raise or lower an electrode as necessary as indicated by block 57.

The fact of whether or not the commands issued by the computer are executed are monitored at block 58 and if any errors are noted the computer activates an error handling routine 59 which will result in an alarm being given or an error being indicated on the display panel as may be required. All the information as to whether or not a tap position has been raised or lowered or an electrode raised or lowered as well as errors which have been noted are sent to the display from the computer as indicated by block 60. All information can be connected to be displayed on the display panel and therefore it will be an easy matter for a furnace operator to establish against which limit the furnace is operating.

It will be understood from the above that a micro-computer will be adequate for the purposes of carrying out the control on an arc furnace and the computer can easily be programmed by a computer programmer.

5

It will be appreciated that the exact mechanical and electrical operation of the controller may be implemented by anyone skilled in the art of furnace control and the computer programme necessary will be easily written by a computer programmer.

10

It will be understood by those skilled in the art that the invention may be implemented in various ways and by means of a variety of different types of computers to achieve any particular desired control of arc furnaces.

1. A method of operating a multi-phase arc furnace by controlling the required values in the secondary circuits comprising the measurement and computation of such values from selected primary and/or secondary circuit measurements excluding secondary phase voltages measured with respect to the furnace bath, computing the desired values for effecting control of the furnace on the basis of an assumption that the behaviour of the inductances of the secondary circuits is predictable during other variations in the particular furnace, and, applying such computed values to the furnace control means optionally subject to any desired limits imposed on the variables of the furnace.

2. A method as claimed in claim 1 in which the computation, and optionally control, is effected by means of a computer programmed to operate on the basis of the assumption concerning the inductances of the secondary circuit.

3. A method as claimed in claim 2 in which the computer is programmed to control the furnace to prevent operation outside certain limits of operation thereof, these limits being
5 selected from the group consisting of individual electrode current; individual transformer currents; total real power being consumed by the furnace; apparent power (MVA) of the transformers; and resistance and
10 voltage of the furnace.
4. A method as claimed in claim 3 in which setting of the limits is effected externally by means of manually operable selector switches.
- 15 5. A method as claimed in any one of the preceding claims in which the assumption is that the inductances of the secondary circuits remain equal to one another within the operating ranges of the furnace during
20 other changes in the circuits.
6. A method as claimed in any one of the preceding claims in which facility is provided for the control of any one electrode to impose special

varying limits on the conditions thereof
whilst such electrode is being "baked-in"
with the rest of the furnace remaining
under normal control.

- 5 7. A method as claimed in any one of the
preceding claims in which the computed values
of the furnace variables are utilized to
effect raising or lowering of the transformer
tap positions of the individual electrodes as
10 may be required.
8. A method as claimed in any one of the preceding
claims in which the individual resistances of
the electrode circuits are computed and the
computed values utilized to determine whether
15 or not the furnace electrodes should be
raised or lowered to alter the resistances
towards a desired value.
9. A method as claimed in claim 8 in which
alteration of the resistances of the electrode
20 circuits is only effected if the computed values
vary from the desired values by more than a pre-
determined amount thereby providing a deadband
in which no control activity is actuated.

10. A method as claimed in any one of the preceding claims in which the selected primary and secondary circuit measurements measured include the following:-

- 5 (i) Transformer tap position, K
- (ii) Transformer primary current I_1', I_2', I_3' , which can be scaled by the transformer ratio at tap position K to give secondary currents I_1, I_2, I_3 .
- 10 (iii) Transformer primary voltages $V_{12}', V_{23}', V_{31}'$, which can be scaled down by the transformer ratio at tap position K to give secondary voltages V_{12}, V_{23}, V_{31} .
- (iv) Total circuit power P.
- 15 (v) Electrode hoist position h_1, h_2, h_3 .

11. A method as claimed in claim 10 in which the computation is effected by solution of any two pairs of the following three pairs of equations or their equivalents using the assumption that the behaviour of the inductances of the secondary circuits is predictable:-

20

$$\left. \begin{aligned} (I_{2R} \times R_2 - I_{2I} \times X_2) - (I_{1R} \times R_1 - I_{1I} \times X_1) &= V_{12R} \\ (I_{2I} \times R_2 + I_{2R} \times X_2) - (I_{1I} \times R_1 + I_{1R} \times X_1) &= V_{12I} \end{aligned} \right\} \text{-- (8)}$$

$$\left. \begin{aligned} (I_{3R} \times R_3 - I_{3I} \times X_3) - (I_{2R} \times R_2 - I_{2I} \times X_2) &= V_{23R} \\ (I_{3I} \times R_3 + I_{3R} \times X_3) - (I_{2I} \times R_2 + I_{2R} \times X_2) &= V_{23I} \end{aligned} \right\} \text{-- (9)}$$

$$\left. \begin{aligned} (I_{1R} \times R_1 - I_{1I} \times X_1) - (I_{3R} \times R_3 - I_{3I} \times X_3) &= V_{31R} \\ (I_{1I} \times R_1 + I_{1R} \times X_1) - (I_{3I} \times R_3 + I_{3R} \times X_3) &= V_{31I} \end{aligned} \right\} \text{-- (10)}$$

12. A method as claimed in any one of the preceding claims in which the assumption is that the inductances are equal in the phases i.e.

$$X_1 = X_2 = X_3 = X.$$

13. A method as claimed in any one of the preceding claims in which the assumption is that

$$X_1 = X + f(l_1)$$

$$X_2 = X + g(l_2)$$

$$X_3 = X + h(l_3)$$

14. A method of controlling a furnace substantially as herein described or exemplified with reference to the accompanying drawings.

15. An electrical multi-phase arc furnace control arrangement comprising means for detecting required values other than voltages relative to the furnace bath, computing means to which

such required values are fed, said
computing means being adapted to compute
the required control values on the basis
that the inductances of the secondary
5 circuits are predicted theoretically
during other changes in the circuits and
means for applying said control values to
the furnace optionally subject to any desired
limits imposed on the variables of the
10 furnace.

16 An electrical arc furnace control arrangement
as claimed in claim 15 in which the means
for detecting required values of a furnace
are adapted to detect:-

- 15 (i) Transformer tap position, K
Transformer primary current I_1', I_2', I_3' , which
can be scaled by the transformer ratio at
tap position K to give secondary currents
 I_1, I_2, I_3 .
- 20 (iii) Transformer primary voltages $V_{12}', V_{23}', V_{31}'$,
which can be scaled down by the transformer
ratio at tap position K to give secondary
voltages V_{12}, V_{23}, V_{31} .
- (iv) Total circuit power, P.
- 25 (v) Electrode hoist position h_1, h_2, h_3 .

17. An electrical multi-phase arc furnace control arrangement as claimed in either of claims 15 or 16 in which the computing means is adapted to solve two of the following three pairs of simultaneous equations on the basis that the inductances of the secondary circuits are predictable:-

$$\left. \begin{aligned} (I_{2R} \times R_2 - I_{2I} \times X_2) - (I_{1R} \times R_1 - I_{1I} \times X_1) &= V_{12R} \\ (I_{2I} \times R_2 + I_{2R} \times X_2) - (I_{1I} \times R_1 + I_{1R} \times X_1) &= V_{12I} \end{aligned} \right\} \text{-- (8)}$$

$$\left. \begin{aligned} (I_{3R} \times R_3 - I_{3I} \times X_3) - (I_{2R} \times R_2 - I_{2I} \times X_2) &= V_{23R} \\ (I_{3I} \times R_3 + I_{3R} \times X_3) - (I_{2I} \times R_2 + I_{2R} \times X_2) &= V_{23I} \end{aligned} \right\} \text{-- (9)}$$

$$\left. \begin{aligned} (I_{1R} \times R_1 - I_{1I} \times X_1) - (I_{3R} \times R_3 - I_{3I} \times X_3) &= V_{31R} \\ (I_{1I} \times R_1 + I_{1R} \times X_1) - (I_{3I} \times R_3 + I_{3R} \times X_3) &= V_{31I} \end{aligned} \right\} \text{-- (10)}$$

18. An electrical multi-phase arc furnace control arrangement as claimed in claim 17 in which the computing means is adapted to treat the inductances of the secondary circuits as being equal i.e. $X_1 = X_2 = X_3 = X$.

19. An electrical multi-phase arc furnace control arrangement as claimed in any one of claims

15 to 19 in which said computing means is a suitably programmable computer.

5 20. An electrical multi-phase arc furnace control arrangement as claimed in any one of claims 15 to 19 in which the means for applying the control values to the furnace is a normal control console and actuator assembly.

10 21. An electrical multi-phase arc furnace control arrangement substantially as herein described or exemplified with reference to the accompanying drawings.

22. An electrical arc furnace having a control arrangement as claimed in any one of claims 15 to 21.

15 23. An electrical multi-phase arc furnace adapted to be operated by a method as claimed in any one of claims 1 to 14.

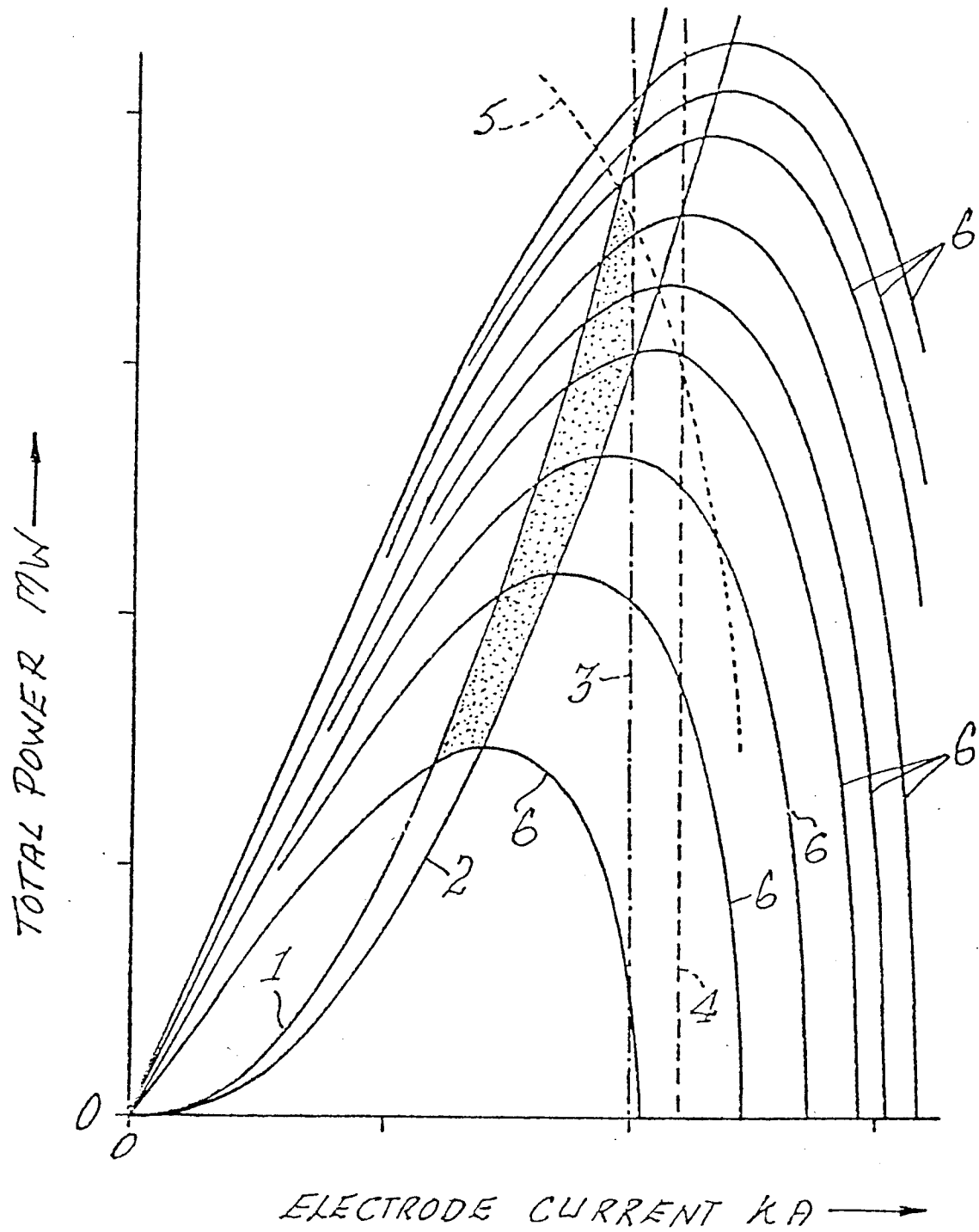


Fig 10

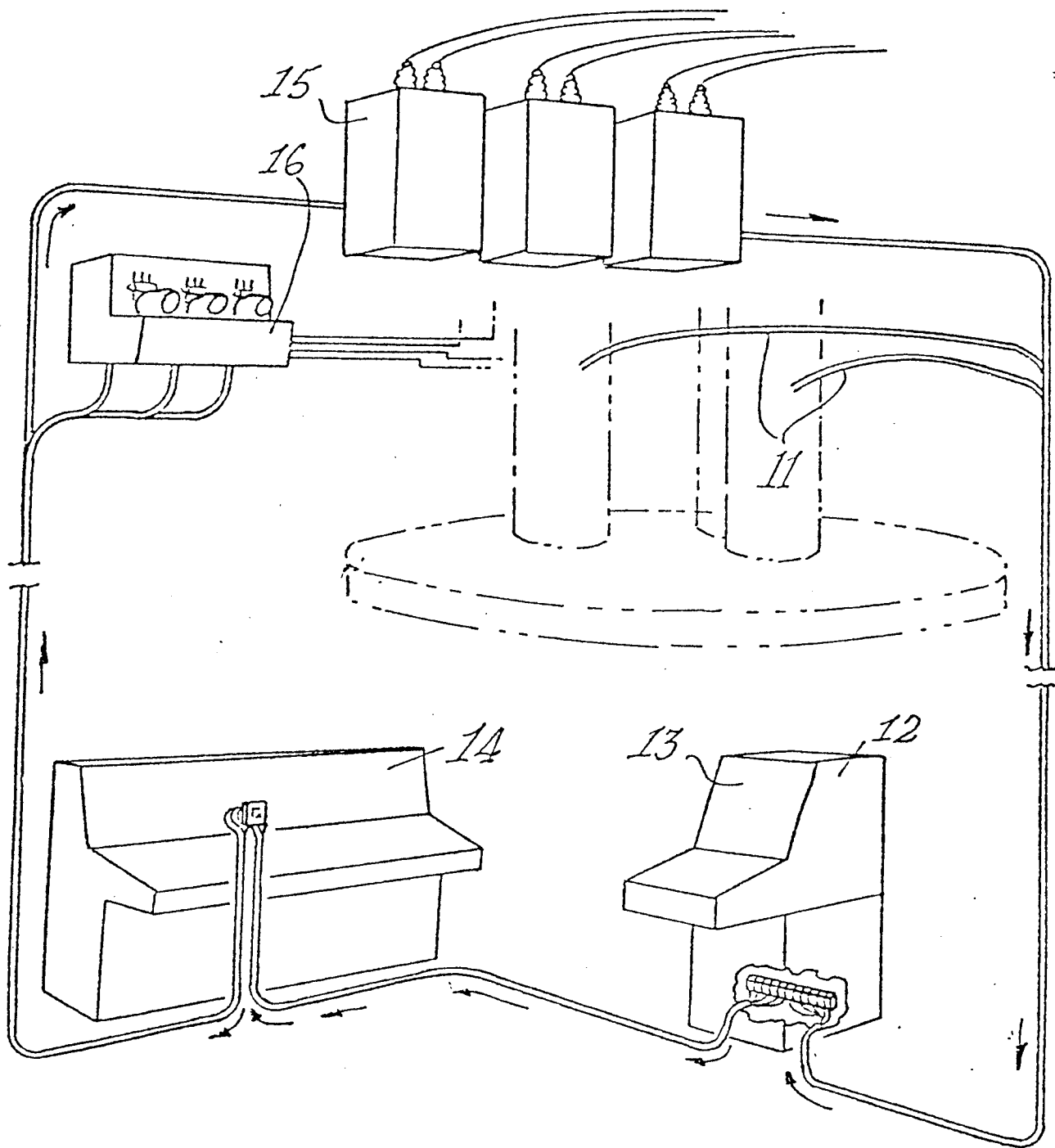


Fig. 2.

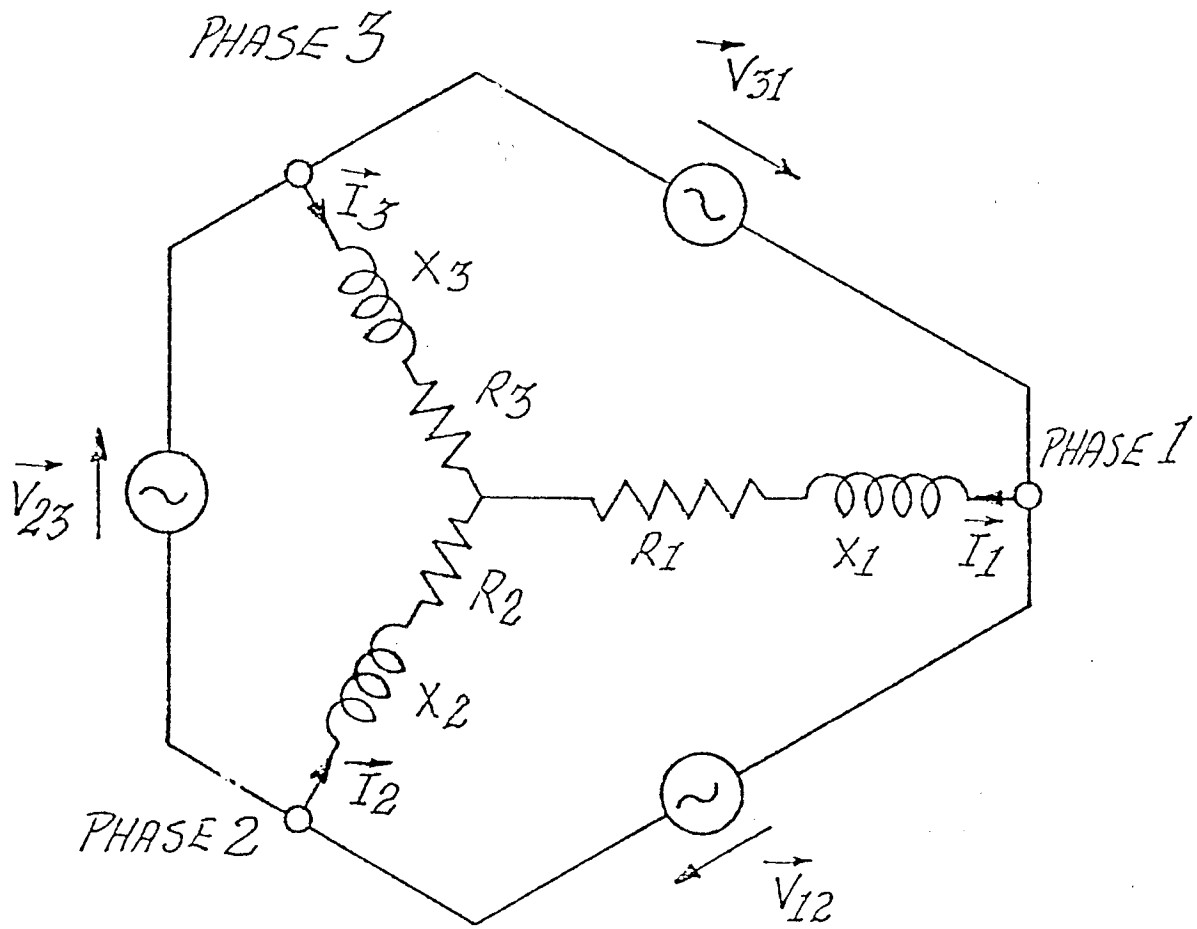


Fig 5

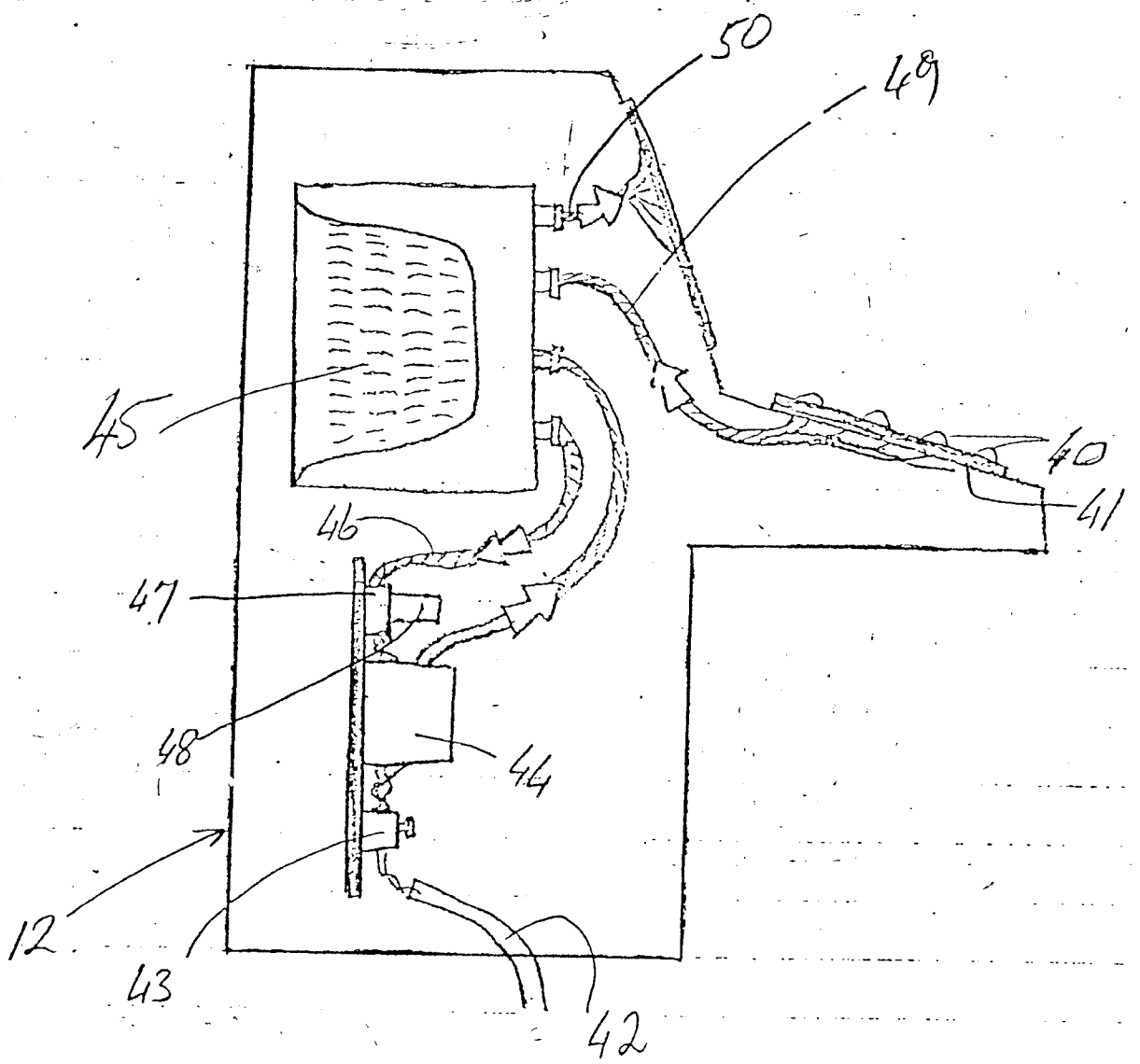


Fig 4

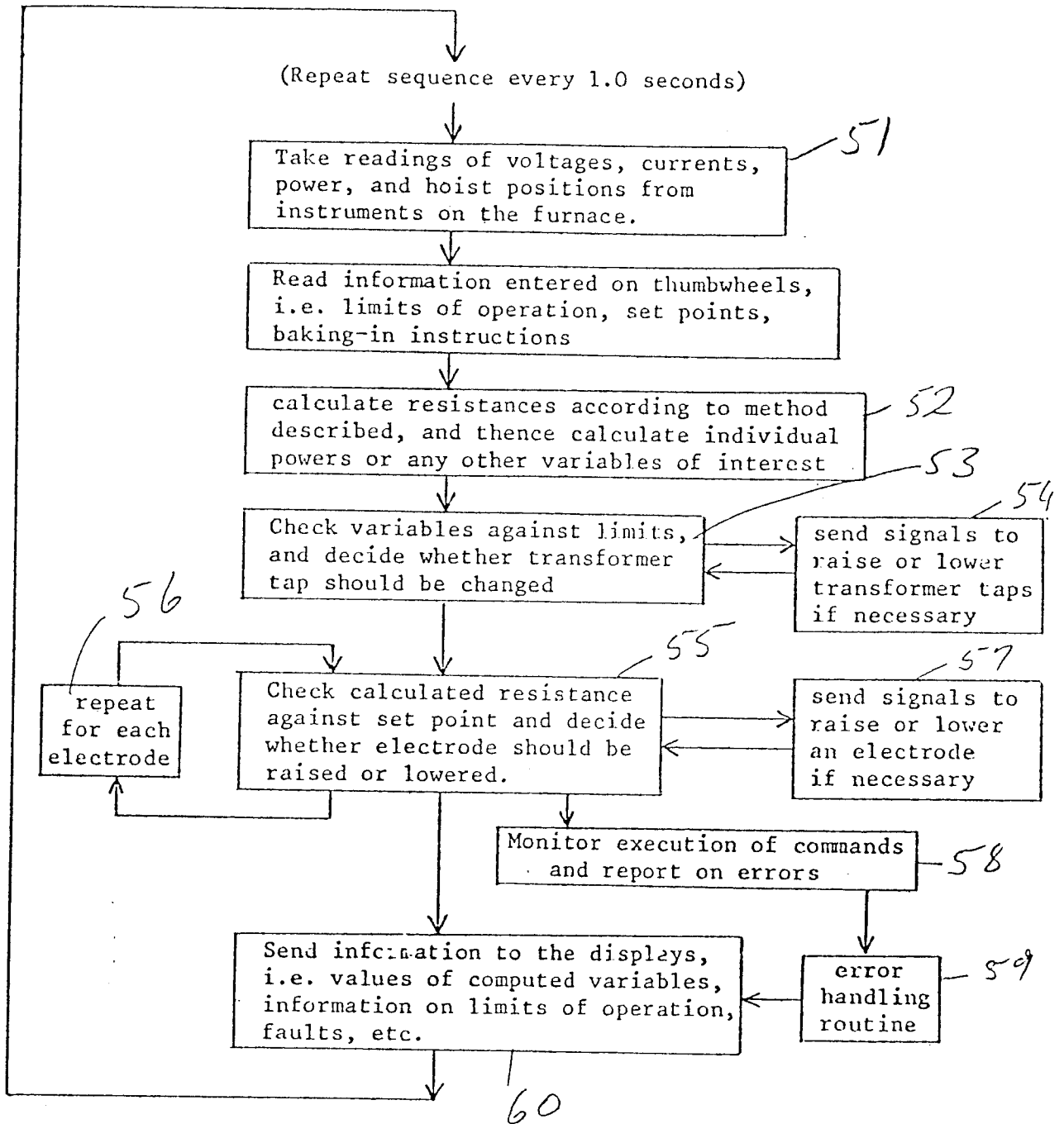


FIGURE 5