MODELLING OF ARC REGULATION PROCESSES IN ELECTRIC ARC FURNACE.[*]

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Abstract.

This work deals with improving the performance of Electric arc furnaces for production steel alloys. To improve the control in such furnaces the a proper cooperation between three separate control systems (three Electrods) was taken to get one united control system. That is, we consider the electric arc furnace as a multivariable object. Also it contains industrial practical data and theoritical anlaysis to introduce the modelling of arc regulation processes. The parameters of the object under consideration are presanted. The investigation shows that the arc impedance is very small, even the difference between the values of controlled object are very small.

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[*] This work was carried out in Copper Works plant, Alexandria A.R.E., Furnacesses department, 25 ton Electric arc Furance.

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I- Introduction:

In steel making processes, the Electric arc furnaces have a wide opplication for producing steel alloys. In this type of the furnaces, transformation of electric energy into heat energy is carried out by electric discharge across a gap between an electrode and metal through gas or vacoum. Fig.1. Consequently, the electrode position is one of the main controlled parameters in such furnaces. Generally the electric arc may be characterized by the following parameters:

1. arc Length L,
2. arc voltage V_a,
3. Current through the electrode I,
4. Voltage - to - current ratio V_a/I
5. Power P.

These are to be considered from the point of view of possibility to employ them as controllable variables of the arc regime [1] . Of course electrodes position are changed instantanusly and hence all the parameters of the object. The purpose of this article it to measure the actual arc impedance, to find the parameters of our object and mathematical model of such technological processes.

II- Amplidyne-type differential controller as existing system in the industry.

Amplidynes are now widly used in the electric-arc-furnaces automation as a separate control system. A circuit diagram of such controller is given in Fig.2. The phase current and voltage affect the control winding CW of the amplidyne A via the current transfarmer CT, autotransformer AT, current rectifer, CR, voltage transformer VT and voltage rectifier VR - the rectified current pass through the adjustable resistors R_1, R_2 and through the control winding. Fb is the feedback winding. Under a certain adujstment of AT, R_1 and R_2, the current through the control winding is zero. This state corrospondes to a desired voltage to current ratio when the electrode is kept moveless, When the ratio differs from its desired magnitude, a current begins to flow through the control winding. Then the amplidyne is excited and produces its output voltage V_o whose magnitude is approximately proportional to the current in the control winding CW, while the polarity is determined by direction of current in the same winding. So V_o is function of deviation of the actual voltage-to current ratio from its desired value. The voltage V_o is applied to the D.C. type motor M with separate exci-

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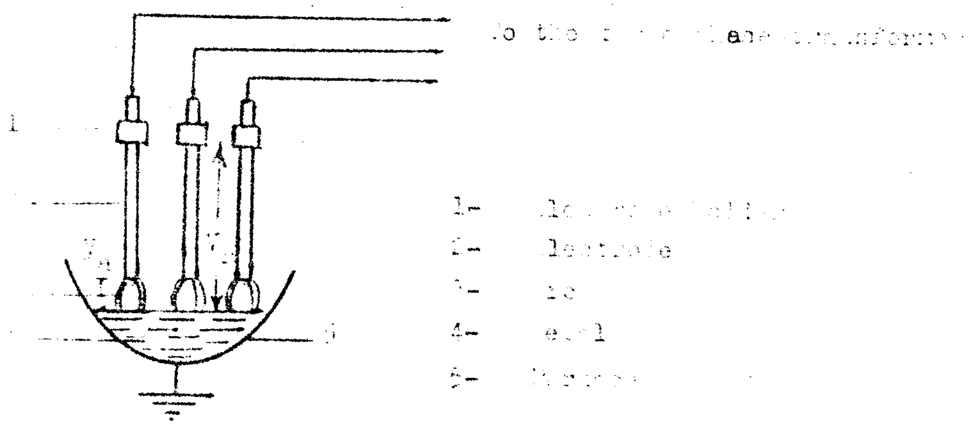
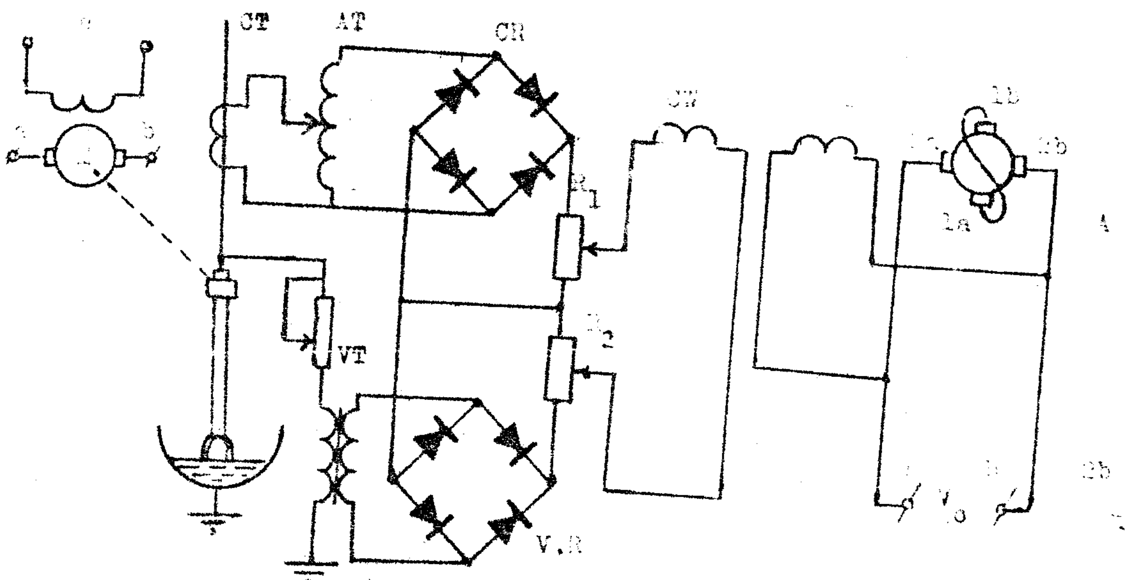


Fig.1 Three- phase arc furnace



Current transformer
Voltage transformer
Current Rectifier
Voltage Rectifier
Resistor

C.W control winding
1a, 2a, 1b, 2b brushes
V_c = Control voltage.= V_o
W_e = exictasion winding
AT= outotransformer

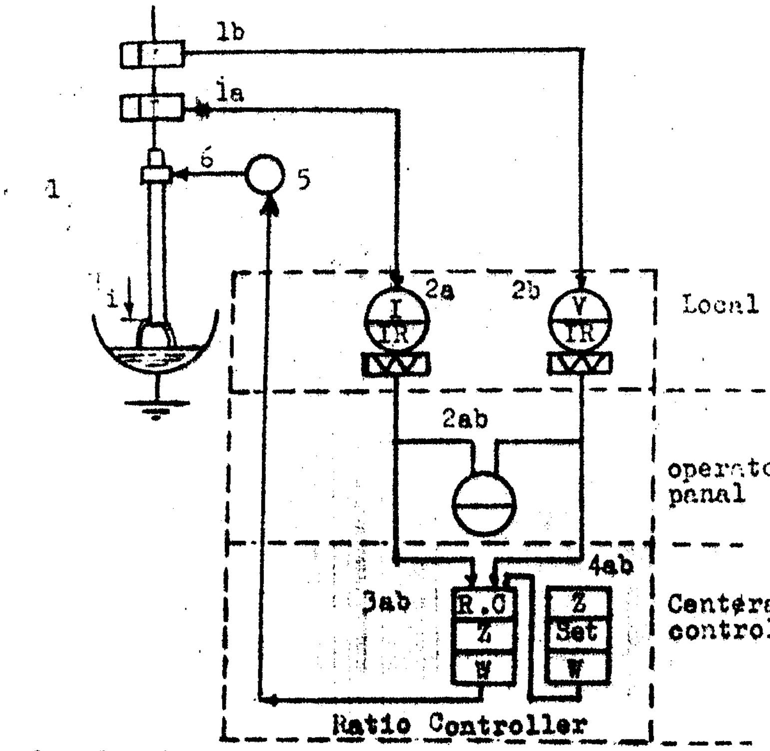
Fig.2. Simplified circuit diagram of Amplidyne type regulator for Electric arc furnace.

tation by the voltage V_0. This motor drives the electrode until the desired voltage - to - current ratio is reached. [1] .

In this system each electrod considers as a single object. For each electrode of three, the impedance Z_i $(i = 1,2,3)$ of the arc is measured through measurments of the electric current and voltage across the arc.Singal is then fed to stabilizing controller; where it is compared with three reference command Z_{io}, the latter being corresponded to the desired heating rate. If there is any actual deviation $Z_i = Z_i - Z_{io}$, the controller moves the i, th electrode, thus changing the length of the ith arc H_i to get $Z_i \longrightarrow Z_{io}$. If $Z_i > Z_{io}$, the ith electrode moves in dawenward direcation and vice versa Fig.3 indicats the principle scheams. This method needs three seperate feedback control system Fig.4 corrosponding to the three electrods.

III- Electric arc furnace as a multivariable object:

In the proposed system to improve the control the care may be taken of a proper cooperation between three mentioned seperate systems to get one united control system. That is, we consider the electric arc furance as a object, having a transfer matrix which relates the all output controlled impedances (Z_i) to all input arc lengths ΔH_i, i.e.



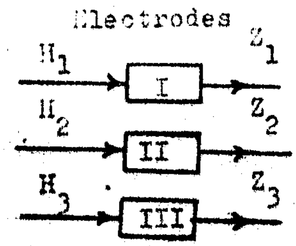


Fig.4 Arc Control by using separate control system.

1. 1a, 1b current and voltage coil
2. 2a, 2b current and voltage. Indicating and measuring devices, 2ab Indicating device. 3. 3ab ratio controllor (V/I)
4. 4ab setter for impedance value of arc 5. servo motor
6. Electrode holder.

Fig.3. Principle Scheame Electric arc furnace (for one electrode)

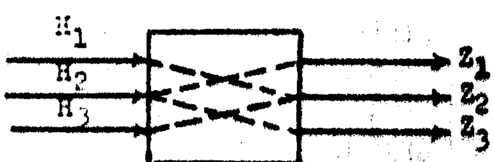


Fig 5a

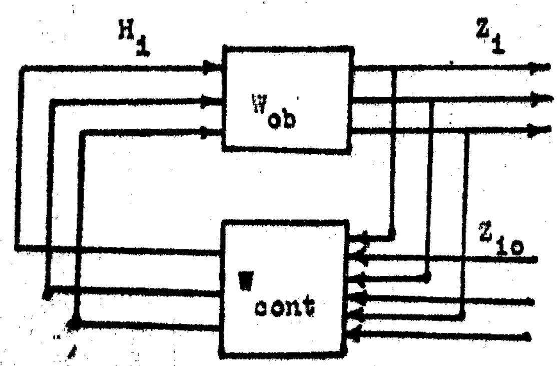


Fig. 5b

Fig. 5 Block diagram of Electric arc as a multivariable control system.

$$\left[Z \right] = \left[W_{ob} \right] \left| \Delta H \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where

$$\left[Z \right] = \begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \end{bmatrix} \quad ; \quad \left| \Delta H \right] = \begin{bmatrix} \Delta H_1 \\ \Delta H_2 \\ \Delta H_3 \end{bmatrix} ;$$

$$\left[W_{ob} \right] = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

Z_1, Z_2, Z_3 are the impedance of the arc in the first, second and third phasses; ΔH_1, ΔH_2, ΔH_3 are the displacement of the corrospanding electrodes. Fig.5 Shows the block diagrams.

For simplicity, If we consider the furance in its steady state condition at a certain operating point as in case of refining period, so $\left| W_{ob} \right|$ contains static elements only [1] , [2] , [3] and [4] . Then the obove object equation becomes.

$$\left.\begin{aligned} Z_1 &= a_{11}\Delta H_1 + a_{12}\Delta H_2 + a_{13}\Delta H_3 \\ Z_2 &= a_{21}\Delta H_1 + a_{22}\Delta H_2 + a_{23}\Delta H_3 \\ Z_3 &= a_{31}\Delta H_1 + a_{32}\Delta H_2 + a_{33}\Delta H_3 \end{aligned}\right| \quad .....(2)$$

In a simple case, the impedance may be estimated as pure resistances, and so factors a_{11}, a_{12}, ..., a_{33} are scalar numbers.

Experimental determination of them is available for an industrial furnace. To get 9 unknown factors a_{ij}, at least 9 experiments should be performed, each containing different set of Z_i, ΔH_i. Each experiment will give one equation which numerically known Z_i, ΔH_i and unknowns a_{ij}. Sloving these 9 numerical equations we can get numerical values of a_{ij}. These experimental equations can be arranged as follows:

$$\left.\begin{aligned} Z_{11} &= a_{11}\Delta H_{11} + a_{12}\Delta H_{12} + a_{13}\Delta H_{13} \ ; \\ Z_{12} &= a_{11}\Delta H_{21} + a_{12}\Delta H_{22} + a_{13}\Delta H_{23} \ ; \\ Z_{13} &= a_{11}\Delta H_{31} + a_{12}\Delta H_{32} + a_{13}\Delta H_{33} \ ; \end{aligned}\right| \quad .....3$$

$$Z_{21} = a_{21} \Delta H_{11} + a_{22} \Delta H_{12} + a_{23} \Delta H_{13} \; ;$$
$$Z_{22} = a_{21} \Delta H_{21} + a_{22} \Delta H_{12} + a_{23} \Delta H_{23} \; ; \qquad \ldots\ldots(4)$$
$$Z_{23} = a_{21} \Delta H_{31} + a_{22} \Delta H_{32} + a_{23} \Delta H_{33} \; ;$$

$$Z_{31} = a_{31} \Delta H_{11} + a_{32} \Delta H_{12} + a_{33} \Delta H_{13} \; ;$$
$$Z_{32} = a_{32} \Delta H_{21} + a_{32} \Delta H_{22} + a_{33} \Delta H_{23} \; ; \qquad \ldots\ldots(5)$$
$$Z_{33} = a_{33} \Delta H_{31} + a_{32} \Delta H_{32} + a_{33} \Delta H_{33} \; ;$$

IV-Industrial practical data and determination the charactéristic of Electric arc furnace under investigation.

Experimental data were obtained at 25-ton capacity furnace at couppor works plant, Alexandria. The test were made by variation of electrode displacements accompanied with measuring voltage and current of each phase, from which the obsolute volues of phase impedance Z_1, Z_2 and Z_3 were calculated afterwards. These experimental data was registerd and tabulated in the following table.

Table of experimental data to obtain object equations.

Variables No. of exper.	H_1,cm	H_2,cm	H_3,cm	v,volt	I,Kamp	$Z = \frac{V}{I}$ Milli ohm
1	20	25	15	311	13.0	$23.9 = Z_{11}$
2	15	20	10	290	15.5	$18.7 = Z_{12}$
3	10	5	20	260	21	$12.4 = Z_{13}$
4	20	25	15	300	14.2	$21.1 = Z_{21}$
5	15	20	10	295	15	$19.7 = Z_{22}$
6	10	5	20	255	22	$11.6 = Z_{23}$
7	20	25	15	285	16	$17.8 = Z_{31}$
8	15	20	10	265	20	$13.3 = Z_{32}$
9	10	5	20	300	14.5	$20.7 = Z_{33}$

By substituting the experimental numerical data from the prrevious table into the object equations 3, 4 and 5 we get:

$$23.9 = 20\,a_{11} + 25\,a_{12} + 15\,a_{13}\ ;$$
$$18.7 = 15\,a_{11} + 20\,a_{12} + 10\,a_{13}\ ;$$
$$12.4 = 10\,a_{11} + 5\,a_{12} + 20\,a_{13}\ ;$$

$$21.1 = 20\,a_{21} + 25\,a_{22} + 15\,a_{23}\ ;$$
$$19.7 = 15\,a_{21} + 20\,a_{22} + 10\,a_{23}\ ;$$
$$11.6 = 10\,a_{21} + 5\,a_{22} + 20\,a_{23}\ ;$$

$$17.8 = 20\,a_{31} + 25\,a_{32} + 15\,a_{33}\ ;$$
$$13.3 = 15\,a_{31} + 20\,a_{32} + 10\,a_{33}\ ;$$
$$20.7 = 10\,a_{31} + 5\,a_{32} + 20\,a_{33}\ ;$$

From which we calculate

$a_{11} = -1.494$; ; $a_{12} = 1.568$; $a_{13} = 0.975$

$a_{21} = -12.650$; $a_{22} = 8.024$; $a_{23} = 4.900$

$a_{31} = -3.642$; $a_{32} = 2.250$; $a_{33} = 2.293$

.˙. The object matrix is.

$$W_{ob} = \begin{bmatrix} -1.494 & 1.568 & -.975 \\ -12.65 & 8.024 & 4.900 \\ -3.642 & 2.250 & 2.293 \end{bmatrix}$$

Thus the characteristics of the controlled arc furnace were determined experimentally.

V- Modelling of Electric arc furnaces

From the previous experimental data it is clear to notice that the value of controlled variable which represents the impedance of the arc is very small value $Z_a < 0.01$ ohm., even the deferences between each impedance of electrodes are very small. Actually it is difficult to measure this value directly, and it is not accurate to design the suitable controller by using the inverse matrix technique. For this reason we measure the value of electrode level H,cm as observable parameter function of arc impedance Z_a in mill ohm. to find the mathematical model for such processes.

From Fig 1. the length of power ful arc can be expressed by the formula .

$$L_a = \frac{V_a}{B} \qquad \ldots\ldots\ldots\ldots\ (6)$$

Where B = potential gradient in the arc. The potential gradient, irrespective of the current, strongly depends on tempeature varying from B-12 V/mm for the cold charge up to B=1.1 V/mm for the hot metal inside the furance [1] .

Practically, the voltage V_a across the arc cannot be directly measured because of a very high temperature. Only a part V_s of the supply roltage can be measured. Then we have .

$$L = \frac{V_s - \alpha}{B}$$

or $V_s = \alpha + BL$ ....(7)

where = sum of the anode and cathode voltage drops being in magntude of 25 - 40% of V_a [1]

The values of B and α are depending on the temperature and current respectively.

If we take the arc impedance as a controllable parameter Z_a. It takes the form of V_s/I and can be stabilized to ensurs the the following condition

$$aI - bV_s = 0$$

where a and b are constants, i.e.

$$R_a = \frac{V_s}{I} = \frac{a}{b} = \text{Constant} \quad ....(4)$$

Hence this method enables stabilization of the arc resistance R_a (together with the resistance of the electrode) by moving the electrode i.e. varying H and changing the arc lenghth L.

Considering the entire secondary circuit, that consists of the furance and a connecting line, fed by a transformer tap voltage V_t we have the expression.

$$V_t = \sqrt{(V_s + Ir)^2 + (Ix)^2} \quad \ldots\ldots\ldots\ldots(8)$$

in which r and x are resitance and reactance of the line from which the value of V_s can be obtained according to the following formula

$$\therefore V_s = \sqrt{V_t^2 - (Ix)^2} - Ir \quad \ldots\ldots\ldots\ldots(9)$$

substituting the value of V_s from Eq. 7 in Eq. 9 we have

$$L = \frac{1}{B} \left(\sqrt{V_t^2 - (Ix)^2} - Ir - \alpha \right) \quad \ldots(10)$$

It follows that the more L the less I and vice versa. The following Eq. represents the rate of change arc length L w.r.t. the current I.

$$\frac{dL}{dI} = -\frac{1}{B} \left[\frac{Ix^2}{\sqrt{V_t^2 - (Ix)^2}} + r \right]$$

$$= -\frac{1}{B} \left[\frac{x^2}{\sqrt{(\frac{V_t}{I})^2 - x^2}} + r \right] \quad \ldots\ldots\ldots(11)$$

Hence the total circuit's impedance taks the form

$$\frac{V_t}{I} = \sqrt{(R_a + r)^2 + x^2} \quad \text{...........(12)}$$

Now the term arc gain K_I can be interoduced and takes the forms $\frac{dI}{dL} = \frac{dI}{dH}$

$$\frac{dI}{dL} = \frac{\Delta I}{\Delta L} = \frac{\Delta I}{\Delta H} = K_I = \frac{E(R_a + r)}{r^2 + r\,R_a + x^2} \quad \text{......(12)}$$

The Last Eq. represents the change in the current passing through the electrode with respect to arc length L or electrode position H. Also with respect to arc voltage gain K_v it can taks the form K_v where

$$K_v = \frac{dV_a}{dL} = \frac{dV_s}{dL} = \beta \quad \text{........(13)}$$

Due to the distinction between the gains K_I and K_v, the change of L is accompanied changes in the current and voltage in opposite sence until their desired ratio is ensured. The last two Eqs are representing the mathematical models of the arc impedance conrol in electric arc furance.

IV. <u>Conclusion:</u>

From the previous practical & mathematical data this article presents the following results:

- It is possible to impove the perofrmance control of electric arc furance, we can consider it as a multivariable control system by taking the proper cooperation between the electrodes position as individual control system to get one united control system.

- Determination of the parameters of the electric arc furance under consideration and mathematical model of arc regulation processes.

- It is not accurate and actually difficult to apply the rules of inverse transfer matrix techinque to design the optimal controller in such technological processes.

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MODELLING OF ARC REGULATION PROCESSES IN ELECTRIC ARC FURNACE

BY

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يهدف البحث الى اعداد النموذج الرياضى المتعلق بتنظيم الشراره الكهربائيـــة فى الافران ذات الشرارة الكهربية والتى تستعمل على نطاق واسع فى الصناعة لانتــــــاج الصلب السبائيكى ٠

وقد تتضمن البحث النقاط التالية :ـــ

أـ دراسة ميدانية فى الشركات المتخصصة لانتاج هذا المنتج وعمل التجارب اللازمـه على الافران الموجوده بها ٠

ب ـ استنتاج العناصر المكونه للنموذج الرياضى المماثل للفرن والتى بمعرفتها يمكــن تصميم منظم اتوماتيكى امثل (Optimum Regulator) يعمل به الفرن لكى تصل العملية التكنولوجية والمنتج الى المستوى المطلــــوب ٠

جـ ـ استنتاج الدراسات النظرية لاعداد النموذج المطلوب ٠

د ـ توصل الباحث الى النموذج الرياضى والتغيرات المطلوبه التى تؤدى الى تحسين العملية التكنولوجية الخاصة بالتحكم الآلى فى الافران ذات الشرارة الكهربية ٠

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