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AUTOMATIC SETTLEMENT SYSTEM OF LIQUID STEEL LEVEL INTO THE TUNDISH FOR CONTINUOUS CASTING MACHINE

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ABSTRACT

The increasing quality of steel and a reliability indices of the afferent installations need an automation system for continuous steel casting machines. This paper presents an original solution of automatic settlement of liquid steel debit and level in tundish as well as an analysis of the dynamic behaviour of automatic installation.

The results of continuous casting timing satisfy quite all the quality conditions of technological operations: the level variation stands in admissible limits while the records of the level allow the control of installation functions. During all the experiments, the automatic settlement was stable and reliable.

The realization of automatic settlement system of liquid steel level in tundish is important for the continuous casting slab quality (under the purity aspect of non-metalic inclusions) as well as the surface defects avoidance, with efects over productivity of continuous casting machines and cost reduction.

KEYWORDS: continuous casting machine, tundish, liquid steel level, dynamic behavior

1. Introduction

The increasing quality of steel and a reliability index of the afferent installations need an automation system for continuous steel casting machines.

The spatial mechanism of closing gate represents an element of automatic settlement system of level in tundish [2]. In the following paper there is an original solution of automatic settlement of level in tundish and an analysis of the dynamic behaviour of automatic installation.

2. The automatic settlement algorithm of liquid steel level in tundish

The automatic settlement system adoption needs a reliable mechanism, taking into account that the mechanism is running in heavy conditions. The use of a settlement system with continuing action should lead to a permanent running of the spatial mechanism, resulting in its pronounced wear. The basic idea of the proposed system consists in running a mechanism, that works in heavy conditions (mechanic and thermic variations), with an adequate electric system command that works in parsing. The idea is the adoption of a settlement system with sampling. Sampling period, T, is adopted equal to 10 s.

At a some discrete value of time kT, (k = 0, 1, 2, ….), it runs the next processes that compare the reaction purveyed by the signal of transducer, with the reference signal; if the resulted error in absolute value surpasses an imposed limit then, a short displacement commands the adequate assignment quantity. If the error is smaller than the imposed limit, the mechanism is not activated. Between the sampling periods, the mechanism stands.

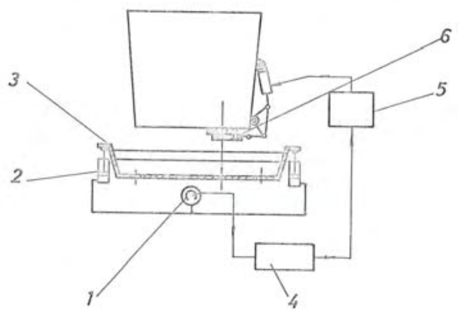

***Fig. 1**. Draft of settlement system of liquid steel level in tundish.*

The tenet draft of the settlement system of liquid steel level in tundish is given in figure 1, in which: 1 is pressure traductor, 2 – hydraulic drum, 3 – tundish, 4 – command element by impulses (with sampling), 5 – execution element, 6 – mechanism with sliding gate.

The move and the vertical position of the tundish is adjusted by a hydraulic installation with a behaved electric pump and four hydraulic cylinders with lifter rods and pistons, placed on the sustenance support of the tundish-car. Assigned uniform task on the sustenance pistons of tundish creates in the hydraulic cylinder a pressure which can be metered. [1]

The level variation in the machines tundish of continuous casting translates in the pressure variation from the hydraulic cylinder of tundish sustenance, which it transmited to transducers in unified system or pressure-gauges with electric contacts.

The reaction signal, given by transducers is transmitted by impulses to the command element, which is a tripozitional controller with sampling. Delicate purveyed command by the controller applies hydraulic execution element, which acts the rectifying mechanism of passage reach.

The running tenet of automatic settlement system of level in tundish is ilustrated by the given diagram in figure 2, in which enters the indicial reply of h(t) system, to an applied variation of reference, the execution size action x_m (the settlement organ opening), and also the delicate purveyed command controller.

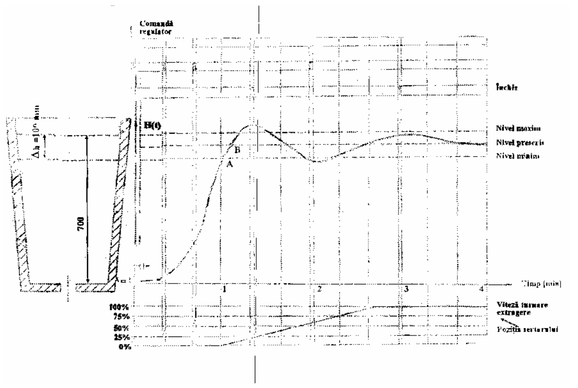

***Fig. 2**. The running tenet of automatic settlement system of liquid steel level in tundish*

3. Automatic dynamics installation study

The representation by input-output sizes of the formed installation is given in figure 3, in which: h is the level (the output size), x_m – case opening (execution size), x_{p1} – liquid steel level in the casting container, x_{p2} and x_{p3} – settlement organs position to the exhaust from tundish, x_{p4} – metal temperature, x_{p5} – steel quality etc. (x_{pk}, k = 1, 2, …, are disturbed sizes).

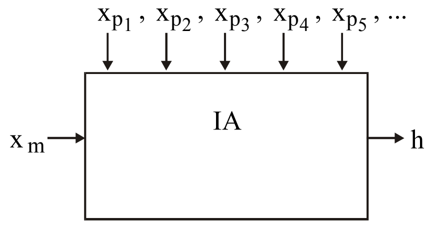

***Fig. 3**. The formed installation representation by input-output sizes.*

The mathematical pattern of automatic installation is formed from state equation, representing the material balance-sheet in tundish and from the relations which explain the intermediate variables which appear in the state equation.

The material balance-sheet equation is:

$$\frac{d(V\rho)}{dt} = Q_1 - Q_2 \qquad (1)$$

in which:

V is the liquid steel volume;

ρ – steel consistency

Q_1 and Q_2 – input debits and, respectively, the output debits.

It does the next hypotheses, according to the physical process:

- The liquid steel temperature variation is negligible, therefore, ρ = constant;
- The interest variation of free surface liquid, in the stabilization behaviour of level is negligible.

For a given quality of steel, the disturbed sizes which intervene are: x_{p1} , x_{p2} and x_{p3} .

From the relation (1), with the exposed hypotheses, results:

$$A \cdot \rho \frac{dh}{dt} = Q_1 - Q_2 \qquad (2)$$

where, A is the free surface area of liquid.

The input debit in tundish is:

$$Q_1 = S(x_m) \cdot \rho \cdot 60 \sqrt{\frac{2gh_1}{2 + \lambda \frac{L}{D}}} \qquad (3)$$

in which:

$S(x_m)$ is constructive characteristic of settlement organ to the steel exhaust from the casting container;

h_1 – liquid level from the casting container;

D – rated diameter of outflow orifice;

λ - endurance ratio (constant);

L – by-pass span.

The relation (3) be written also can under form:

$$Q_1 = k_1 \cdot S(x_m) \cdot \sqrt{h_1} = k_1 \cdot S(x_m) \cdot \sqrt{x_{p_1}} \qquad (4)$$

where, k_1 is a ratio depending the static running point parameters on settlement organ characteristic.

Alike, it is inferred the debit relation to the exit from tundish:

$$Q_2 = k_2 \cdot \sqrt{h}\left[S_1\left(x_{p_2}\right) + S_1\left(x_{p_3}\right)\right] \quad (5)$$

in which $S_1\left(x_{p_2}\right)$ and $S_1\left(x_{p_3}\right)$ are the constructive characteristics of settlement organs to the steel exhaust from tundish, while k_2 is a suchlike ratio k_1.

The non-linear pattern of automatic installation is:

$$A\rho\frac{dh}{dt} = k_1 S(x_m)\sqrt{x_{p_1}} + k_2\sqrt{h}\left[S_1\left(x_{p_2}\right) + S_1\left(x_{p_3}\right)\right] \quad (6)$$

As the installation functions in stabilization behaviour of level, the mathematical pattern can be lineared around rated running point. Considering that all the physical sizes from system hold a constant component (the par) and a variable component, relatively small tcompared to the par, namely:

$$h = \overline{h} + \Delta h and x_m = \overline{x}_m + \Delta x_m and x_{p_k} = \overline{x}_{p_k + \Delta x_{pk}}, k = 1,2,... \quad (7)$$

where the pars are barred, linearization supposes the relations subrogation (7) in equation (6) and hold the first two terms from the serial development Taylor of non-linear terms

$Q_1 = Q_1\left(x_m, x_{p_k}\right)$ and $Q_2 = Q_2\left(h, x_{p_2}, x_{p_3}\right)$.

It results as that:

$$Q_1\left(x_m, x_{p_1}\right) \cong \overline{Q}_1 + \frac{\partial \overline{Q}_1}{\partial x_m}dx_m + \frac{\partial \overline{Q}_1}{\partial x_{p_1}}dx_{p_1} \quad (8)$$

$$Q_2\left(h, x_{p_2}, x_{p_3}\right) \cong \overline{Q}_2 + \frac{\partial \overline{Q}_2}{\partial h}dh + \frac{\partial \overline{Q}_2}{\partial x_{p_2}}dx_{p_2} + \frac{\partial \overline{Q}_2}{\partial x_{p_3}}dx_{p_3} \quad (9)$$

in which:

$\overline{Q}_1 = Q_1\left(\overline{x}_m, \overline{x}_{p_1}\right)$, $\overline{Q}_2 = Q_2\left(\overline{h}, \overline{x}_{p_2}, \overline{x}_{p_3}\right)$,

while barred derivatives entail the rated running behaviour.

Taking account of the expressions (4) and (5), it results:

$$Q_1 = \overline{Q}_1 + \frac{\partial \overline{S}}{\partial x_m}\overline{k}_1\sqrt{\overline{x}_{p_1}}\Delta x_m + \frac{1}{2}\frac{\overline{k}_1}{\sqrt{\overline{x}_{p_1}}}S\left(\overline{x}_m\right)\Delta x_{p_1} \quad (10)$$

$$Q_2 = \overline{Q}_2 + \frac{1}{2}\frac{\overline{k}_2}{\sqrt{\overline{h}}}\left[S_1\left(\overline{x}_{p_2}\right) + S_1\left(\overline{x}_{p_3}\right)\right]\Delta h + \overline{k}_2\sqrt{\overline{h}}\left[\frac{\partial \overline{S}_1}{\partial x_{p_2}}\Delta x_{p_2} + \frac{\partial \overline{S}_1}{\partial x_{p_3}}\Delta x_{p_3}\right] \quad (11)$$

In fixed behaviour there are the valid relations:

$$\overline{Q}_1 = \overline{Q}_2 = \overline{Q} \quad (12)$$

$$\frac{dh}{dt} = \frac{d\Delta h}{dt}; \quad \overline{k}_1 = \frac{\overline{Q}_1}{S\left(\overline{x}_m\right)\sqrt{\overline{x}_{p_1}}};$$

$$\overline{k}_2 = \frac{\overline{Q}_2}{\sqrt{\overline{h}}\left[S_1\left(\overline{x}_{p_2}\right) + S_1\left(\overline{x}_{p_3}\right)\right]} \quad (13, 14, 15)$$

and from the relations (10) and (11) it is calculated grafo-analytically, utilizing the constructive characteristic plots of settlement organs.

$$\frac{\partial \overline{S}}{\partial x_m} = \frac{\Delta S}{\Delta x_m}\bigg|_{\overline{x}_m} = S_1 \text{ and}$$

$$\frac{\partial \overline{S}_1}{\partial x_{p_{2,3}}} = \frac{\Delta S_1}{\Delta x_{p_{2,3}}}\bigg|_{\overline{x}_{p_{2,3}}} = S_{2,3} \quad (16, 17)$$

Replacing the relations (13) and (17) in equations (10) and (11), it results:

$$Q_1 = \overline{Q} + \frac{\overline{Q}}{\overline{S}}s_1\Delta x_m + \frac{1}{2}\frac{\overline{Q}}{\overline{x}_{p_1}}\Delta x_{p_1} \text{ and}$$

$$Q_2 = \overline{Q} + \frac{1}{2}\frac{\overline{Q}}{\overline{h}}\Delta h + \frac{\overline{Q}}{\overline{S}_{1,2} + \overline{S}_{1,3}}\left(s_2\Delta x_{p_2} + s_3\Delta x_{p_3}\right) \quad (18,19)$$

where are utilized the notations:

$\overline{S} = S\left(\overline{x}_m\right)$, $\overline{S}_{1,2} = S_1\left(x_{p_2}\right)$ and $\overline{S}_{1,3} = S_1\left(x_{p_3}\right)$.

Pursuant to the relations (13), (18) and (19), the state equation of automatic installation becomes:

$$A \cdot \rho \cdot \frac{d\Delta h}{dt} = \frac{\overline{Q}}{\overline{S}}s_1\Delta x_m + \frac{1}{2}\frac{\overline{Q}}{\overline{x}_{p_1}}\Delta x_{p_1} - \frac{1}{2}\frac{\overline{Q}}{\overline{h}}\Delta h - \frac{\overline{Q}}{\overline{S}_{1,2} + \overline{S}_{1,3}}\left(s_2\Delta x_{p_2} + s_3\Delta x_{p_3}\right) \quad (20)$$

It can be observed that all the ratios from the lineared pattern equation (20) express contingent on the constructive characteristics or the parameters of installation, as well as contingent on the pars of physical sizes ($\overline{Q}, \overline{h}$ etc.), to the numeric values computation of those ratio is a highly simple problem.

Using the notations:

$$T = \frac{2 \cdot A \cdot \rho}{\overline{Q}} \cdot \overline{h}; \quad k_1 = \frac{2 \cdot \overline{h}}{\overline{S}} \cdot s_1; \quad k_2 = \frac{\overline{h}}{\overline{x}_{p_1}} \text{ and}$$

$$k_{3,4} = \frac{2 \cdot s_{2,3}}{\overline{S}_{1,2} + \overline{S}_{1,3}} \cdot \overline{h} \quad (21, 22, 23 \text{ and } 24)$$

the linear pattern of automatic installation becomes:

$$T\frac{d\Delta h}{dt}+\Delta h=k_1\Delta x_m+k_2\Delta x_{p_1}-k_3\Delta x_{p_2}-k_4\Delta x_{p_3} \quad (25)$$

whereupon it correponds the flow-process chart from figure 4.

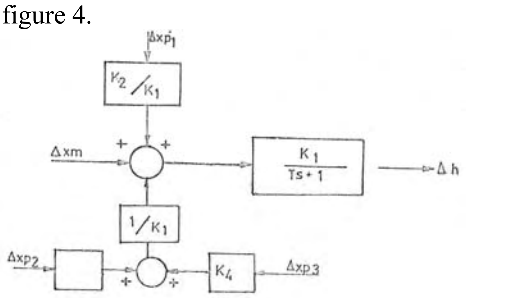

***Fig. 4**. Flow-process chart of lineared pattern of automatic installation*

The lineared pattern ratios computation did in hypothesis as the sizes from system have small variances around pars. This hypothesis is valid for all the sizes from the analysed process, except for size $x_{p_1}\equiv h_1$. The use of the analytic relation (23) manages to an incertitude taking into account the value adoption $\overline{x}_{p1}$. In order to care with of this problem, we have the curve families which give the debit Q_1, contingent on h_1 and of equivalent diameter D of outflow reach. In the equation (18), the variable ratio x_{p1} entails average slope of curves which give the debits. Thus, the relation (18) becomes:

$$Q_1=\overline{Q}+\frac{\overline{Q}}{\overline{S}}s_1\Delta x_m+\alpha\Delta x_{p_1} \qquad (26)$$

where α entails chart: $\alpha=\frac{\Delta Q_1}{\Delta h_1}\cdot\overline{D}$ (27)

In the final equation, the ratio k_2 will entail the relation:

$$k_2=\frac{2\alpha\overline{h}}{\overline{Q}} \qquad (28)$$

The mathematical pattern of pressure transducer is formally presented:

$$T_T\frac{dx_r}{dt}+x_r=K_T\Delta h \qquad (29)$$

where T_T and K_T are the roll parameters of the apparatus.

The mathematical modelling of hydraulic execution element wa pursuant to the acquainted methodology establishment of dynamics equations for a tundish system – hydraulic drum. Considering the cynetic energy filling in the elements found in movement and taking account of noted delay [1] with T_m, in the command transmission electro-hydraulic, the execution element equation is:

$$T'\frac{d^2\Delta x_m(t)}{dt^2}+\frac{d\Delta x_m(t)}{dt}=k\cdot x_C(t-T_m) \qquad (30)$$

where x_C is the given command data of the controller.

Flow-process chart of settlement system of level in tundish, with details of mathematical pattern of managed process, is given in figure 5.

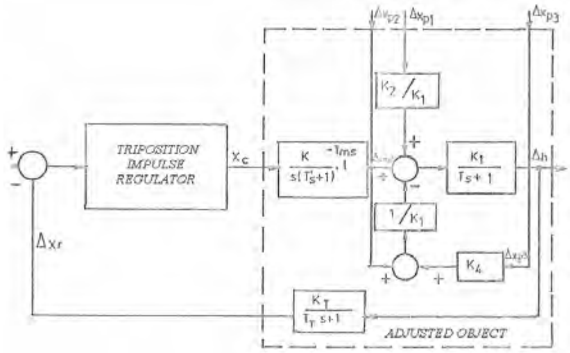

***Fig. 5**. Flow-process chart of settlement system of level in tundish*

4. The settlement level system realization in tundish and tests data

The proposed settlement system performances study did by numeric simulation and by experiments on the physical system realized.

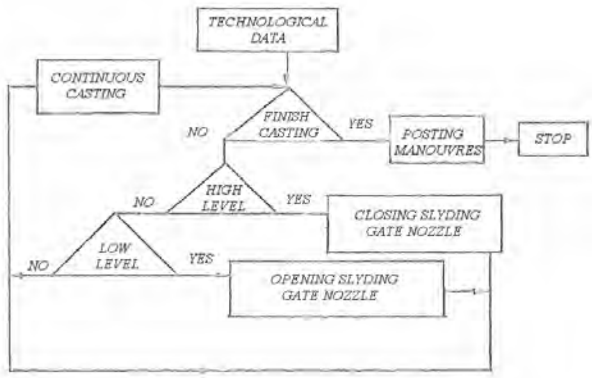

***Fig. 6**. Logical draft of command system on the normal function.*

Logical draft of command system on normal function is given in figure 6, while logical draft command of controller by impulses is given in figure 7, in which PA_{max} is the maximum acting pressure, PA_{min} – the minimum acting pressure, DSS – distance between centers, P_{min} and P_{max} – pressure chosen limits.

[1] The delay period determination T_m was realized by experimental way, and qualitative analytic evaluations.

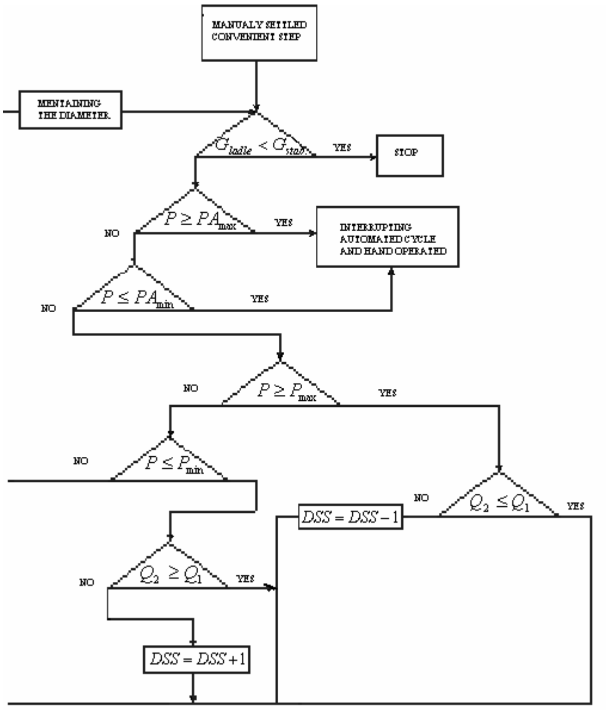

***Fig. 7**. Logical draft of controller by impulses*

Conclusions

The obtained results by continuous casting timing satisfy quite all the quality conditions and technological operations: the level variation stands in admissible limits, the level record allows the control of installation function. In figure 8, are given records of level variation, in manual settlement behaviour and in automatic settlement behaviour.

The records of level variation in manual settlement behaviour and in automatic settlement behaviour as well as the performance indices became decisive in favour of the automatic settlement.
During all the experiments, the automatic settlement was stable and reliable.

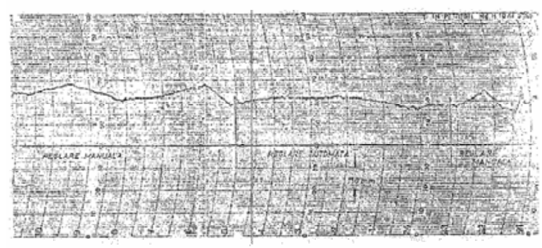

***Fig. 8**. The liquid steel level in tundish in manual and automatic settlement behaviour*

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