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Quality control system for the process of continuous casting of steel

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ABSTRACT

Purpose: Purpose of this research was to create new quality control system.
Design/methodology/approach: For the purpose of new quality control system, the base of technological parameters of the process of continuous casting of steel (CCS) has been programmed; it consists of 53 parameters. The optimal values for the technological parameters are necessary to proper functioning of databases and are essential element of quality control system. For each parameter, some target values have been empirically defined i.e. upper and lower bound, which assured proper functioning of a new process quality system for CCS.
Findings: The author has modernized the loss function in such a way that it includes the whole range of technological parameters of CCS process.
Practical implications: Having such an investigation material the scope and concept of a new quality system have been designed. The essentials component of the new quality system are the mathematical basis on which a modernized Taguchi's loss function have been developed.
Originality/value: On the basis of the performed investigations, a new quality system for concast slab of carbon steel which functions in industrial conditions has been developed.
Keywords: Quality assessment; Casting; Steel; Control

1. Introduction

During CCS process, the circuits for parameter recording and operation quality control for individual parts of the equipment, which compose of integrated system of process and quality control [1] are installed. Moreover, which protect from the bleedout in the continuous casting mould, of breakout prevention systems type are also used. Modern quality systems of QAART (Quality Assurance Assessment in Real Time) [2,3] register high number of parameters which influence the quality of continuous casting and compare them to the set values which guarantee the quality. Systems of CAQC registers the exceeding of tolerance values for the parameters within the database. The structure of many quality systems is based on: process model, logistic systems and theories of quality systems. For creation of the author's system of quality control for continuous castings the author based on the theory of Taguchi's loss function [4]. Due to the abovementioned fact, it has been assumed that the definition of the target value and the tolerance of technological parameters for continuous casting of steel is of very high importance for the quality of concast slab. Therefore the determination of the boundary values for the tolerance of technological parameters is of priority importance. The values for the tolerance and target point of technological parameters determined in an experimental way are essential to develop a new quality system. Making use of mathematical possibilities of functional the decision was made to develop a new system of quality control for the concast slab made of carbon steel.

2. Description of method for quality system development

Controlling the CCS parameters and the definition of the appropriate technological values to ensure the optimal quality of the concast slabs is a basic element of the quality system. Optimal technological parameters are essential for functioning of the database of computer system for quality control CAQC [1,2] and for new quality system.

One of the important disadvantages of CAQC system is that the computer program shows only exceeding the upper and lower values of technological parameters from the system database. In case of exceeding the data of a few parameters the application faces the problem which is not able to be interpreted by it; then the specialist should be called to make the appropriate decisions.

Therefore the investigations have been started in order to develop such a process quality system CCS which could show not only the transgression of the parameter value but also its distance from the target point. Moreover, the computer system should define the importance and meaning of each parameter to the quality process CCS. In practice it would mean combining of each CCS process parameter with the value of loss in quality /defective steel/ of the steel for casting.

For the purposes of the new quality system it was decided to classify the parameters in order to facilitate its functioning. For each CCS parameter value, the values of upper and lower bound $\mathbf{T_d}$ i $\mathbf{T_g}$ or only one boundary value have been determined; at the same time, the target value **m** [5,6] has been determined. The target value of the parameter is necessary to define an optimal quality for the COS process. The technological parameters have been systemized in a following way:

- parameter marked - ▼- with the value of 10 points means strong influence on the process,
- parameter marked - □ - with the value of 5 points mean the average dependence of the influence on the process,
- parameter marked - ○ - with the value of 1 point means poor influence on the process.

The parameters have been divided into three categories, i.e.:

- nominanta – when the standard deviation for the parameter is known **-** $\boldsymbol{\sigma}$ or the variance $\boldsymbol{\sigma^2}$ of the characteristic
- minimanta – when the target value of the parameter **m** approaches 0,
- maksymanta – when the target value of the parameter **m** approaches ∞ (or, the higher value, the better).

3. The characteristics of the new quality system base

The modernized database of the computer system CAQC includes 53 CCS process technological parameters. By use of them, the process and the quality of the concast slab for the new quality system is optimized.

Functioning of the CAQC is also supported by the received, during measurement, by means of sensors, current values for such parameters as:

- temperature
- casting speed
- steel level in continuous casting mould

The values of remaining technological parameters are entered into the current system register. This is done by the maintenance workers after the measurements. The values for other parameters are found or calculated by the computer according to the values or dependencies preset for the computer. The mutual interrelations between the elements of the system database is shown in the Figure 1.

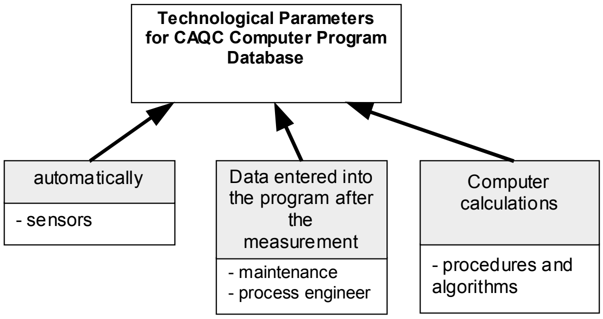

Fig. 1. The methods of entering the values of technological parameters into the CAQC computer program database and the new quality system

4. Carbon steel concast slab quality system

The process of continuous casting of steel results in the semi-finished product to be processed into carbon steel sheet. The development of quality system is usually set on the final product (sheet) or on a certain stage of a process and it means the concast slab.

The assumption for the quality system have been based on the Deming's PDCA circle [7] (Plan – Do – Check – Act), but preserving main Taguchi's loss function [4,6] yet preferring the problem solution method suggested by Shainin [8,9].

4.1. Application of the modernized Taguchi's loss function to structure the quality system

Taguchi's theory [4] introduces the concept of the loss function, which is the measure of the deviation of the real state from the target value. It gives the opportunity to determine, for each process parameter, the optimal value **m** and the function which defines the deviation from that point.

Application of this theory gives the opportunity to investigate and determine the approximation of the real state to the target value. The theory assumes that for each process characteristic the unique function can be found, which determines the dependence between the loss, deviation of the characteristic's state or parameter, which is shown in the Figure 2.

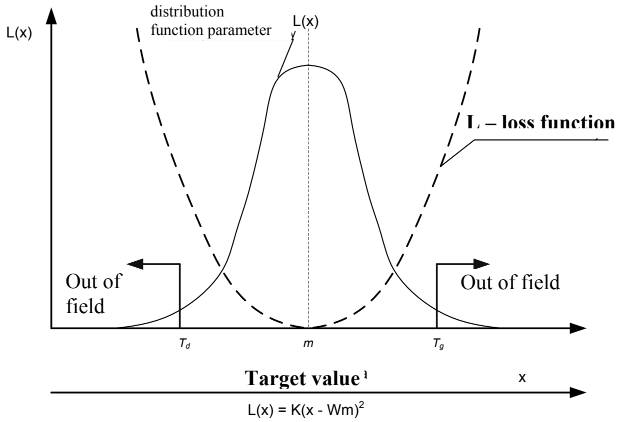

Fig. 2. Illustration of the hypothetic loss connected with the deviation of the product or process characteristic's state from the target value [10]

In ideal point (x = **m**) the function has a shape :

$$L(x) = K (x - \mathbf{m})^2 \tag{1}$$

where:

K – loss constant,

x - characteristic's or parameter state,

m – target value.

Loss constant K should be understood as a loss made in a boundary case, where the characteristic's state reaches the tolerance bound. In case of symmetrical tolerance fields, a loss for the lower bound T_d and upper bound T_g equals K_o :

$L(x)=K(x-m)^2$

$$K = \frac{K_0}{T^2} \tag{2}$$

For the tolerance bound x = **m** + T

Loss function in this case is expressed by the equation:

$$L (x) = K [\sigma^2 + (x – \mathbf{m})^2] \tag{3}$$

with: σ - being standard deviation for the process characteristic or parameter

In case of normal distribution of the characteristic's measure, the loss function assumes the following shape:

a) - for nominanty $L(x) = K [\sigma^2 + (x – \mathbf{m})^2]$

b) - for minimanty (with the target value 0) $L(x) = K(\sigma^2+x^2)$

c) - for maksymanty (with the target value ∞)

$$L(x) = \frac{K}{x^2}\left[1 + \frac{3\sigma^2}{\mu^2}\right]$$

with μ – average for characteristics

Hypothesis of normality of the process parameter distribution has been investigated by the Pearson's test [11]. The abovementioned assumptions, though theoretical, give the opportunity to maintain or to approach the process to the target values for the technological parameters. The Taguchi's theory can be adapted to most of the CCS process parameters and the loss function can be incorporated in the quality system. In some cases the CCS parameters describe functions of two parameters more closely, distributed in the 3D coordinate system.

For the binary loss function L (x,y) should be assumed that variable x is related to the target point – mx and the loss constant is, accordingly:

$$K_x = \frac{K_{0x}}{T_x^2} \tag{4}$$

variable y is related to the target point – m_y and the loss constant is, accordingly:

$$K_y = \frac{K_{0y}}{T_y^2} \tag{5}$$

Loss function, after taking the dependences (4) and (5) equals:

$$L(x,y) = K_x (x – m_x)^2 + K_y (y – m_y)^2 \tag{6}$$

assuming:

$K_x = K_y = K$

and $m_x = m$ i $m_y =o$

give:

$$L (x,y) = K (x – m)^2 + K y^2 = K [(x – m)^2 + y^2] \tag{7}$$

The purpose of the suggested quality system is minimizing the steel loss which occur during process of continuous casting. The significant component of such a quality system are 53 technological parameters necessary to consider minimizing of the loss function. These parameters fall into three categories, i.e.:

A – 37 parameters according to the Taguchi's theory

B – 5 parameters, which function according to the extended concept suggested by the author, equation 40,

C – 11 parameters with the value form the<0,1> set,

on which the decision yes or no is made or the logic function with the values < true, false>.

For the first group of parameters the method for statistical determination of the loss function for the parameter No. 1 Fig. 3. The parameter here is the value of the temperature of the liquid steel in the intermediate ladle. The values for the bounds T_d = 5 and T_g = 30 were calculated statistically for the minimal deviations in temperature ranges for the intermediate ladle during casting of one heat. To ensure the above mentioned technological conditions the dosing frequency of the liquid steel should be appropriately controlled in order to ensure its optimal level in the intermediate ladle. For the T_d and T_g bounds the estimated loss amounts to 22 kg of steel/heat (100 Mg t), which is marked with the dashed line in the Figure 2. The value of the loss constant is to be estimated for each parameter of (A and B) group. Approaching the target point m for the parameters of the C group is done by the shortest way – along the straight line, thus the unit value of the loss constant has been assumed.

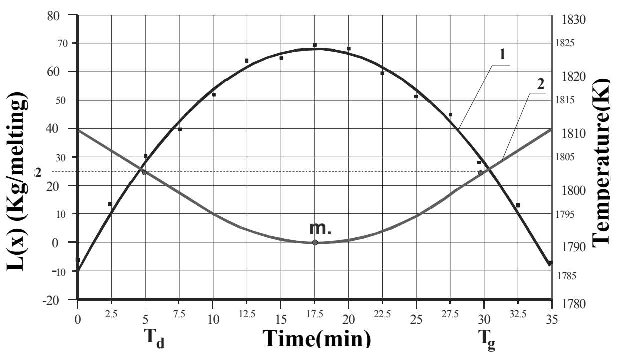

Fig. 3. Course of changes in the temperature value for the intermediate ladle of 18G2A steel during heat's casting.

The equation (1) which describes this dependence takes a form:

$y_1 = -0.25 x^2 + 8.65 x - 8.34$.

Curve (2) means loss function determined by the dependence

$y_2 = 0.14 (x - m)^2$.

Value of the loss constant equals $K_1 = 0.14$. for the parameter No. 1. After the categorization of the parameters it can be assumed that the criterion according to which the minimizing of the loss function will occur is the functional based on the transformation $f : R^{58} \rightarrow R$ (including 5 binary parameters).

Loss function has been grouped according to CCS process parameters categories (A, B and C) in the following way:

- $L(x) = K (x-m)^2$ - for the parameters of the nominanta of A group type,
- $L(x) = K x^2$ - for the parameters of the minimanta of A group type,
- $L(x,y) = K[(x-m)^2 + y^2]$ - for the binary parameters of B group, according to the equation (7),
- $L(x) = K x$ - for the parameters of C group, $K = 1$ and $x = 0$ or $x = 1$

Such a grouping of the loss function becomes a functional's set. The functional's form $f : R^{58} \rightarrow R$ assumes that the variables for the suggested functional assume the relation:

$$\gamma = f(x_1, x_2, x_3, x_4, ..., x_{53}, y_1, y_2, y_3, y_4, y_5),$$

and that variable y will be systematized according to the accepted order of process parameters in a following way:

$$y_1 = y^{(8)}, y_2 = y^{(11)}, y_3 = y^{(30)}, y_4 = y^{(37)}, y_5 = y^{(53)}$$

Finally, we get the abovementioned functional:

$$L(\gamma) = \sum_{i=1}^{28} W_i \cdot K_i \cdot (x_i - m_i)^2 + \sum_{i=29}^{37} W_i \cdot K_i \cdot (x_i)^2 + \sum_{i=38}^{42} \sum_{j=1}^{5} W_i \cdot K_i \cdot \left[(x_i - m_i)^2 + (y_j)^2\right] + \sum_{i=43}^{53} W_i \cdot K_i \cdot x_i \quad (8)$$

with: W_i – process weight [%]

Weights values have been assumed according to the described influence of parameters on the process, i.e.:

strong -▼, medium -□ and poor-○.

Percentage participation of these parameters influencing the decision on the CCS process falls as following:

for the category ▼ – 62%, (26 parameters) ,

for □ – 31 % , (20) , and for ○ - 7% (7) .

After calculating the influence on the parameter one can get the appropriate weight values:

category ▼ = 2.384 , category □ = 1.550 , category ○ = 1.

These weights values for the parameters are the initial set for each category which during the technological process are subject to correction within the self-optimizing procedures of the quality system. The performed (by means of the functional, equation 8) calculations enabled to define the criterion threshold at the level 185.3 kg of steel per heat (100 t), assuming the invariability of the tolerance for all the parameters of the described process. Exceeding this threshold means improper process operation and exceeding the tolerance for some technological parameters of CCS. It enables to make right decisions which relate to the parameters which these transgressions concern.

The developed quality system for the concast slabs have been prepared on the basis of the available literature knowledge and own studies which were created during the investigation of the real process of continuous steel casting. The currently used quality systems using computerized systems CAQC are integral part of the production control systems such as e.g. OPT, JiT or KANBAN [12-14]. The quality system is based on two components:

- computer program CAQC, compatible with the new quality system
- functional, which is used for minimizing of steel loss during CCS process.

The first component of the system, based on the CAQC program functions on the modified database and enables to detect the exceeding of the value for the lower and upper CCS process parameters. The usability of the second quality system component – a functional – is higher, since it enables to minimize the loss during the process; therefore it is a very operative tool. The functional is additionally equipped with minimizing criterion which determines the value for the loss function while preserving the invariability of the process parameters tolerances. The efficiency of the functional is manifested by the fact that it indicates the quantitative deviations from loss function. The current value of the functional can be used in optimization of the loss function.

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