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ALGORITHM FOR PREVENTION OF MOLTEN STEEL STICKING ONTO MOLD IN CONTINOUS CASTING PROCESS

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Preliminary Note – Prethodno priopćenje

In continuous casting steel production a significant loss reduction – in terms of scrap material, time and money – can be achieved by developing an appropriate algorithm for the prevention of molten steel sticking onto mould. The logic of such algorithm should be simple and manageable to ensure its practical implementation on a computer system via the usage of thermo sensors. This suggests that both the algorithm and the automated data collection can be implemented by means of applicative software. Despite its simplicity, the algorithm should accurately trace physical phenomena in molten steel.

Key words: continuous casting, temperature monitoring, sticking prevention, algorithm

Algoritam za prevenciju ljepljenja čelika za stijenke kokile u procesu kontinuiranog lijevanja. U procesu kontinuiranog lijevanja čelika, značajne uštede - u smislu smanjenja škarta, uštede vremena i novca - mogu se postići razvojem odgovarajućeg algoritma za prevenciju lijepljenja metala za stjenke izljevne posude. Logika algoritma treba biti jednostavna i praktična kako bi bila moguća njegova fizička implementacija uz pomoć računalnog sistema i termo senzora. To navodi na zaključak da ovakav matematički model, kao i sistem za automatsko prikupljanje podataka mogu biti implementirani u vidu aplikativnog softvera. Bez obzira na jednostavnost, algoritam mora točno opisivati pojave u rastaljenom čeliku.

Ključne riječi: kontinuirano lijevanje, praćenje temperatura, prevencija lijepljenja, algoritam

INTRODUCTION

Major loss in terms of time and money in modern steel production are due to inefficient execution of the continuous casting process. The lack of monitoring and control by means of computer systems, over manual execution, for example, i.e. the inefficient continuous casting process operation, may often cause delays in workflow performance, raise the percentage of scrap material and, in extreme cases, may even cause equipment damage which should, in turn, affect even more seriously the production workflow schedule.

An efficient and effective process of continuous casting, calls for an adequate algorithm [1] that would be applicable in a computer system. Such an algorithm would enable a software system to monitor the ongoing process in real time and apply mathematical equations on the data collected [2]. The software system must be designed thus to inform the system operator on corrective actions to be taken and even to execute them itself.

The achievement of this goal requires the application of a new methodology, empirical data and theoretical models needed for solving practical problems – in order to achieve optimal results.

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THEORETICAL BACKGROUND

A timely prevention of sticking of molten steel onto mold shell surface enables to perform all necessary tasks to optimally guide the continuous casting workflow.

Basic Phenomena in Continuous Casting Process

Molten steel flows from a ladle, through a tundish into the mold during the continuous casting process (Figure 1.). Once in the mold, the molten steel freezes against the water-cooled copper mold walls to form a solid shell. The semi-solidified material then exits the copper mold and passing through a series of roles the material assumes its final shape [3].

For an undisturbed flow of semi-solidified material through copper mold and through a series of roles, all sides of copper mold are lubricated with metallurgical powder. In contact with molten steel, metallurgical powder forms on the surface of the solidified shell lubrication and protective film [4]. If metallurgical powder is used, new powder has to be constantly added into the mold [5]. Moreover, to prevent sticking, adding powder is not sufficient and periodical oscillations of entire mold are to be made. If oscillations are inadequate or if

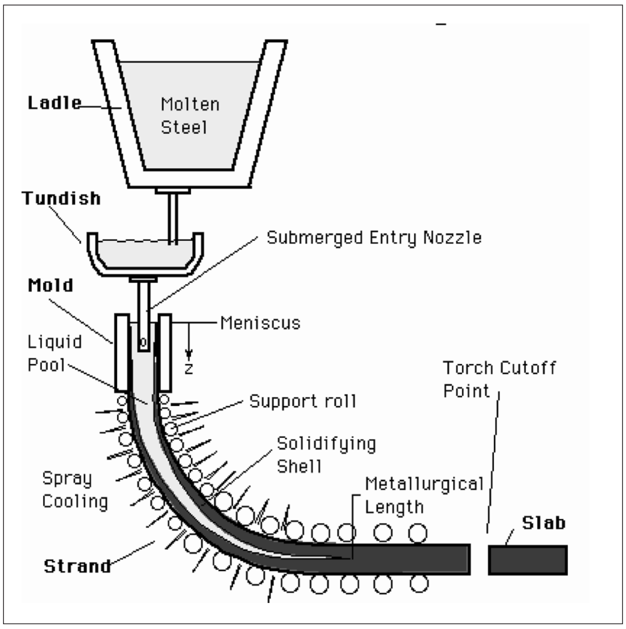

Figure 1. Continuous casting workflow

an insufficient quantity of new powder is added into the mold, the sticking of molten material and copper mold will occur [6]. Furthermore, discernible temperature deviations will be noticed during the process monitoring before and after the occurrence of sticking. By using this information corrective action can be taken to prevent sticking [7].

Temperature Observation with Mathematical Models Appliance

Due to specific conditions in continuous casting workflow, only a limited amount of information can be collected during the production process. This limited information should be sufficient for prevention of molten steel sticking onto mold. The easiest information to collect is the temperature values on the mold surface. Temperature observation can be done by using thermocouples located on all lateral sides of the mold.

Two identical arrays with the same number of rows and columns can be formed from the values received from these thermocouples. Those arrays of data are collected in regular intervals and recorded by making use of a longer period of time. Recent data are then compared with previously received data using the algorithm described hereafter. Results received from this calculation are used to issue a sticking warning.

ALGORITHM FOR PREVENTION OF MOLTEN STEEL STICKING ONTO MOLD

Consider the assumption that the information about the temperature values on the shell surface recorded by thermocouples is well known and this information is available in real time by means of an adequate software system. Such temperature values on the shell surface recorded by thermocouples form arrays with m x n elements. These arrays will have indexes 1...4 for every lateral side of the mold:

$$a_{ij} \in A = \lfloor a_{ij} \rfloor, i = 4 \ldots m, j = 1 \ldots n \qquad (1)$$

and:

$$p_{ij} \in P = \lfloor p_{ij} \rfloor, i = 4 \ldots m, j = 1 \ldots n \qquad (2)$$

where:

A - is the array of currently measured thermocouple values,

P - is the array of thermocouple values measured in time t_p,

t_P - is time in which are measured thermocouple values for array P (previously measured values),

Array A and array P are the same type. Than the arrays are:

$$m \times n \geq 12 \times 9 \qquad (3)$$

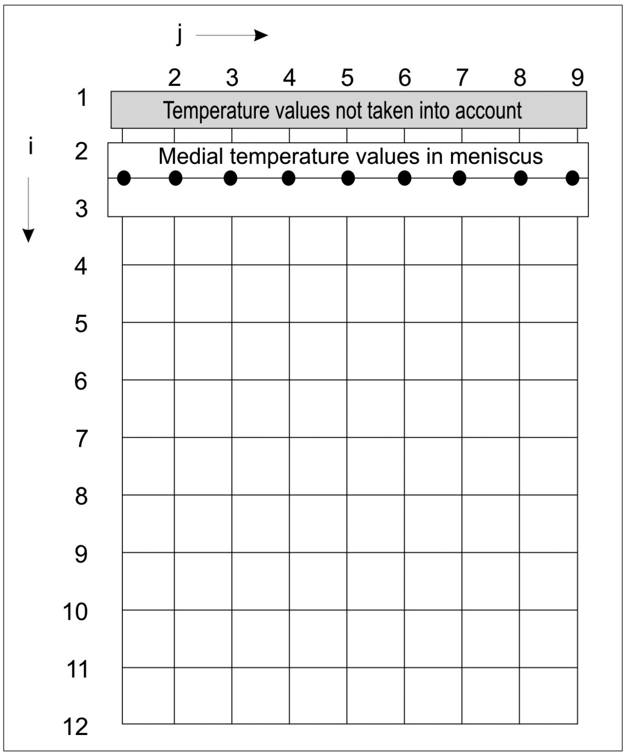

Figure 2. Medial temperature values that should be taken into account

In the first step the medial values in the meniscus of the mold are to be calculated (black spots on Figure 2.) and temperature deviation for these medial values.

Temperature values at the top of the mold are not to be taken into account as they values would bring to inadequate results due to the oscillations of the molten steel level in the mold. For this reason the calculation starts from the second row of the array.

Then for:

$$g_{1j} \in V_A = \lfloor g_{1j} \rfloor, j = 1 \ldots n \qquad (4)$$

and:

$$h_{1j} \in V_P = \lfloor h_{1j} \rfloor, j = 1 \ldots n \qquad (5)$$

where:

V_A - is the vector of currently measured thermocouple values in the meniscus,

V_P - is the vector of thermocouple values in the meniscus measured in time t_p,

t_P - is the time in which are measured thermocouple values for array *P* (previously measured values),

With mapping of vector V_A in vector V_P:

$$f : V_A \rightarrow V_P \tag{6}$$

taking the assumption that vectors V_A and V_P are of the same type emerges:

$$g_{1j} = \frac{a_{2j} + a_{3j}}{2} \; \forall \; j = 1 \ldots n \tag{7}$$

The medial value of temperature deviation in meniscus is therefore calculated using the following expressions:

$$d_{1j} \in M_d = \lfloor d_{1j} \rfloor, \; j = 1 \ldots n \tag{8}$$

therefore:

$$d_{1j} = \frac{g_{1j} - h_{1j}}{\Delta t} \tag{9}$$

where:

M_d – is the array of temperature deviation in meniscus,

Δt – is the time difference between current and previous temperature observation.

and:

$$\Delta t = t_A - t_p \tag{6}$$

where:

t_A – is the time in which are measured thermocouple values for array *A* (currently measured values),

t_P – is the time in which are measured thermocouple values for array P (previously measured values).

If:

$$d_{1j} < c_2 \wedge t_A - t_0 < c_3, \forall \; j = 1 \ldots n \Rightarrow t_0 = t_A \tag{10}$$

where:

c_2 , c_3 – are the empirically obtained values,

t_o – is the time in which the expression (10) has bean last time satisfied.

If:

$$k_{ij} \in K = \lfloor k_{ij} \rfloor, \; i = 4 \ldots (m - c_4), \; j = 1 \ldots n \tag{11}$$

then for every *j* for which expression (11) is valid results in:

$$k_{ij} = a_{ij} - g_{1j} \;\; \forall \; i = 4 \ldots (m - c_4) \tag{12}$$

where:

K – is the array of control temperature values with the dimension of ,

c_4 – is the empirically gained value.

For:

$$k_{ij} > c_5 \Rightarrow l + 1 \rightarrow l \tag{13}$$

where:

c_5 – is the empirically gained value,

l – is the sticking warning factor gained empirically.

The limiting condition for the possibility for sticking between mold shell surface and molten steel can be represented as:

$$l > c_6 \tag{14}$$

or, if observing all lateral sides of the mold:

$$l_1 > c_6 \vee l_2 > c_6 \vee l_3 > c_6 \vee l_4 > c_6 \tag{15}$$

where:

c_6 – is the empirically gained value.

All empirically gained values are to be found by performing several experiments in real production conditions. Depending on the size of the mold, type of cast steel, velocity of adsorption, these values will vary.

IMPLEMENTATION OF ALGORITHM BY MEANS OF APLICATIVE SOFTWARE

By developing a real manufacturing execution system application called “MBDS” (Figure 3.) that implements the above explained algorithm the performance and usefulness of it has been tested and verified.

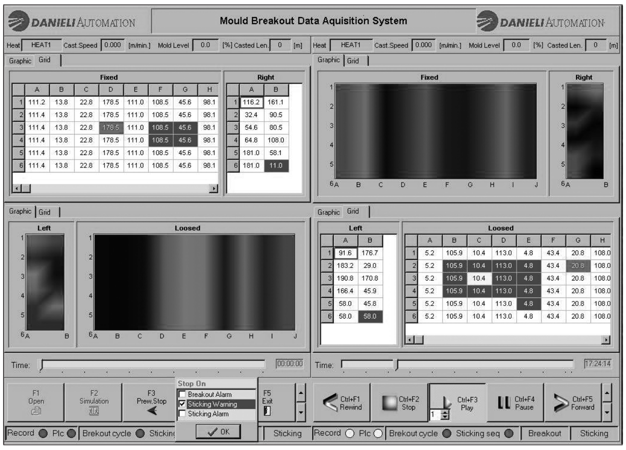

Figure 3. Screenshot of the MBDS program

CONCLUSION

The algorithm for early recognition and prevention of sticking between mold shell surface and molten steel presented here has proved very useful in continuous casting steel production. The key factor for this algorithm is the ability to implement it easily by means of a computer software system. Equations and Boolean logic of this algorithm can be easily implemented in software and optimized for fast execution. All this leads to conclude that a practical application of this algorithm is unimaginable without modern computer equipment. First because of the quantity of data that the software needs to process, secondly because all data need to be stored in permanent memory and displayed on screen for fine tuning of software.

REFERENCES

[1] Q. Yuan, B. Zhao, S.P. Vanka, B.G. Thomas, Materials Science & Technology, 2, (2004), 333-343

[2] B.G. Thomas, Journal of Metals, 54, (2002), 1, 20-21

[3] B.G. Thomas, Encyclopedia of Materials: Science and Technology, Pergamon Elsevier Science Ltd., Oxford UK, 2005, str. 1595-1598,

[4] M. Jenkins, B.G. Thomas, Proceedings, 80th Steelmaking Conference Proceedings, Chicago, IL, 1997, Iron and Steel Society, Warrendale, PA, 1997, str. 285-293,

[5] Y. Meng, B.G. Thomas, Metallurgical & Materials Transactions, 34B, (2003), 5, 685-705,

[6] H.J.Shin, G.G. Lee, W.Y. Choi, S.M. Kang, J.H. Park, S.H. Kim, B.G. Thomas, Proceedings, AISTech, Nashville, TN, 2004, 1157-70, Warrendale, PA, 2004, str. 1157-70,

[7] L. M. Mika, B.G. Thomas, Proceedings, Modeling and Control of Casting and Welding Processes – IV, Palm Coast, FL, 1988, A.F. Giamei , G.J. Abbaschian (Ured.), The Metallurgical Society, Warrendale, PA, 1988, str. 459-469.

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