Cooling water flow control realized with systems based on fuzzy mechanism

G O Tirian¹, C A Gheorghiu², T Hepuț³ and C P Chioncel³

¹Politehnica University of Timisoara, Electrotechnical Engineering and Industrial Informatics Department, 5 Revolution Street, Hunedoara, 331128, Romania
²Politehnica University of Timisoara, Department of Engineering and Management, 5 Revolution Street, Hunedoara, 331128, Romania
³Eftimie Murgu University/Electrical Engineering and Informatics, Resita, Romania

E-mail: ovidiu.tirian@fih.upt.ro

Abstract. This research proposed a solution based on fuzzy mechanisms for controlling the flow of cooling water on the first zone of the secondary cooling of steel. For this purpose, a fuzzy system with three input variables and three output variables was designed, the proposed system was tested and validated by simulation made in Matlab Simulink based on actual data collected from the continuous casting process.

1. Introduction

The necessity of manufacturing using continuous casting of some products of high quality and in the same time competitive can be made only by thorough knowledge of the phenomena and the complex processes which take place on the technological development and casting.

The method of continuous casting consists of introducing the liquid metal with a well determined temperature in a cava shape which has the walls cooled inside with water named crystallizing, and the evacuation is made on the opposite side where is obtained the solidified chord [1], [2].

A fuzzy solution is proposed that placed on the existing structure of the control system of continuous casting will reduce fissures in the secondary cooling by generating necessary value adjustments to change the water flow and the velocity of the casting.

There are no current systems in the world that can eliminate cracks if they are detected in the secondary cooling steel. Basically, the rules database was designed specifically for this purpose and it contains measures to be taken to mitigate the risk of a crack.

A very important component of the continuous casting installation is the secondary cooling zone. The secondary cooling zone has the role to continue the wire cooling after it has emerged from the crystallizing and to assure the total solidification of the semi–product. It is considered “the heart” of a continuous casting and has the role of ensuring the quality of the material, the material surface shape and has to ensure a homogeneous cooling and a uniform repartition of the water on the materials surface [3], [4].

During the continuous casting of steel, in the secondary cooling stage, the process of crust solidification continues and can develop cracks. In order to detect and remedy cracks that may occur a simulation was made using Matlab Simulink which analyzes the signals from a temperature sensor and provides the necessary corrections. Thus, compared to the old methods of tackling the problem of crust cracks in the continuous casting of steel, such as technological methods (requiring a certain
speed, adjusting the composition and quantity of powders, etc.), the new method proposed and developed, brings safety and precision in this complex process.

2. Structure of the fuzzy system

Fuzzy logic allows the treatment of vague variables whose values can continually vary across any defined numerical range, making decisions based on the position of the indicator in the numerical range and predefined rules.

The applicability of fuzzy logic is varied, the metallurgical field being one in which fuzzy systems are increasingly used.

Methods based on fuzzy logic do not have very strictly defined algorithms, and they appeal largely to the experience of the specialist in the field. For the issue in question, a database was built from information gathered from technology experts. This database was supplemented with the information obtained from the mathematical model of the solidification process.

Designed fuzzy systems receive the following values from the process, depending on the casting area in which the preform is located:
- the casting speed in the cooling zone 1, \( v_1 \)
- the cooling water flow rate in the cooling zone 1, \( q_1 \)
- steel temperature in the cooling zone 1, \( T_1 \)
- the casting speed in the cooling zone 2, \( v_2 \)
- the cooling water flow rate in the cooling zone 2, \( q_2 \)
- steel temperature in the cooling zone 2, \( T_2 \)
- the casting speed in the cooling zone 3, \( v_3 \)
- the cooling water flow rate in the cooling zone 3, \( q_3 \)
- steel temperature in the cooling zone 3, \( T_3 \)

Because conditions and rules change depending on the area where the blank is located, it was necessary to design different fuzzy systems for each cooling zone separately.

Depending on the casting speed and the temperature of the steel, the technological risk coefficient, which displays a percentage value and determines the risk of a crack, if the value returned is higher than 75% the system is blocked.

After the input data is processed, the necessary corrections are made to change the required values of the casting rate and the secondary cooling water flow, respectively, in order to eliminate any cracks in the blank.

It is for the first time on a national and global scale when ordering to change the six sizes (\( v_1, v_2, v_3, q_1, q_2, q_3 \), casting speed and cooling water flow for each cooling zone separately) to eliminate cracks in the mold continuously. The rules are designed so that the first size that changes is the flow rate of the cooling water, and then the casting speed is changed. This principle has been used to maintain the plant's productivity as far as possible (the decrease in casting speed leads to decreased productivity). IFS works with three bases of different rules, selected according to the signal received from the neural network for the detection of primary fissures. Figure 1 presents the block diagram of the IFS assembly.

![Figure 1. Block diagram of the IFS assembly](image)

In Figure 2 is presented the block diagram of the proposed structure, which is a fuzzy decision system (IFS). V-casting speed; Q-water flow to secondary cooling; T-temperature of steel;
RT-technological risk; Two-speed pouring correction; Δq-secondary water cooling flow correction.

![Figure 2. Block scheme of the fuzzy decision system](image)

In this situation, IFS is making changes in casting speed and water flow from secondary cooling to eliminate the risk of a crack. It is noted that for the first time, the risk of crust cracking is taken into account, in case of a risk percentage of over 75% the thread is blocked, in the literature there is no reference to this aspect.

Establishing the bases of rules required an analysis of all possible cases. To this end, a number of technology experts with extensive experience in the exploitation of continuous casting facilities have been contacted. Also, for each individual case, an analysis of the crust solidification phenomenon was performed. Of course, the bases of rules thus obtained are not perfect, and they are also influenced by a number of factors that take into account the state of the equipment and other practical considerations. Therefore, they are to be improved when commissioning and testing the proposed scheme.

3. Design of IFS (Intelligent fuzzy system)

The actual design of IFS was done in Matlab using the fuzzy toolbox. Basically, there are three IFSs, one IFS for each secondary cooling zone, called IFS Z1 (intelligent fuzzy system for cooling zone 1), IFS Z2 (intelligent fuzzy system for cooling zone 2) and IFS Z3 (intelligent fuzzy system for cooling zone 3), and have input rates for casting speed v, water flow in secondary cooling q, steel temperature T. The three Systems produce 3 outputs, namely: secondary cooling water flow correction, casting speed correction and technological risk.

For the qualitative analysis of IFS operation, it is proposed to simulate it using the Matlab-Simulink environment. Figure 3 shows the implementation of IFS-Z1 in Matlab-Simulink. The temperature reading is simulated by the data obtained from the process using a numeric data string. To start the simulation, the casting speed and water flow sizes must be entered, the program will correct these values using a loop through which the correction obtained changes the input data. The running time of the simulation is 1000 seconds, each calculation loop having 3.2 seconds.

![Figure 3. Implementation in Simulink of IFS-Z1,Z2,Z3](image)
Figure 4 shows the values of the input variables. We know the temperature and the starting variables of casting, in this case we chose the simulation start speed of 1.5 m/sec and 168 l/min for the cooling water flow, we chose these high risk factors to highlight the risk remedy in the first 30 seconds of the simulation that can be seen in Figure 5.

![Figure 4. Values of input variables for IFS-Z1](image)

Figure 5. Corrections made by IFS-Z1

Figure 6 shows the values of the input variables. Known are the temperature and the starting variables of casting, in this case we have chosen the start value of the simulation for the casting speed of 1.4 m/min and 220 l/min for the cooling water flow, we have chosen these high risk factor values for To highlight the risk remedy in the first 25 seconds of the simulation that can be seen in Figure 7.

The steels heat is partially removed by heating the cooling water, but the most heat is extracted by water evaporation, even if the evaporation percentage of the sprayed water on the wires surface is in general lower than 20%. All the unevaporated water which flows from the wires surface are collected filtered and reused [5-7]. Fuzzy logic can process vague variables whose values can vary continuously.
in any numerical range defined by taking decisions depending on the position indicator in the numerical range and predefined rules [8-11].

Figure 6. Values of input variables for IFS-Z2

Figure 7. Corrections made by IFS-Z2

Figure 8 shows the values of the input variables. We know the temperature and the starting variables of casting, in this case we chose the start value of the simulation for the casting speed of 1.3m / sec and 280l / min for the cooling water flow, we chose these high risk factor values to highlight the risk remedy in the first 20 seconds of the simulation that can be seen in Figure 9.

Laying the foundation of rules required an analysis of all possible outcomes. To this end, a number of expert technologists with extensive experience in the operation of the casting machines were consulted.

Also, for each case was carried out an analysis of the phenomenon of solidification of the crust. For the issue in question a database was built that consists of information gathered from
technologists experts. This database was supplemented with information from the mathematical model of solidification process [7].

4. Conclusions
Analyzing simulation results shows that regardless of the values of the generated input, IFS develops the necessary corrections casting speed and primary cooling water flow, which confirms the validity of system operation. It is considered that, in terms of quality, use fuzzy decision system is an effective, practical and easy to implement, in order to analyze complex phenomena and nonlinear.

The goal of fuzzy system is to improve this classical adjustment system, the introduction of some adaptive components in the adjustment loops and some overall predictions over the continuous casting machine.

This paperwork introduces a new and original concept of the structure of a control system for the continuous casting.
The goal of the Simulink system is to improve this classical adjustment system, the introduction of some adaptive components in the adjustment loops and some overall predictions over the continuous casting machine.

Acknowledgment
This work was supported by a grant of the Romanian National Authority for Scientific Research and Innovation, CNCS – UEFISCDI, project number PN-III-RU-TE-2014-4-1788.

References
[1] Efimov V A 1986 Casting and crystallizing of steel, Ed. Technical, Bucuresti
[2] Kiflie B and Alemu D 2000 Thermal Analysis of Continuous Casting Process, 5th Annual Conference on Manufacturing &Process Industry, Faculty of Technology, Addis Ababa University, Ethiopia
[3] O’Conner T and Dantzig J 1994 Modeling the Thin Slab Continuous Casting Mold, Metallurgical and Materials Transactions 25B(4) 443-457
[4] Pinca C and Tirian G O 2006 The numerical analysis of the asymmetrical thermal tension from hot rolling mill cylinders, National Conference of Metallurgy and Materials Science, Bucuresti, Romania, pp 296-303
[5] Bouhouch S, Lahreche M, Moussaoui A and Bast J 2007 Quality Monitoring Using Principal Component Analysis and Fuzzy Logic. Application in Continuous Casting Process, American Journal of Applied Science 4(9) 637-644
[6] Singh J and Ganesh A 2008 Design and Analysis of GA based Neural/Fuzzy Optimum Adaptive Control, Transactions on Systems and Control 5 (3)
[7] Ardelean E, Ardelean M, Socalici A and Hepuț T 2007 Simulation of continuous cast steel product solidification, Revista de Metalurgia 43 (3) 181-187
[8] Lee C C 1990 Fuzzy logic in control systems: Fuzzy logic controller, IEEE Trans. Systems, Man & Cybernetics 20(2) 404-435
[9] Tirian G O, Gheorghiu C A, Hepuț T and Rob R 2016 Fuzzy control strategy for secondary cooling of continuous steel casting, IOP Conf. Ser.: Mater. Sci. Eng. 200 012046
[10] Tirian G O, Gheorghiu C A, Hepuț T and Chioncel C 2016 Control system of water flow and casting speed in continuous steel casting, IOP Conf. Ser.: Mater. Sci. Eng. 200 012047
[11] Tirian G O, Gheorghiu C A, Hepuț T and Tirian A 2017 Cracks detection in continuous casting processes used unconventional methods, International Conference on Automatic Control, Modelling and Simulation, Barcelona, Spain