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Fuzzy Logic Controllers for High Performance in Secondary Cooling

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The main target of this paper is to develop and implement structures of fuzzy control in the continuous casting process (in the secondary cooling) capable of eliminating the surface flaws and casting rejects, to increase the quality of continuously cast products and implicitly to increase the productivity of the installation by controlling the water flow rate in the secondary cooling circuit. In order to achieve this objective, a solution will be developed and implemented, meant to control the casting process by a fuzzy system, allowing the control of the water flow rate in the secondary cooling, by appropriate distribution along the cooling area. This necessity is imposed by the fact that actual control systems do not correlate in real time the variations of the multiple variables related to the continuous casting process and stick to a rigid distribution of the water flow rate on each cooling area.

Keywords*: Terms-continuous casting, secondary cooling stage, fuzzy systems, water flow*

1. Introduction.

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].

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.

Basically, the rules database was designed specifically for this purpose and it contains measures to be taken to mitigate the risk of a crack.

2. Continuous casting plant.

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].

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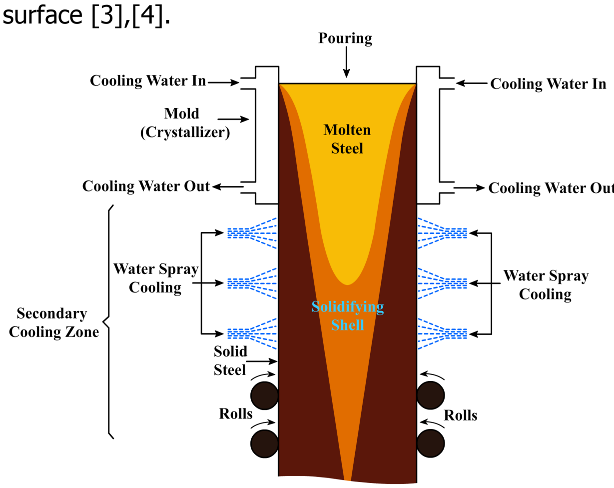


Figure 1. The text of figure caption.

The crust created in the crystallizing gives the shape of the molded section. In most cases the crust doesn't offer sufficient mechanical resistance to the action of Ferro static pressure. To complete solidification and guidance in good conditions of the wire it is created the secondary cooling zone. This cooling is achieved by direct spraying pressurized water, through nozzles, it is able to cross the steam layer formed by evaporation and ensure continuous water-metal contact. In figure 1 it is presented the scheme of the primary and secondary solidification [5], [6].

The secondary cooling can be made in different cooling environments. In practice, the water is used especially as cooling agent that is sprayed through nozzles (circular conical, conical ring and slot). In special cases it is added to the water compressed air for optimizing the automation sprayed water [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 [8], [9], [10].

3. Design of fuzzy systems.

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 [11], 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.

The secondary cooling system is divided into 3 subareas such as: area 1 or foot roller area located on the crystallizing exit, area 2 and area 3, these areas are controlled individually. In general the sprayed water flow must decrease from the crystallizing in the direction of the cast. The sprayed water flows must be bigger in the superior side of the casting machine (area 0 and area1), for realizing the increasing of the semi-products crust and thus improve the resistance crust according to the effort. Lowering the cooling intensity in the casting direction must prevent that the surfaces temperature became too low in the straightening points [9].

The cooling is done using some valves by using some classical PID loops which adjust the water flow depending on reference measure. The goal of an intelligent 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.

The fuzzy system which will be created must also take into consideration the distance between the rings and the length of the curved wire. The installations geometry will reveal for a certain speed and casting recipe the needed quantity of the water to obtain the desired quality, this will make a spraying recipe which will give the quantity of water for every area, the values of the minimal flows needed for ensuring a minimal pressure in this areas (the minimal pressure for this areas is 2 bar) and implicitly the information needed to create the fuzzy systems rules which may take the needed measures in case the waters pressure is too low or too high, pressure which must be assured by a corresponding flow [7], [12], [13].

The classical nowadays systems are limited to a rigid repartition of the water flow in each area such as: 40% on the first area, 40% on the second area, and 20% on the third area. An intelligent system has the capacity of eliminating this nowadays systems disadvantage by having the possibility of modifying in real time the water flow repartition for each area taking into consideration what happens in the installation. Leaving from the installations geometry with 3 cooling areas will be created 3 fuzzy regulators for each area separately, each one having 3 inputs such as: speed, pressure and flow and 2 outputs such as: flow correction and speed (figure 2).

After the 3 fuzzy controllers are done it will be designed a fuzzy adaptive system which correlates the, three cooling areas so that the water flow to be the same. For example if the water flow is lowed in the first area it will automatically increase the water flow in the second and third area so that it will be the same value of the water flow but the repartition on each area will be different. Matlab implementations of fuzzy controllers [14], [15] are present in next part of the paper.

Designed fuzzy systems receive the following values from the process, depending on the casting area in which the perform is located:

- the casting speed;
- the cooling water flow in the cooling Z1, Z2, Z3;
- steel temperature in the cooling Z1, Z2, Z3;
- the flow correction Z1, Z2.

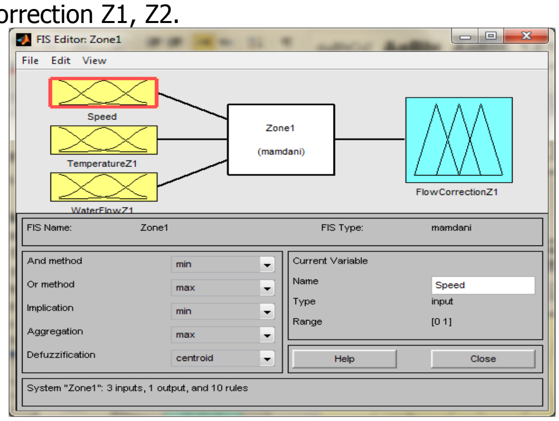
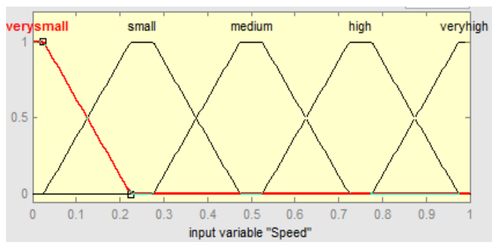


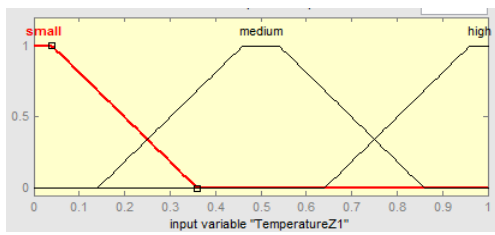
Figure 2. Block diagram of the fuzzy controller for Zone1.

In figures 3 a) and b) we describe the membership functions for the input sizes. Membership function „WaterFlowZ1" is the same like membership function

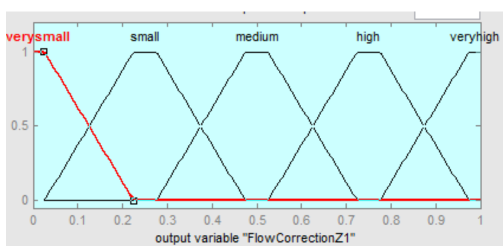
„Speed”. In figure c) we describe the membership functions for the output size.



a) Membership function „Speed”



b) Membership function „TemperatureZ1”



c) Membership function „FlowCorrectionZ1”

Figure 3. Membership function.

Considering process features it was adopted some trapezoidal-type connection functions for all input and output sizes. The type of connection functions for input quantities is described in figures a and b. For "speed" input size it was chosen five linguistic terms, for “temperature Z1”, input size it was chosen three linguistic terms meanwhile for „WaterFlowZ1”, it was chosen five linguistic terms. For output size “FlowCorrectionZ1”it was chosen five linguistic terms [16].

A part of control surfaces obtained by simulations according to the block diagram from the figure 4 and figure 5 are listed below.

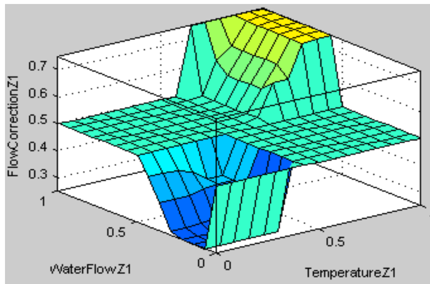


Figure 4. Control surface - Flow correction Z1=f (water flow, temperature).

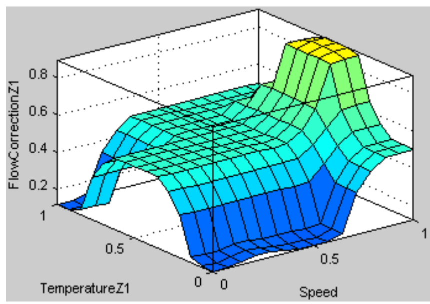


Figure 5. Control surface - Flow correctionZ1=f (temperature, speed).

In figure 6 we presented the block diagram of the fuzzy controller for Zone 2.

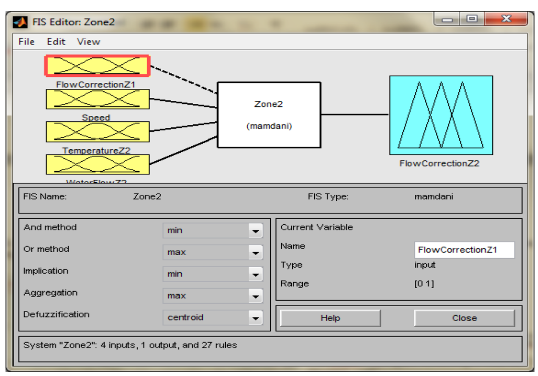
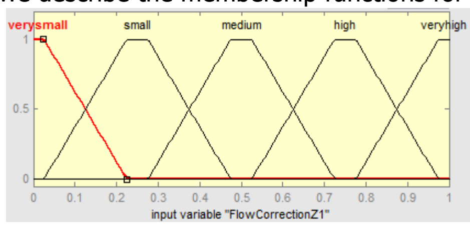
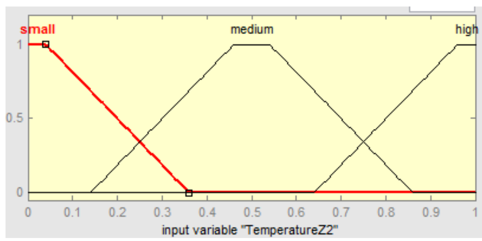


Figure 6. Block diagram of the fuzzy controller for Zone 2.

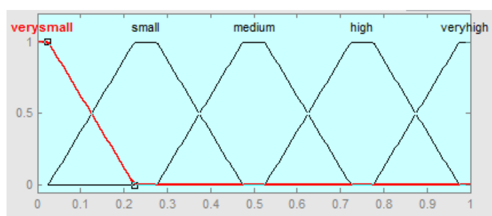
In figures 7 a) and b) we describe the membership functions for the input sizes. Membership function for "speed", „WaterFlowZ1"and "FlowCorrectionZ1" are the same. In figure c) we describe the membership functions for the output size.



a) Membership function „FlowCorrectionZ1”



b) Membership function „TemperatureZ2”



c) Membership function „FlowCorrectionZ2”

Figure 7. Membership function.

Considering process features it was adopted some trapezoidal-type connection functions for all input and output sizes. The type of connection functions for input quantities is described in figures d) and e). For "FlowCorrectionZ1" input size it was chosen five linguistic terms, for „speed” input size it was chosen five linguistic terms, for "temperature Z2", input size it was chosen three linguistic terms meanwhile for „WaterFlowZ1”, it was chosen five linguistic terms. For output size „FlowCorrectionZ2” it was chosen five linguistic terms [16].

A part of control surfaces obtained by simulations according to the block diagram from the figure 8, figure 9 are listed below.

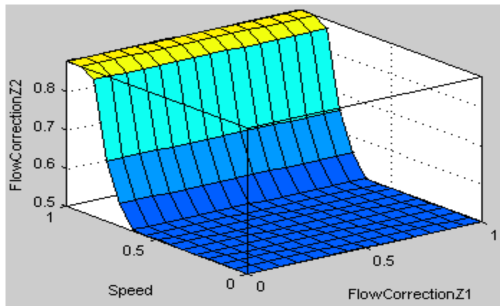


Figure 8. Control surface - Flow correctionZ2=f (speed, flow correctionZ1).

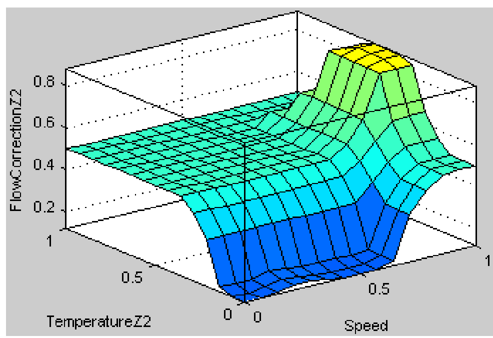


Figure 9. Control surface - Flow correctionZ2=f (temperatureZ2, speed).

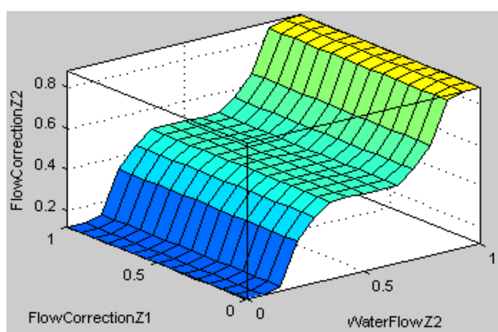


Figure 10. Control surface - Flow correctionZ2=f(flow correctionZ1 water flowZ2).

In figure 11 we presented the block diagram of the fuzzy controller controller for Zone3.

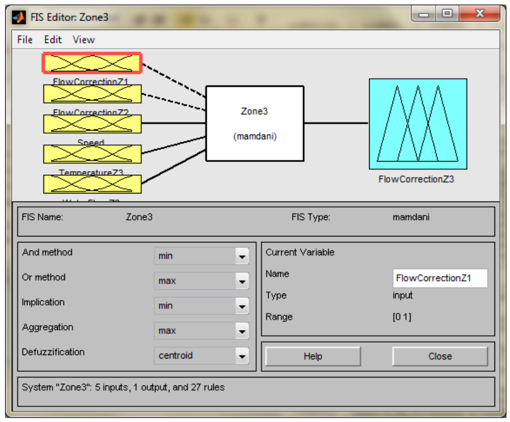
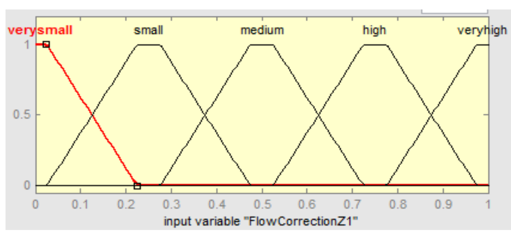
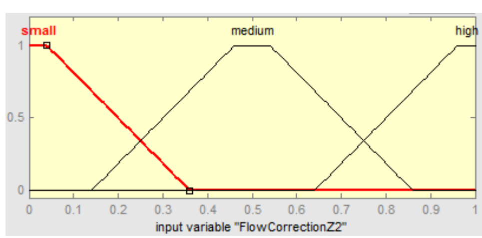


Figure 11. Block diagram of the fuzzy controller for Zone3.

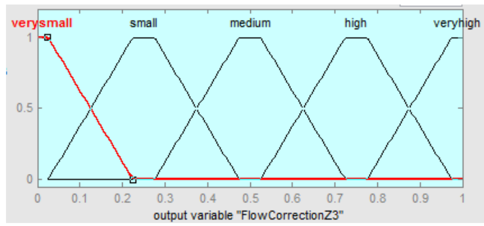
In figures 12.a. and 12.b. we describe the membership functions for the input sizes. Membership function for "FlowCorrectionZ1","Speed" and „WaterFlowZ3" are the same. Also "FlowCorrectionZ2" and "Temperature Z3" are the same. In figure 12.c. we describe the membership functions for the output size.



a) Membership function „FlowCorrectionZ1"



b) Membership function „FlowCorrectionZ2"



c) Membership function „FlowCorrectionZ3"

Figure 12. Membership function.

Considering process features it was adopted some trapezoidal-type connection functions for all input and output sizes. The type of connection functions for input quantities is described in figures g) and h). For "FlowCorrectionZ1" input size it was chosen five linguistic terms, for "FlowCorrectionZ2" input size it was chosen three linguistic terms, for „speed" input size it was chosen five linguistic terms, for "temperature Z3", input size it was chosen three linguistic terms meanwhile for „WaterFlowZ3", it was chosen five linguistic terms. For output size „FlowCorrectionZ3" it was chosen five linguistic terms [16].

A part of control surfaces obtained by simulations according to the block diagram from the figure 13 and figure 14 are listed below.

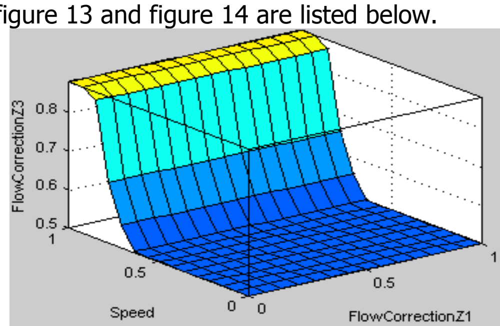


Figure 13. Control surface - Flow correctionZ3=f (speed, flow correctionZ1).

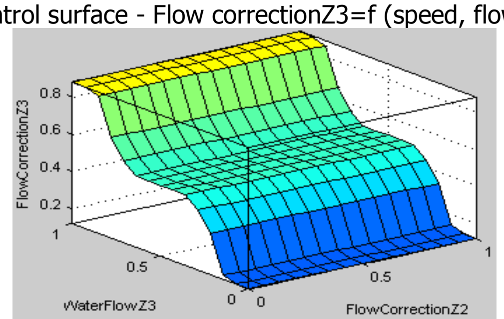


Figure 14. Control surface - Flow correctionZ3=f(water flowZ3, flow correctionZ2).

4. Conclusions.

This paperwork introduces a new concept of the structure of a control system for the continuous casting. This method contains 3 fuzzy controllers which, based on a set of rules established with the help of the mathematical model to the crust solidification process and uses the experience of human experts, requires changes of the water flow in the secondary cooling.

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.

References

[1] Efimov V.A., *Casting and crystallizing of steel*, Ed. Technica, Bucuresti, 1986.

[2] Kiflie B., Alemu D., *Thermal Analysis of Continuous Casting Process*, ESME 5th Annual Conference on Manufacturing &Process Industry, Faculty of Technology, Addis Ababa University, Ethiopia, 2000.

[3] O'conner T., Dantzig J., *Modeling the Thin Slab Continuous Casting Mold*, Metallurgical and Materials Transaction s 25B(4): 443-457, 1994.

[4] Pinca C., Tirian G.O., *The numerical analysis of the asymmetrical thermal tension from hot rolling mill cylinders*, National conference of metallurgy and materials science, pg. 296-303, Bucuresti, 2006.

[5] Bouhouch S., Lahreche M., Moussaoui A., Bast J., *Quality Monitoring Using Principal Component Analysis and Fuzzy Logic. Application in Continuous Casting Process*, American Journal of Applied Science (AJAS), 4(9), 2007, pp. 637-644.

[6] Singh J., Ganesh A., *Design and Analysis of GA based Neural/Fuzzy Optimum Adaptive Control,* Transactions on Systems and Control, Issue 5, Volume 3, 2008.

[7] Ardelean E., Ardelean M., Socalici A., Heput T., *Simulation of continuous cast steel product solidification*, Revista de Metalurgia 43 (3), pg. 181-187, Spain, 2007.

[8] Thomas B.G., *Modeling of the continuous casting of steel-past,present and future*, 59th Electric Furnance Conference, Phoenix, AZ,2001.

[9] Recktenwal W.G., *Finite-Diference Approximations to the Heat Equation,* Mechanical Engineering Department Portland State University, USA, January 21, 2004.

[10] Lagrat I., El Ougli A., Boumhidi I., *Optimal Adaptive Fuzzy Control for a Class of Unknown Nonlinear Systems*, WSEAS Transactions on Systems and Control, Issue 2, Volume 3, February 2008, pp. 89-98.

[11] Spunei E., Piroi I., Piroi F., *Basic Concepts in the Diagnosis of Traffic Safety Installations Using Fuzzy Logic Based Models*, Analele Universităţii "Eftimie Murgu" Reşiţa, Anul XXII, Nr. 2, 2015, 327-335.
[12] Drainkov D., Hellendoom H., Reinfrank M., *An Introduction to Fuzzy Control*, Springer-Verlag, Berlin, 1993.
[13] Lee C.C., *Fuzzy logic in control systems: Fuzzy logic controller*, IEEE Trans. Systems, Man & Cybernetics 20(2): 404-435, 1990.
[14] Zulfatman, M.F. Rahman, *Application of Self-Tunning F fuzzy PID.*
[15] Tirian G.O., Gheorghiu C.A., Heput T., Rob R., *Fuzzy control strategy for secondary cooling of continuous steel casting,* IOP Conference Series: Materials Science and Engineering 200 012046.
[16] Tirian G.O., Gheorghiu C. A., Heput T., Chioncel C, *Control system of water flow and casting speed in continuous steel casting*, IOP Conference Series: Materials Science and Engineering 200 012047.

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