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THE MANAGEMENT OF THE PROCESS OF SECONDARY COOLING FOR STEEL CONTINUOUS CASTING

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ABSTRACT
The paper introduces a new method of controlling the process of secondary cooling in steel continuous casting, using the fuzzy logic. Thus we can take into consideration several magnitudes that influence the quality of the process, thereby obtaining superior results.

KEY WORDS: fuzzy, continuous casting

1. INTRODUCTION

The aim of secondary cooling for steel continuous casting is to continue the cooling of the stream after its coming out of the mold in view of its cross-sectional complete solidification. The zone of secondary cooling comes right after the mold and is given in figure 1, together with the circuits of cooling water (both for the secondary cooling zone and for the mold).

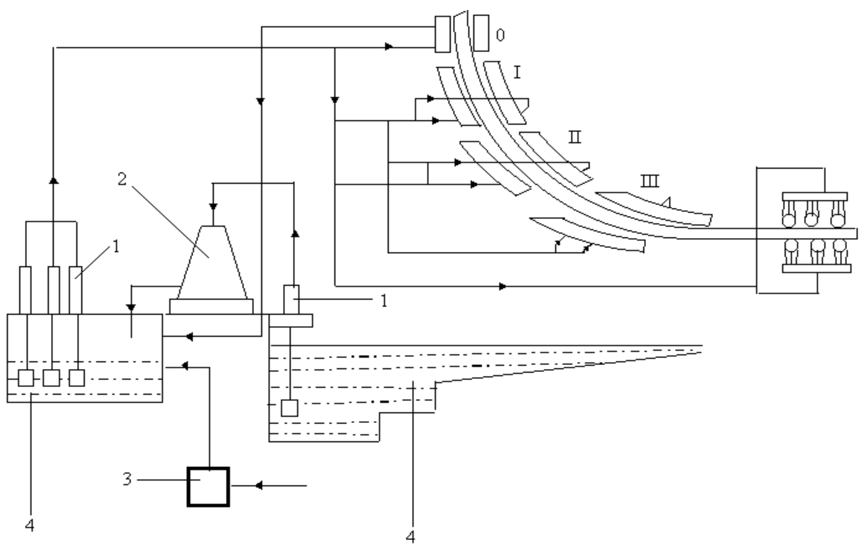


Fig. 1
The diagram of cooling water circuits:
1 - pump; 2 – cooling tower; 3 – water preparation station; 4 - collector.

The cooling agent in this zone is water or a mixture of air and water, sprayed through sprinklers on the surface of the stream and controlled in such a way so as the stream surface should evenly decrease its temperature in the direction of the casting.

At present, the cooling operation is controlled by analogical correction loops, not taking into consideration the decrease gradient in the temperature of the material and neither considering the anticipative effects of certain regulations in the metal level inside the mold.

This situation can be improved using an expert system whose necessity has been imposed by the fact that the process cannot be precisely modeled mathematically and some parameters (steel fluidity, its chemical properties, the heat transfer conditions, etc.) change in time in a way that cannot be anticipated.

For the implementation of the expert system we created a specific database, materialized in a set of linguistic rules, which form the reasoning according to which the system operates, on analyzing the real values of the variables.

2. THE FUZZY ALGORITHM OF CORRECTION OF THE SECONDARY COOLING PROCESS

In order to obtain a higher precision of regulation, the process has been divided into two work conditions: starting – stopping and actual continuous casting. For each stage we determined the rule database and the membership functions according to which we obtained – experimentally – the correction surfaces and the static characteristics.

The fuzzy controllers corresponding to these two work conditions are of the type **four inputs**, (viteza_t, temp.1, temp.2, temp.3) – **three outputs** (db.apa.1, db.apa.2, db.apa.3) – **several rules**.

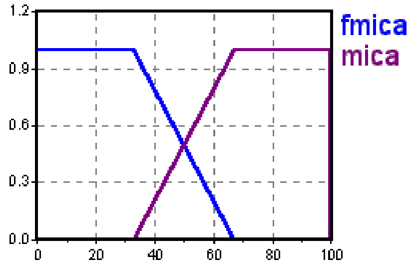
2.1 The Starting – Stopping Process of Continuous Casting

The variation domains and the number of states of the input, respectively output magnitudes are given in table 1:

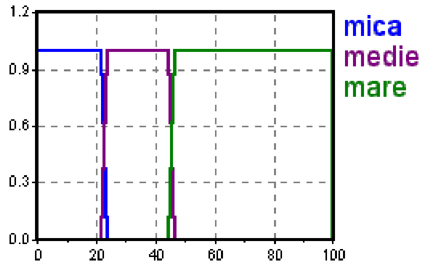
Table 1.

Magnitude	States	Real Domain [m/min]	The Domain of Norm Values [%]
viteza_t (casting rate, [m/min])	fmică	0,3 ÷ 0,59	0 ÷50
	mică	0,59 ÷ 0,88	50 ÷100
temp.1 (temperature of stream in zone1, [°C])	mică	1230 ÷ 1255	0 ÷ 22,72
	medie	1255 ÷ 1280	22,72 ÷ 45,45
	mare	1280 ÷ 1340	45,45 ÷100
temp.2 (temperature of stream in zone 2, [°C])	mică	1096 ÷ 1130	0 ÷ 28,08
	medie	1130 ÷ 1160	28,08 ÷ 53,33
	mare	1160 ÷ 1216	53,33 ÷100
temp.3 (temperature of stream in zone 3, [°C])	mică	960 ÷ 965	0 ÷ 25
	medie	965 ÷ 975	25 ÷ 75
	mare	975 ÷ 1000	75 ÷100
db.apa.1 (cooling water flow in zone1, [Lit/min])	minim	52,8	0
	normal	53	50
	maxim	53,2	100
db.apa.2 (cooling water flow in zone 2, [Lit/min])	minim	64,8	0
	mic	65	14,28
	mare	66	85,71
	maxim	66,2	100
db.apa.3 (cooling water flow in zone 3, [Lit/min])	minim	85,8	0
	mic	86	8,33
	mediu	87	50
	mare	88	91,66
	maxim	88,2	100

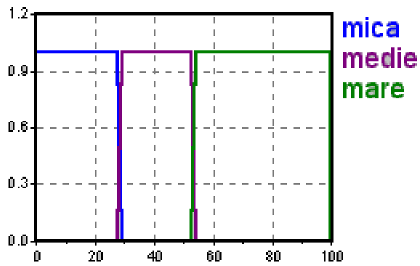
The fuzzification of the input variables is done with belonging trapezoidal functions 1 (figure 2), with a coverage degree 1, and for the output variables we used belonging singleton-type functions.



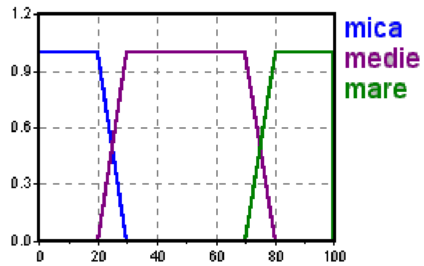
a) viteza_t



b) temp.1



c) temp.2



d) temp.3

Fig.2

The belonging functions of the input variables

The rule database will include 54 rules and is given in Table 2. The chosen inference method is of the max-min type, and the defuzzification is done by the method of the gravity center.

Table 2.

WENN	viteza_t = fmica	UND temp1 = mica	UND temp2=mica	UND temp3=mica
DANN	db.apa1=minim	UND db.apa2=minim	UND db.apa3=minim (100%)	
WENN	viteza_t = fmica	UND temp1 = mica	UND temp2=mica	UND temp3=medie
DANN	db.apa1=minim	UND db.apa2=minim	UND db.apa3=mic (100%)	
WENN	viteza_t = fmica	UND temp1 = mica	UND temp2=mica	UND temp3=mare
DANN	db.apa1=minim	UND db.apa2=minim	UND db.apa3=mediu (100%)	
WENN	viteza_t = fmica	UND temp1 = mica	UND temp2=medie	UND temp3=mica
DANN	db.apa1=minim	UND db.apa2=mic	UND db.apa3=mic (100%)	
WENN	viteza_t = fmica	UND temp1 = mica	UND temp2=medie	UND temp3=medie
DANN	db.apa1=minim	UND db.apa2=mic	UND db.apa3=mediu (100%)	
WENN	viteza_t = fmica	UND temp1 = mica	UND temp2=medie	UND temp3=mare
DANN	db.apa1=minim	UND db.apa2=mic	UND db.apa3=mare (100%)	
WENN	viteza_t = fmica	UND temp1 = mica	UND temp2=mica	UND temp3=mica
DANN	db.apa1=minim	UND db.apa2=mare	UND db.apa3=mic (100%)	
WENN	viteza_t = fmica	UND temp1 = mica	UND temp2=mica	UND temp3=medie
DANN	db.apa1=minim	UND db.apa2=mare	UND db.apa3=mediu (100%)	
WENN	viteza_t = fmica	UND temp1 = mica	UND temp2=mare	UND temp3=mare
DANN	db.apa1=minim	UND db.apa2=mare	UND db.apa3=maxim (100%)	
WENN	viteza_t = fmica	UND temp1 = medie	UND temp2=mica	UND temp3=mica
DANN	db.apa1=normal	UND db.apa2=minim	UND db.apa3=minim(100%)	
WENN	viteza_t = fmica	UND temp1 = medie	UND temp2=mica	UND temp3=medie
DANN	db.apa1=normal	UND db.apa2=minim	UND db.apa3=mic (100%)	
WENN	viteza_t = fmica	UND temp1 = medie	UND temp2=mica	UND temp3=mare
DANN	db.apa1=normal	UND db.apa2=minim	UND db.apa3=mediu (100%)	
WENN	viteza_t = fmica	UND temp1 = medie	UND temp2=medie	UND temp3=mica
DANN	db.apa1=normal	UND db.apa2=mic	UND db.apa3=mic (100%)	
WENN	viteza_t = fmica	UND temp1 = medie	UND temp2=medie	UND temp3=medie
DANN	db.apa1=normal	UND db.apa2=mic	UND db.apa3=mediu (100%)	
WENN	viteza_t = fmica	UND temp1 = medie	UND temp2=medie	UND temp3=mare
DANN	db.apa1=normal	UND db.apa2=mic	UND db.apa3=mare(100%)	

WENN DANN	viteza_t = fmica db.apa1=normal	UND temp1 = medie UND db.apa2=mare	UND temp2=mare UND db.apa3=mic (100%)	UND temp3=mica
WENN DANN	viteza_t = fmica db.apa1=normal	UND temp1 = medie UND db.apa2=mare	UND temp2=mare UND db.apa3=mediu (100%)	UND temp3=medie
WENN DANN	viteza_t = fmica db.apa1=normal	UND temp1 = medie UND db.apa2=mare	UND temp2=mare UND db.apa3=maxim (100%)	UND temp3=mare
WENN DANN	viteza_t = fmica db.apa1=normal	UND temp1 = mare UND db.apa2=mic	UND temp2=mica UND db.apa3=minim (100%)	UND temp3=mica
WENN DANN	viteza_t = fmica db.apa1=maxim	UND temp1 = mare UND db.apa2=mic	UND temp2=mica UND db.apa3=mic(100%)	UND temp3=medie
WENN DANN	viteza_t = fmica db.apa1=maxim	UND temp1 = mare UND db.apa2=mic	UND temp2=mica UND db.apa3=mediu (100%)	UND temp3=mare
WENN DANN	viteza_t = fmica db.apa1=maxim	UND temp1 = mare UND db.apa2=mare	UND temp2=medie UND db.apa3=mic(100%)	UND temp3=mica
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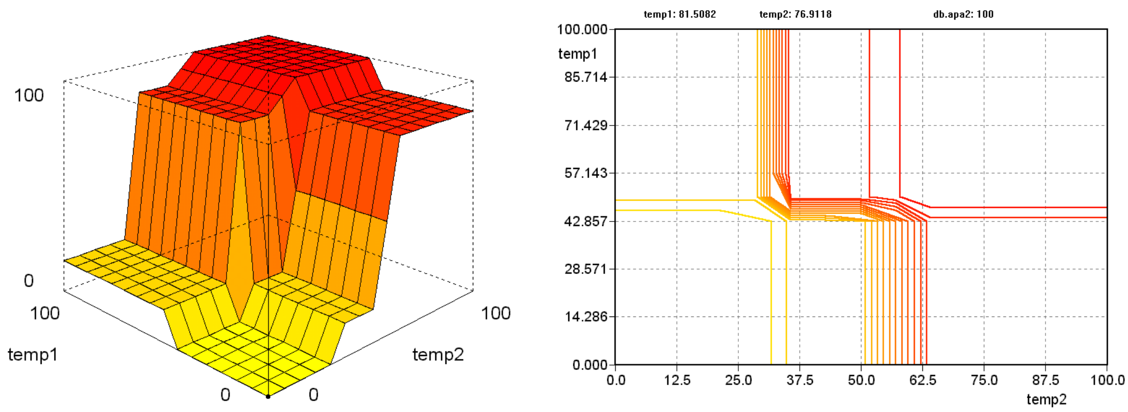
WENN DANN	viteza_t = fmica db.apa1=maxim	UND temp1 = mare UND db.apa2=mare	UND temp2=medie UND db.apa3=mare(100%)	UND temp3=mare
WENN DANN	viteza_t = fmica db.apa1=maxim	UND temp1 = mare UND db.apa2=maxim	UND temp2=mare UND db.apa3=mic (100%)	UND temp3=mica
WENN DANN	viteza_t = fmica db.apa1=maxim	UND temp1 = mare UND db.apa2=maxim	UND temp2=mare UND db.apa3=mediu (100%)	UND temp3=medie
WENN DANN	viteza_t = fmica db.apa1=maxim	UND temp1 = mare UND db.apa2=maxim	UND temp2=mare UND db.apa3=maxim (100%)	UND temp3=mare
WENN DANN	viteza_t = mica db.apa1=minim	UND temp1 = mare UND db.apa2=minim	UND temp2=mica UND db.apa3=minim(100%)	UND temp3=mica
WENN DANN	viteza_t = mica db.apa1=minim	UND temp1 = mica UND db.apa2=minim	UND temp2=mica UND db.apa3=mediu (100%)	UND temp3=medie
WENN DANN	viteza_t = mica db.apa1=minim	UND temp1 = mica UND db.apa2=minim	UND temp2=mica UND db.apa3=mare (100%)	UND temp3=mare
WENN DANN	viteza_t = mica db.apa1=minim	UND temp1 = mica UND db.apa2=mic	UND temp2=medie UND db.apa3=mic (100%)	UND temp3=mica
WENN DANN	viteza_t = mica db.apa1=minim	UND temp1 = mica UND db.apa2=mic	UND temp2=medie UND db.apa3=mediu (100%)	UND temp3=medie
WENN DANN	viteza_t = mica db.apa1=minim	UND temp1 = mica UND db.apa2=mic	UND temp2=medie UND db.apa3=mare (100%)	UND temp3=mare
WENN DANN	viteza_t = mica db.apa1=minim	UND temp1 = mica UND db.apa2=mare	UND temp2=mare UND db.apa3=mediu (100%)	UND temp3=mica
WENN DANN	viteza_t = mica db.apa1=minim	UND temp1 = mica UND db.apa2=mare	UND temp2=mare UND db.apa3=mare (100%)	UND temp3=medie
WENN DANN	viteza_t = mica db.apa1=minim	UND temp1 = mica UND db.apa2=mare	UND temp2=mare UND db.apa3=maxim (100%)	UND temp3=mare
WENN DANN	viteza_t = mica db.apa1=normal	UND temp1 = medie UND db.apa2=minim	UND temp2=mica UND db.apa3=minim (100%)	UND temp3=mica
WENN DANN	viteza_t = mica db.apa1=normal	UND temp1 = medie UND db.apa2=minim	UND temp2=mica UND db.apa3=mediu (100%)	UND temp3=medie
WENN DANN	viteza_t = mica db.apa1=normal	UND temp1 = medie UND db.apa2=minim	UND temp2=mica UND db.apa3=mare (100%)	UND temp3=mare
WENN DANN	viteza_t = mica db.apa1=normal	UND temp1 = medie UND db.apa2=mic	UND temp2=medie UND db.apa3=mic (100%)	UND temp3=mica
WENN DANN	viteza_t = mica db.apa1=normal	UND temp1 = medie UND db.apa2=mic	UND temp2=medie UND db.apa3=mediu (100%)	UND temp3=medie
WENN DANN	viteza_t = mica db.apa1=normal	UND temp1 = medie UND db.apa2=mic	UND temp2=medie UND db.apa3=mare (100%)	UND temp3=mare
WENN DANN	viteza_t = mica db.apa1=normal	UND temp1 = medie UND db.apa2=mare	UND temp2=mare UND db.apa3=mediu (100%)	UND temp3=mica
WENN DANN	viteza_t = mica db.apa1=normal	UND temp1 = medie UND db.apa2=mare	UND temp2=mare UND db.apa3=mare (100%)	UND temp3=medie
WENN DANN	viteza_t = mica db.apa1=normal	UND temp1 = medie UND db.apa2=mare	UND temp2=mare UND db.apa3=maxim (100%)	UND temp3=mare
WENN DANN	viteza_t = mica db.apa1=maxim	UND temp1 = mare UND db.apa2=mare	UND temp2=mica UND db.apa3=minim (100%)	UND temp3=mica
WENN DANN	viteza_t = mica db.apa1=maxim	UND temp1 = mare UND db.apa2=mare	UND temp2=mica UND db.apa3=mediu (100%)	UND temp3=medie
WENN DANN	viteza_t = mica db.apa1=maxim	UND temp1 = mare UND db.apa2=mare	UND temp2=mica UND db.apa3=mare (100%)	UND temp3=mare
WENN DANN	viteza_t = mica db.apa1=maxim	UND temp1 = mare UND db.apa2=maxim	UND temp2=medie UND db.apa3=mic (100%)	UND temp3=mica

WENN	viteza_t = mica	UND temp1 = mare	UND temp2=medie	UND temp3=medie
DANN	db.apa1=maxim	UND db.apa2=maxim	UND db.apa3=mediu (100%)	
WENN	viteza_t = mica	UND temp1 = mare	UND temp2=medie	UND temp3=mare
DANN	db.apa1=maxim	UND db.apa2=maxim	UND db.apa3=mare (100%)	
WENN	viteza_t = mica	UND temp1 = mare	UND temp2=mare	UND temp3=mica
DANN	db.apa1=maxim	UND db.apa2=maxim	UND db.apa3=mediu (100%)	
WENN	viteza_t = mica	UND temp1 = mare	UND temp2=mare	UND temp3=medie
DANN	db.apa1=maxim	UND db.apa2=maxim	UND db.apa3=mare (100%)	
WENN	viteza_t = mica	UND temp1 = mare	UND temp2=mare	UND temp3=mare
DANN	db.apa1=maxim	UND db.apa2=maxim	UND db.apa3=maxim (100%)	

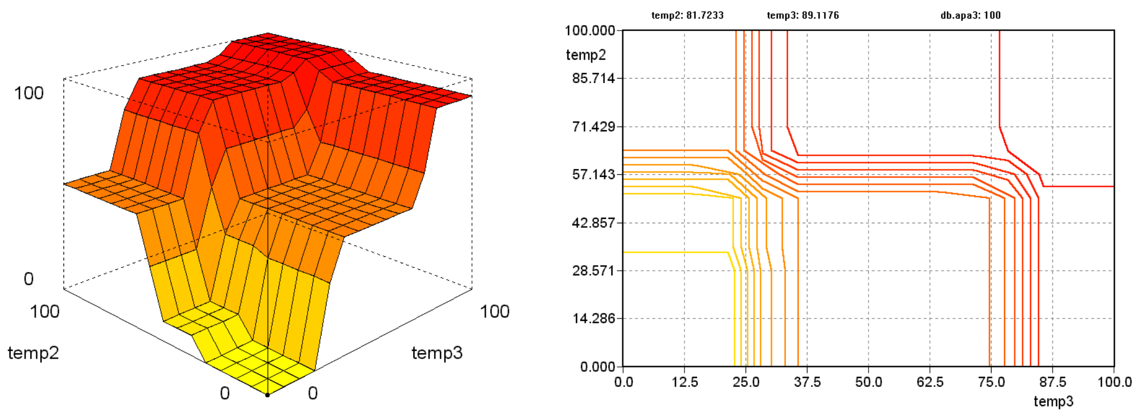
We checked the correctness of the rule database by simulation, obtaining the control surfaces and the static characteristics given in fig. 3, 4 (for certain significant situations).



a) control surface

b) static characteristic

Fig. 3
db.apa 2=f (temp1, temp2)
viteza_t = fmica, temp3 – medie



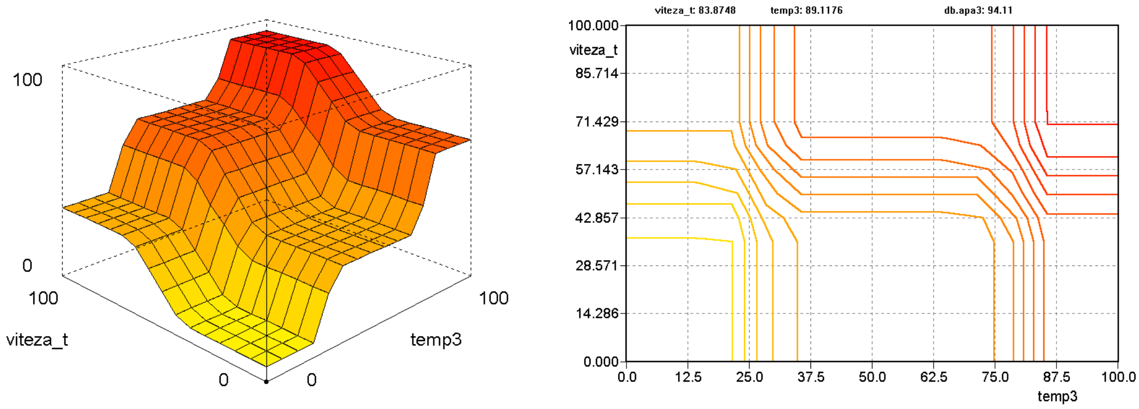
a) control surface

b) static characteristic

Fig. 4
db.apa 3 = f (temp2, temp3)
viteza_t = mică, temp1 = medie

2.2 The Actual Continuous Casting Process

Similar to the previous case, we determined the input and output magnitudes with their variation fields, the rule database (including 54 rules) and its testing. Out of space restrictions, we give in fig, 5 the control surface and the static characteristics for just one variant.



a) control surface

b) static characteristic

Fig. 5
db.apa 3 = f(viteza_t, temp3)
temp1 = medie, temp2 = medie

3. CONCLUSIONS

The method we suggested allows obtaining high results in the actual control system of the secondary cooling process, as the correction of water flow takes into consideration both the casting rate and the temperature in the respective area, as well as the temperatures measured in the adjacent areas. The success of the method depends on the quality of the rule database, drawn up after having consulted a large number of technology professionals. Taking in to account the variety of actual situations (the casting of several typo-dimensional semi-finished parts), the rule database needs modifications. They can be operated easily, which constitutes another advantage of the method we introduced.

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