Cracks detection in continuous casting processes used unconventional methods

GELU OVIDIU TIRIAN, CSABA ATTILA GHEORGHIU, TEODOR HEPUT, ANDREEA TIRIAN
Department of Electrical Engineering and Industrial Informatics
Department of Engineering and Management
Politechnica University of Timisoara
Revolutiei str., no. 5, Hunedoara
ROMANIA
ovidiu.tirian@fih.upt.ro, jciobi@yahoo.com, teodor.heput@fih.upt.ro, andreea.tirian@fih.upt.ro

Abstract: - The paper present an intelligent system for crack detection in continuous casting processes. The intelligent system is made up by a neural network used for crack detection and a fuzzy-controller for predicting and eliminating them. This system uses all data in the process to correct the casting speed and the cooling water. We have changed the system in a Matlab-Simulink environment, and hence, we have designed a simulation pattern, the input signal generators, the fuzzy controller, and the prediction block for all speed and water flow values. When using the model, we have applied a number of input data sets, and the pattern has generated real output values, also acknowledging the system design. The solution is a new concept who combine neural networks with fuzzy logic for a good solution to control continuous casting process.

Key-Words: - control system, continuous casting, cracks, fuzzy logic, neural networks, casting speed, water flow

1 Introduction

Continuous casting equipment is currently powered by automatic systems organized into different hierarchical levels.

Control systems ensure the right working algorithms required by an appropriate system working – both technologically and generally speaking – and also in case of classical systems based on PID numerical controller. Usually, there are no measures for crack prediction, thus eliminates results from the process (in terms of tenth of tones of steel). In such case, working staff changes the working methods of the installation, based on internal instructions. The casting programme is not appropriate and that has important economical implications.

Worldwide, there is research [1], [2], [3], [4], who might lead to already-made crack detection (inside the crystallizing apparatus) and damaged goods. Currently used methods do not entirely eliminate the cracks; they are effective only if some features are being accomplished (crack detection at both exits of the crystallizing apparatus, a pretty slow phenomenon feature as far as the cracking correction is concerned etc.).

In [5], [7], we have proposed a number of original solutions allowing the complete crack elimination from the cast material, outside the crystallizing apparatus. Therefore, we have designed a neural network [5] allowing us to detect any primary crack, by a thorough predictive analysis of the information received from a thermo-couple matrix. Information is used by a system bazed on fuzzy logics [7], who enables corrections of the casting speed and of the cooling water flow. Since this method does not lead to a complete crack eliminations (although specialized literature refers to correcting the casting speed alone, in addition to that we have proposed to change the cooling water flow as well), we have adopted a new predictive principle who diminishes any possible cracking. Thus, the fuzzy system [7] analyzes a number of characteristic measurements and, although the neural network [5] has not yet acknowledged any crack, but it considers they may occur, they perform casting speed corrections and cooling water flow occur. Certainly, the solution we have proposed also implies a more complex fuzzy controller, using two sets of distinct set of rules [7].

We consider that using such a double prediction and detection principle the cast material should not suffer any cracks when leaving the crystallizing apparatus. For the moment, this presumption is based on the analysis of the crust solidification, a process based on the mathematical method we have already established (we have analyzed it using a set of rule base) and according to some partial tests made with the real continuous casting installation.

2 Control method of continuous casting process

For implementing crack prediction, detection, and elimination system of the cast material when leaving the crystallizing apparatus, we have considered the following aspects: it should be implemented for any type of continuous casting installation, conventionally automatic, without essentially changing the original management system; we should be able to switch to the original management method any time; based on the working analysis of the system on a real installation, we should be able to make any correction of the sets of rules so that we should consider some particular features of the process itself and of the real results.

All those conditions should be followed when implementing the system we propose.

Figure 1 describes the block design of a control system of the continuous casting we use in S.C. Arcelor Mittal S.A. Hunedoara. This sort of design is currently used for almost all modern continuous casting plants and we have already described it in [6]. Considering this situation, we have highlighted (red line) the additional blocks for implementing the fuzzy neural system for predicting, detecting, and eliminating any cracks of the cast material when leaving the crystallizing apparatus.

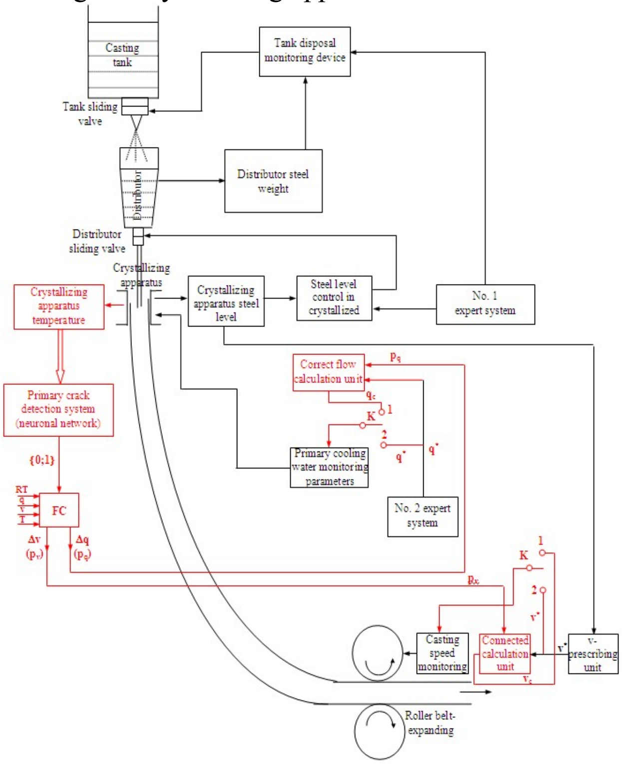


Figure 1. Control method of continuous casting process

We see in figure 1 that the two fuzzy systems exits (speed correction p_v and cooling water flow p_q) have values between 0 and 1; it is used for required value calculation blocks when correcting the speed (v_c) and water flow (q_c), which is applied to parameter control systems that already function inside the installation. Thus, such values should replace both v^* and q^* values required by the two control loops [6], [8].

We should be able to switch between the upgraded system using the solution we have proposed and the original management system, and hence we have introduced two contact devices - K_1 and K_2 - we could mount on 1 or on 2.

3 System simulation in Matlab-Simulink

A. System Description

To review the functioning of all neural and fuzzy systems, we carry out the simulation in a Matlab-Simulink environment. Implementation of the solutions is given in figure 2.

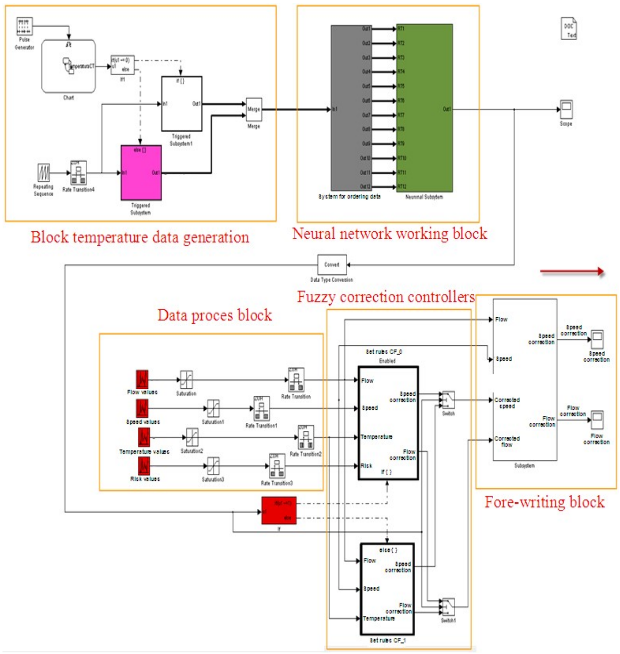


Figure 2. System implementation in Matlab-Simulink

It is noted that the proposed changes do not affect the existing plant automation: each have an additive character and pass from one regime to another easily. This is a requirement imposed by all recipients, for economic reasons and plant safety. Such applications broaden the scope out of the solution proposed to eliminate cracks in continuous casting.

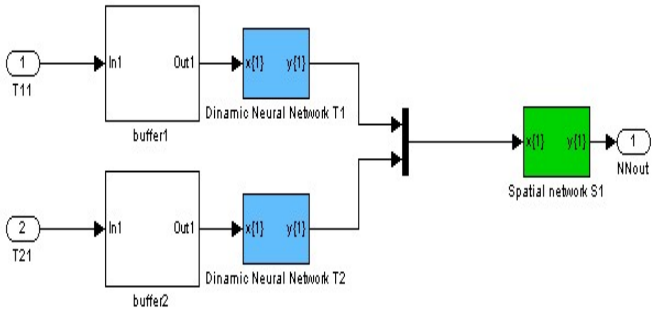


Figure 3. Connecting two dynamic networks to space network for data processing from two thermocouples

It can be grafted on a plant and with minimal costs. Except for the temperatures inside the crystallizing apparatus (thermocouples matrix), the remaining quantities they use as fuzzy system input data are taken from transducers that already exist in all practical schemes. Usually, some are digital transducers, other high precision analogue devices. Technological risk (TR) is determined by the technician, depending on the type ofsteel that is poured and inserted when the steel is changed (usually every few days or less).

Block temperature data generation

In principle, we used recordings of the unfolding process. The best solution is to use two separate sets, one normal and one in case there is a crack.

To switch between the two sets of data, we use a switch - control implemented in Simulink-Stateflow. Depending on a given parameter to the entry of this block, it switches between the two sets of data (1 - with crack, 0 – no cracks). Block "CT Temperature" operate successively (every 120 s), the data "0" or "1", which basically makes the crack to occur or not

All data are memorized in „look-up data" tables.

Neural data processing block

We are able to identify any crack if using data received from the 48 thermocouples mounted in 12 rows and 4 columns (on one side of the crystallizing apparatus). Considering the apparatus has 4 sides, there are 192 thermocouples. Since all phenomenons are identical for each side, we analyze one side and one side only. For each thermocouple, a dynamic neural network processes 10 consecutive temperature values. Any data received from a dynamic network is then processed by a space network who analyzes the values received from the two thermocouples mounted successively (along the casting direction), and it produces 11 space networks for a column. The input size value of such space networks (0 or 1) is introduced into a logical SAU (OR) block [8], [9].

Figure 3 describes the connection amongst two dynamic networks and of a space network for data processing from two thermocouples mounted on successive rows. According to the results of the logical SAU operation (we have analyzed 44 output values of the space networks), when leaving the neural block we get a 0-value (there is no primary crack), and an 1-value (there is a primary crack).

Fuzzy System

According to the value of the output value of the neural network, fuzzy system starts two different base sets: a corresponding base in case there are no cracks for „0" (113 rules), and a corresponding base in case there are some primary cracks (37 rules) [7]. The first set has four entries (casting speed, primary cooling water flow, distributor temperature, and technological risk). They are all read from the process (in real situations). We have used the „Process data block" to simulate it. The „technological risk" parameter is not necessary for the second set of rules, because its value is the highest since we have already detected some cracks. The two outputs of the fuzzy system (p_v - correction of speed, and p_q - correction of flow), are used for the limitation block [7]. Figure 4 describes the implementation of fuzzy system "0", and in figure 5 we describe the implementation of fuzzy system "1" in the environment Matlab/Simulink.

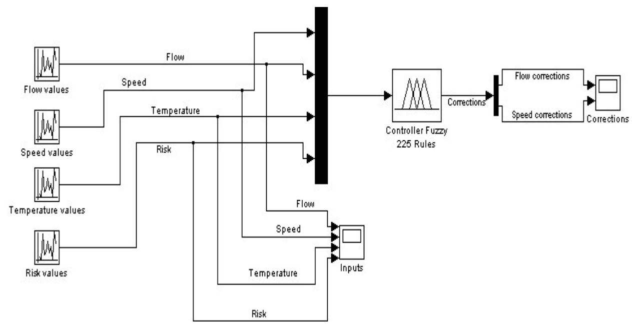


Figure 4. Implementation in Simulink to fuzzy system with basic rules "0"

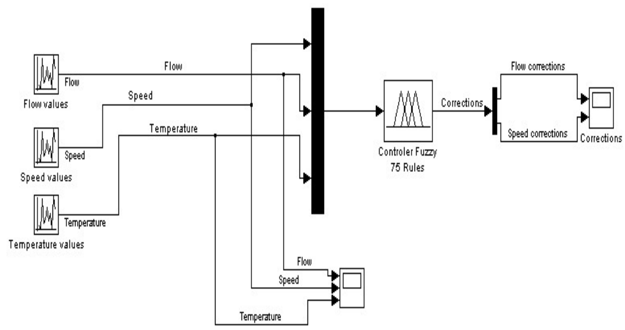
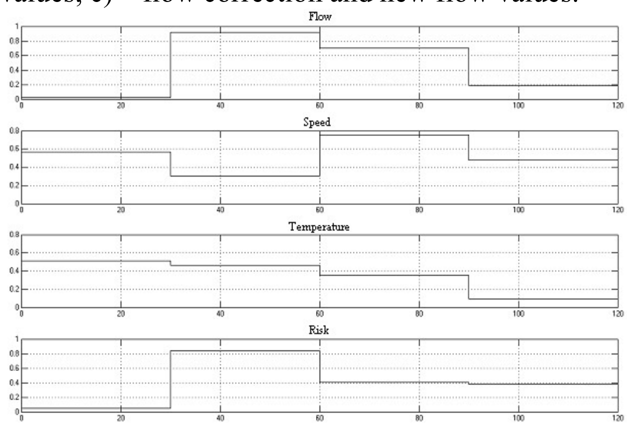


Figure 5. Simulink implementation of the fuzzy system with basic rules "1"

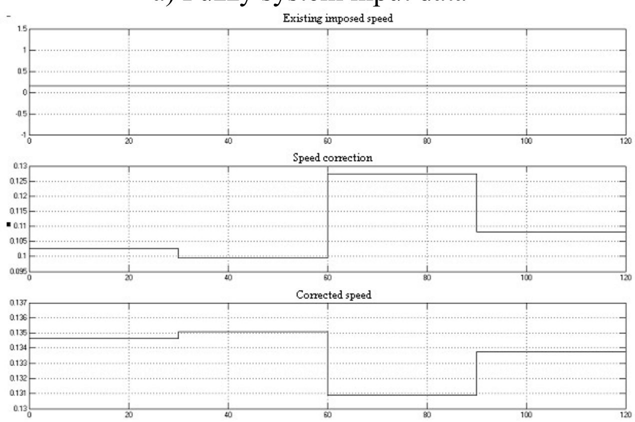
Block prescribing
Block prescribing is replacing the values required for speed and flow (v *, q *), from the installation of automation existing in their new corrected values v_c, q_c), resulting in fuzzy system outputs. For simulation, the values v * and q * were considered equal to those measured sizes of the process (from "Block data processing").

B. Validation of simulated system operation
For validation of simulated system operation, for the entry crack-detention neural network we have applied two different sets of data measured during the current process and stored in tables. One of the sets refers to the situation when there are no cracks and the other one in case there is a crack. Neural network outputs reach 0 and 1 value and they show the network works correctly and it has detected the crack (in case they occur).

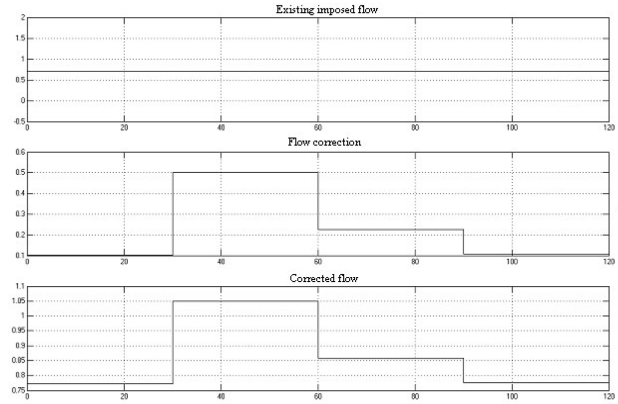
For each of the two cases generated at fuzzy system input, there are several input values (flow, speed, temperature, risk – if the neural network has produced a „0" output – there are no cracks or flow, speed, temperature; - if the neural network has produced a "1" output value – there are primary cracks). These values are described in figure 6 and 7: a) – time variation (120 seconds) of fuzzy system input values; b) – speed correction and new speed values; c) – flow correction and new flow values.



a) Fuzzy system input data

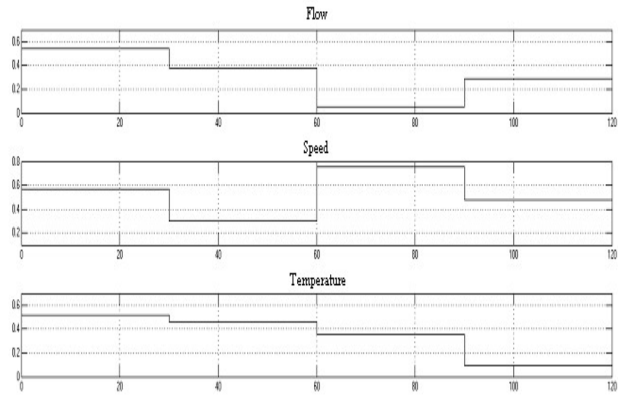


b) Output data – speed

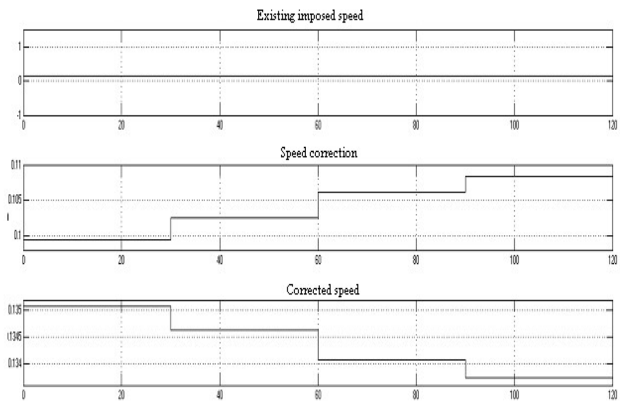


c) Output data - flow
Figure 6. Fuzzy system validation (RN=0)

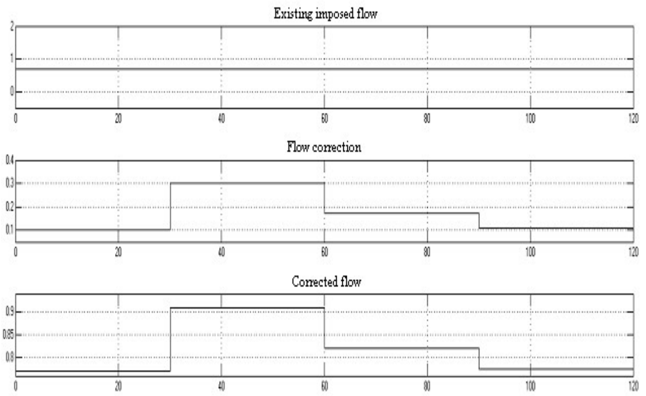
Figure 6 describes the situation during the first 30 simulation seconds, when the cooling water flow is low, the casting speed is low, the temperature inside the crystallizing apparatus is high, and the technological risk is low. Speed correction is very low, hence required casting speed is almost unchanged. During the next simulation 30 seconds, the technological risk increases, the fuzzy controller causes speed correction, and also avoids any crack (casting speed decreases). During the whole time, cooling water flow increases significantly. We can see that the other two simulation rounds are similar.



a) Fuzzy system input data



b) Output data – speed



c) Output data - flow

Figure 7. Fuzzy system validation (RN = 1)

In figure 7 we see that when a crack has already been detected, all measures required by the fuzzy controller are more energical, for the crack should be eliminated. Thus, in a 60-90 seconds range, when generated values show a high casting speed, the required speed decreases compared to the 0-30 seconds range, and the cooling water increases. In such case, cracks are easily eliminated.

When analyzing all cases described in figure 6 and 7, we draw the following conclusions:

- fuzzy system analyzes the input values and elaborates speed corrections and water flow correctly, according to two base sets connected to each output of the neural network;

- fore-writing block corrects all required values for speed and flow, according to fuzzy system outputs.

By simulating in Matlab-Simulink, we have proved that all solutions are correct – predicting, detecting, and eliminating any crack during continuous casting. Such simulation is made for performing a check out on the fuzzy system. During operation, all size values do not change so fast, hence some input values combinations are not that predictable. Once the system is implemented, the rules referring to such situations could be eliminated.

4 Conclusion

Starting from the structure of a control system in a modern continuous casting installation which already works, we propose an implementation method of the cracks prediction, detection, and elimination system form the cast half-product. This product encloses a neural network as the main element for crack detection, as well as a fuzzy controller which enables corrections using all process data. Such corrections correspond to casting speed and primary cooling water flow, made for crack elimination. The implementation itself is possible – with insignificant corrections – on any working installation, with low costs. Costs depreciation is possible within a few months, if eliminating casting defects.

We have performed a Matlab-Simulink simulation of the entire fuzzy neural system. Considering this aspect, we have designed the simulation design and designed input sign generators, a neural network, a fuzzy regulator, and the fore-writing block for speed and flow values. When using this method, we have been able to use several input data sets, and the design has correctly generated all output values, acknowledging the whole system.

Acknowledgment

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