Neurocomputing 125 (2014) 236–245

Contents lists available at ScienceDirect

Neurocomputing

journal homepage: www.elsevier.com/locate/neucom

Adaptive control system for continuous steel casting based on neural networks and fuzzy logic

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ARTICLE INFO

Article history:
Received 19 February 2012
Received in revised form
17 September 2012
Accepted 19 November 2012
Available online 22 June 2013

Keywords:
Neural networks
Fuzzy logic
Continuous casting
Cracks
Adaptive control system

ABSTRACT

The present paper describes a neural network-based strategy for crack prediction aimed at improving the steel-casting process performance by decreasing the number of crack-generated failure cases. A neural system to estimate crack detection probability has been designed, implemented, tested and integrated into an adaptive control system. The neural system, consisting of two distinct neural networks, provides 0 or 1 probability values (1—high probability of crack occurrence, 0—low probability of crack occurrence). Also, a decision block, based on fuzzy logic (implementing an expert system), has been designed and implemented, triggering one or the other specific set of rules (according to 0 or 1 value of neural system) and tuning the set point of the control system.

1. Introduction

The unprecedented advancement of information technologies, the ever-increasing complexity of the controlled process, and the stringent necessity of reaching better quality indicators for the controlled process, have imposed neural network-based control strategies (often in combination with fuzzy logic) as enhanced solutions for industrial applications. The human brain was the inspiration source for the artificial neural networks which try to shape the architecture and functionalities of a biological neural network.

Most usages of neural network-based solutions are justified by the simplified and reduced development cycle, easy implementation and the performances achieved.

The paper presents a neural network-based control strategy for the steel casting process, specific for the complex metallurgic industry domain.

There are several approaches regarding this issue in the reference literature. They are generally theoretical and are not implemented in the actual control of a continuous casting process. Therefore, they do not offer enough accuracy and safety in functioning. Thus, Adamy [1] presents a fuzzy-logic-based system for the detection of fissures. The system does not use a mathematical model that analyzes the solidification phenomenon, but resorts only to a set of rules established by technologists. There are no data related to the testing or practical application of the suggested method. In [2] the authors propose a fuzzy system capable of analyzing in real time the signals received from a fissure diagnosis system and of controlling the casting rate. The solution is not very safe, false alarms are often generated. In [3,4] a set of thermocouples measuring the temperature variation of the semi-finished part is used. The solution given by the authors is realistic and stands as a basis for the detection principle used in the paper, but the way in which the thermocouples are located does not allow the detection of all fissures. Based on a neural network, in [5,6] a structure of a fissure detection system is designed, but just like in the preceding cases, few data are given concerning the possible experiments or industrial testing. Some of the reviews carried out in [7,8] discuss about a method designed to implement a fissure detection structure inside the mold of a complex continuous casting installation. The information related to the fissure elimination is scarce and brings no novelty in this domain. In [9] a neural network for the detection of fissures is developed, but the structure of the network is not detailed enough and neither the way in which the detection is performed; moreover, there is no reference to the practical steps to be taken.

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http://dx.doi.org/10.1016/j.neucom.2012.11.052

The means of crack detection based on temperature variation in the mold shown in some articles is basically correct, but the efficiency of the detection depends on: the type of the sensor matrix, the structure of the neural network analyzing the information received and the adopted strategy [4,8,9]. For instance, in case of a crack, the modification of the casting rate only (as shown in the reference literature) leads to output losses and does not guarantee the elimination of all the cracks arisen (if they appear in the lower part of the mold) [2,9].

In the process of continuous casting, the molten steel in the ladle flows through the tundish into the mold. The steel enters the upper part under precise conditions of temperature and flow rate, while at the bottom, the semi-finished part, having a solidified crust and a liquid core is extracted at a constant rate. Because of the direct contact between the molten metal and the water-cooled mold, the heat transfer is swift and a thin crust appears; one of the major problems that is likely to arise at this stage of the technological flux is the fact that this crust may crack (Fig. 1a).

According to the oscillation cycle of the mold and the casting direction, the crack extends downwards and cross-sectionally at a lower rate than the casting one (Fig. 1b). When the crack reaches the lower part of the mold (at the exit nozzle of the mold), the semi-finished part is broken (Fig. 2). The molten steel inside the semi-finished part flows out and the continuous casting process has to be halted [8,11,12].

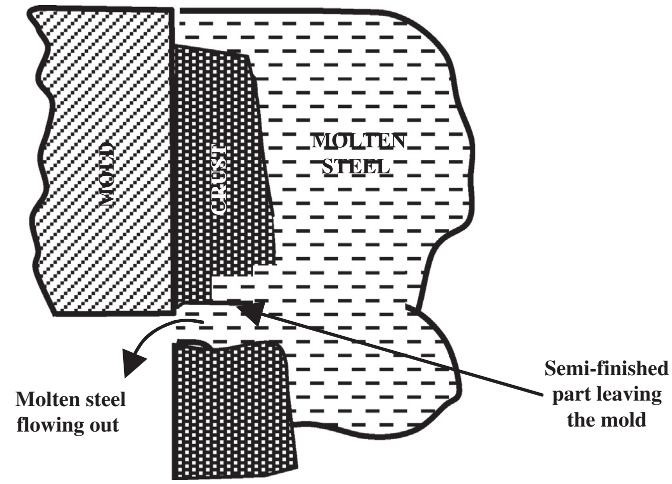

Fig. 2. Breaking of the semi-finished part and out flowing of the molten steel.

2. The architecture of the crack-detection neural system

During the continuous casting technological process, the steel solidification starts inside the mold with the formation of an exterior solid crust. The crust can crack, leading to a major problem. On leaving the mold at the cracked point, the molten steel flows out and pierces it. Such incidents have to be prevented by detecting cracks and by modifying the cooling pattern and casting rate, in order to allow steel solidification and crack elimination [12,13].

In case of a crack occurrence, the steel inside the mold that is not solidified yet comes into contact with its wall and generates an abrupt temperature increase. Starting from this, a crack detection system can be developed by mounting temperature sensors on the mold wall (Fig. 3); their signals are analyzed by a multi-neural system (Fig. 4). It processes the data input of the temperature sensors and the output will be the message of crack occurrence or non-occurrence [14].

Fig. 3 shows the diagram of the temperature sensors positioning on the wall of the mold.

The phenomenon of crack appearance is characterized, on the one hand by the temperature variation registered by each sensor on the mold wall and, on the other hand, by its spatial distribution inside the mold. In order to develop an efficient control system, both the temperature variation and its spatial distribution must be accurately measured and/or calculated [10,15]. An adequate interpretation of these data can be used to estimate the probability of crack occurrence. This goal can be achieved by using a neural network-based algorithm. For the case study in question, a neural model was designed and trained, integrating two neural networks, each with a specific goal [16,17]:

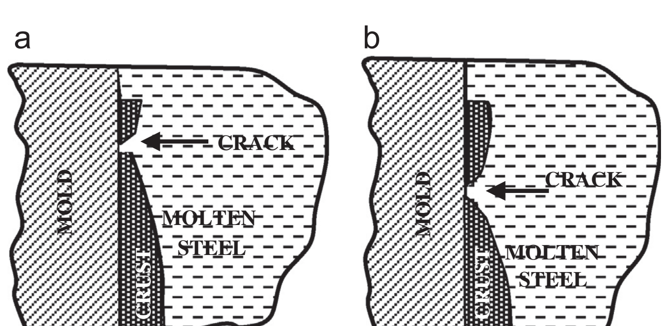

Fig. 1. Semi-finished part crust cracking: (a) crack at initial stage and (b) crack extending towards the mold exit nozzle.

– A dynamic serial network (DSN) analyzing the point temperature variation (whose inputs are the temperature variation from each individual sensor mounted on the mold wall, considering a serial arrangement of the temperature sensors).
– A spatial network (SN) analyzing the spatial distribution of the temperature (whose inputs are the outputs of two dynamic networks, corresponding to each pair of adjacent sensors on the same row).
  The design of crack detection system based on neural networks starting from the structure of the temperature sensors network located on the wall of the mold (see Fig. 3, showing a structure with 12 lines $\times$ 4 sensors/line$=$48 temperature sensors). As well as, the architecture of this neural system (Fig. 4) takes into account two functional targets:
– The detection of a temperature variation at a certain point, practically the temperature shown by a sensor.
– The detection of a temperature variation at a line of sensors level (the crack occurring at the level of an entire line and leading to the breaking of the flow). Unlike other algorithms, the paper proposes a technique to supervise the temperature distribution and variation on a horizontal line of sensors (considering pairs of two adjacent sensors located on a line), which decreases the number of sensors required and simplifies the neural system structure, therefore reducing the computational time.

Based on multiple tests, it was concluded that the measuring of the temperature variation at one single point (sensor) is not sufficiently relevant to predict a crack occurrence, leading to many false alarms. For this reason, additional monitoring of the temperature variations between adjacent sensors on a horizontal line significantly improves the detection sensitivity, substantially reducing the number of false alarms.

Based on these considerations and conclusions, as a first requirement, 48 dynamic serial networks (DSN) are needed (one for each measurement point, so for each temperature sensor). All these 48 DSN are structurally identical and have a similar functionality: the detection of temperature variation at a point level of