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Fault Detection and Diagnosis of Steel Refining Process Based on Multi Neural Network

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Abstract: For steel refining process some of parameters are very critical and can induce to a loss of production by the need of additional corrections in the shape of reblowing. Among these parameters: carbon and manganese contents, temperature of the final product. In order to monitor such a system, we propose a multi neural network based fault detection and diagnosis scheme. A serial/parallel homogeneous configuration is adopted as the basic structure of the detection system. The first stage allows the classification of the sample according to the nature of the steel nuance to be produced while the second stage of the network allows the identification of the volume of oxygen necessary to fusion and will be used as an input for the last stage witch detect and diagnoses the faults. The simulation results illustrated that after training of the neural networks, the system is successfully detects and diagnoses the different failures.

Key words: Fault detection and diagnosis, multi neural network, Radial Basis Function (RBF) neural network, refining process

INTRODUCTION

In the pure oxygen with a vertical spear refining process, obtaining the chemical composition and the desired temperature in the final product, once the blowing process has been achieved, requires an efficient control of the fusion; all of which must result from a concise mathematical model capable of representing the real process dynamic behaviour in a reliable way.

Usually, this type of control is based on a series of chemical composition and temperature measurements taken from a set of samples extracted from the metal before its treatment, at its initial state and from the slag. However these measurements are only accessible once the blowing operation has been made and the converter returned to its initial position.

The length of these operations, namely the temperature measurement and the chemical analysis sample taking, are preponderant factors in the production process; they cause delays with a decrease in the rate of productivity of the fusion mechanism. A second factor which itself represents a major interest in the improvement of this process is the visual monitoring of fusion in the oxygen converter. It is based on eye witness indices: Flame length and colour, smoke colour and density, converter noise, blowing time and total oxygen consumption.

Nevertheless these factors do not determine the end of the fusion in an optimal way. In forty to seventy percent of fusion cases, additional corrections are needed in the shape of reblowing, cooling, carburations or remagnetisation. We observe that the mostly used metal reblowing operation provokes a delay in fusion obtention and the mixing of costly additives such us coke, ferro-alloys, lime….

In order to remedy all these technological and instrumental inconvenients we are going to elaborate a system of detection and diagnosis of the parametric defects (carbon and manganese steel contents and steel temperature recordings).

This will enable us to fix the blowing time within the allowed concentrations limits. It will be done for steel refining process at the oxygen steel mill N°1, MITTAL STEEL Annaba-algerie, by the multi neural network approach.

In the present work, we propose a serial/parallel multi neural network homogeneous configuration based on a set of radial basis function network to solve this problem. The results of diagnosis obtained on the steel refining process are presented.

STEEL MANUFACTURING PROCESS OUT OF CONVERTER

According to the type of constraints (chemical composition), the nature of the requirements (good quality), the cost of establishment, one distinguishes several steel manufacturing process. In general, the steel

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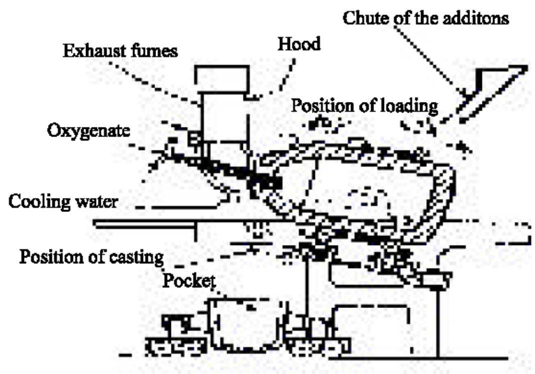

Fig. 1: Representation of LD converter

manufacturing process arises under one of the following forms: Manufacturing process out of converter, manufacturing process out of hearth, manufacturing process out of electric furnace[1].

The principle of the refining of iron in the converter consists to oxidize and eliminate the carbon "C", the silicon "SI", the manganese "Mn" and the phosphorus "P" contained in the cast iron by the use of the oxygen contained in the air; at the same time, the temperature of the liquid cast iron increases under the effect of the heat which emerges starting from the oxidation reactions, so that the cast iron is transformed into steel without having to use fuels. For the manufacturing process of steel out of converter, one recognizes the following categories: Process of blowing by the bottom of the converter, Oxygen converter pure by the top.

In our case one has recourse to a converter of pure oxygen blowing by the top (LD Process) whose principal characteristic comes from the nature of the oxygen used for refining; it is about a pure oxygen with 99.5% which passes in a pipe water-cooled to be puffed up in the cast iron by the top of the converter. The blowing of pure oxygen allowed eliminating all the disadvantages relating to blowing by the bottom, namely:

- More restriction on the chemical composition of the cast iron.(However, it is preferable that the phosphorus content is lower than 0.4%).
- The possibilities of using scrap are considerably wide (up to 30%).
- The nitrogen content is lower than that of steel with blowing by the bottom.

Presentation of oxygen steel mill N°1: The oxygen steel mill N°1 is a part of MITTAL STEEL, established in the south of the hot rolling mill of which it ensures the slab supply. It is conceived to produce 1.360.000 of molten steel per year what is equivalent to (1.300.000 tons). Let us note that the capacity of the unit is calculated for a rate of exploitation of 8000hours/year.

The unit comprises three converters with an identical capacity (85 to 90 tons), operative in a mode two converters in service, one in stand bye. The duration of a production cycle is forty minutes.

For the continuous casting machine it has comprises radial machines whose capacities remains function of the periodicity of sequential casting, taking into account the exploitation of both type of machines, it is envisaged a rated capacity de (1.300.000) ton of slabs per year.

The mechanism of continuous casting requires that produced steel be entirely calmed.

The slabs run uninterrupted are transformed to meet the following needs:

- Heavy sheet hot-rolled construction
- Hot-rolled crowns, sheet and remitted reels
- Tubes welded in spiral
- Wrapped reels die, cold rolled sheets and crowns sheets and reels.
- Galvanized Crowns tinplate.
- Remitted Crowns, sheets, reels and cold rolled and galvanized corrugated sheets.

The worked out nuances with low and average percentage of carbon, are intended for the manufacture of reinforcing bars, wire machine Table 1 shows the various nuances of produced steel

Production cycle: The pure oxygen with a vertical spear refining process includes successively the following operations: charging of the matters, blowing (in the event of need, we can resort to a reblowing), temperature measurement and test sample selection of metal and slag and finally casting of steel with addition of ferro-alloys in the pocket. After the charging of scrap, one pours the liquid cast iron of which the quantity is practically always equal 53 tons. These operations are made with the position inclined on the horizontal one of the converter, with the iron notch is clearly released.

Once the raised converter, in driving position, one reduces the lance to high from 1500 millimetres to the top from the metal bath in order to form the slag (slag) first moments of blowing. After three (03) minutes one adds on average two tons of lime and a quantity of iron ore not exceeding it half thunders. The quantity of lime to be charged in the converter is calculated according to the silicon content in the liquid cast iron.

To improve the conditions of elimination of manganese, we added limestone by portion from 400 to 700 kilogram's with intervals of two minutes as from the tenth minute of blowing. In the event of overheating, one cools the metal bath at the end of the conversion using limestone or iron ore (0.4 to 0.8 tons).

Table 1: Steels Chemical composition in the oxygen steel mill N°1

	Chemical composition of steel					
Moderate	% C	% Mn	% SI	% S	% P	% Al
A10A	0.08÷0.12	0.35÷0.45	0÷0.03	0÷0.02	0÷0.02	0.02÷0.08
A5	0.01÷0.05	0.15÷0.30	0.01÷0.05	0÷0.02	0÷0.025	0.02÷0.08
A7	0.01÷0.07	0.20÷0.40	0÷0.05	0÷0.02	0÷0.02	0.02÷0.08
A9	0.07÷0.11	0.25÷0.45	0.01÷0.05	0÷0.025	0÷0.025	0.02÷0.08
C11A	0.07÷0.13	0.25÷0.60	0.10÷0.30	0÷0.035	0÷0.030	0.02÷0.08
C11B	0.01÷0.10	0.25÷0.50	0.01÷0.10	0÷0.025	0÷0.025	0.02÷0.08
MV10	0.08÷0.14	1.30÷1.50	0.10÷0.20	0÷0.016	0÷0.02	0.02÷0.08
RB40	0.22÷0.28	1.20÷1.35	0.20÷0.30	0	0	0
ST37	0.08÷0.15	0.30÷0.60	0÷0.03	0÷0.02	0÷0.035	0.02÷0.07

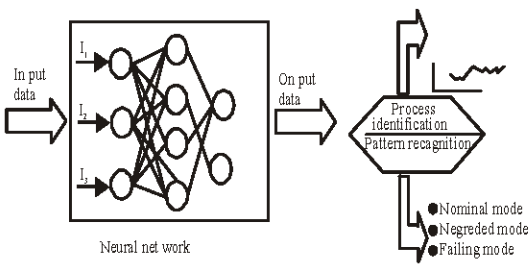

Fig. 2: Application of the neural network in monitoring of industrial plants

During refining, the oxidation of the elements of the metal bath depends on their affinity for oxygen. Silica formed is quickly neutralized by the lime of the slag, manganese after its passage in the slag returns in metal with the increase in the temperature. If the temperature is an obstacle for the oxidation of manganese, it is the principal catalyst in the oxidation of carbon.

The speed of decarburization slows down only at the end of the fusion when the percentage of carbon is very weak. The oxidation of phosphorus and the elimination of sulphur do not raise any difficulty considering their starting concentration (< 0.035%).

In our case the stop of blowing is based on a certain number of observations such as the noise, the flame colour and length and particularly the total flow of oxygen.

Once arrived of oxygen stopped and launches it released, we folds back the converter backwards, we measure the temperature and we take samples of metal and slag. A reblowing is carried out in the case where the chemical composition of metal exceeds the contents envisaged or if the temperature is lowers than that of cast (in this last case we mixed unquestionable quantity of ferro-silicon).The casting of metal is done in steel pockets with, at the same time of the additions for deoxidation.

FAULT DETECTION AND DIAGNOSIS USING NEURAL NETWORKS

The techniques of monitoring containing neural network are founded on the existence of a database of training and not on the existence of a formal model of the equipment. The idea of such approach is summarized as follows: Having a whole of data at the entry of the network let us seek an answer whose parameters are only the estimated parameters of the variables of monitoring, or a representation of the operating condition of the equipment. In is interested in the second description and in this case the problem of monitoring will be regarded as a problem of pattern recognition, such as the classes correspond to the various modes of failures of the system and the forms represent the whole of the measured observations.

Multi neural network architecture: Through the preceding section we have shown that the approach of neural network is one of the very powerful tools that have been explored for fault detection and diagnosis problems because of their properties previously quoted. However they present in some cases, a limited successes because of their complexity (large number of neurons and long learning process)[2]. In order to deal with these disadvantages we propose to study and implement a new approach known as multi neural network approach which take advantage simultaneously from each neuron structure and having the advantage to permits us to limit classification errors.

Multi neural network is an effective method in parameters-varying and nonlinear process[3]. The basic idea is to represent a non linear dynamical system by a set of locally valid sub model.

Two typical structures of a multi models are shown in Fig.3 and 4. Where the first is a serial multi MNN homogenous composed by two stages combining a RBF based classifier with a second RBF decision classification stage. In this case we train the first RBF and then its outputs constitute the learning database of the second one.

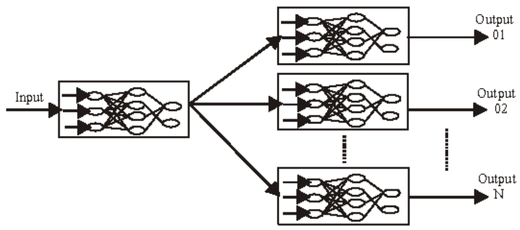

Fig. 3: Serial architecture of multi neural network

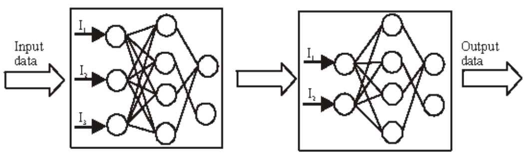

Fig. 4: Serial/parallel architecture of multi neural network

Figure 4 represents the serial/parallel multi neural network homogenous structure. Where the RBF disposed in parallel is used as decision stage. The first network is used as preliminary stage of classification or assignment for each new vector arising at the entry with the one networks structured in parallel. Also in this case we train the first classifier and its outputs constitute the learning database of each RBF network.

PROBLEMS AND DIAGNOSIS

The rate of success at the end of the blowing represents a significant technical-economic parameter in the chain of steelmaking on the level of the oxygen steel mill N°1. It characterizes the attack in fine blowing of the manganese and carbon contents, the temperature of the desired steel nuance. When the rate is raised, that means that the techniques of development are well controlled and the production cost is low. The weak rate of success involves one or more reblowing whose consequences are:

- Increase in the cycle of development.
- Increase in the rate of ferro-alloys (FeSi, FeMn, Al).
- Increase in rate of the additions scorifying and cooling.
- Wear of the refractory garnishing of the converter.
- On oxidation of metal involving a pollution of finished product.

We note, that all these consequences have a disastrous influence on the cost of the product on the one hand and quality on the other hand. With the steel-works with oxygen, the methods of control of the control of blowing are ineffective; the stop of blowing is given according to the apparent indices such as the length and colour flame, time of blowing and the quantity of oxidation. In more the refining process is also subjected to certain disturbances such as:

Table 2: causes and percentages of reblowing fusions

% of reblowing fusions	Causes of the reblowing
3.5	Carbon excess
1.8	Manganese excess
44.7	Lower temperature

- The systematic cleansing of the liquid cast iron.

The reliability of weighing, weight of the entries such as the cast iron, scrap, matters scarifying and cooling.
The reliability of measuring and the control apparatus of flow and oxygen pressure.
The reliability of the measurement and the position of the lance of blowing.

Under these conditions fusions undergo one or more reblowing with an additional matter. Finally reblowing is a residual operation coming from a bad control of the process production .We observe that the absence of parameters allowing the stop of blowing acts directly on the quality of the productivity as well as the purchase price of the ton of steel.

Data analyze: Before studying the problem of detection and diagnosis of the defects for the refining process, we must give an outline on the training database. For the refining strategy, the quantity of charged cast iron is approximately 80 tons, with silicon content from 0.3 to 1.7%. The blowing mode depends on the level of the metal bath and the converter age; generally the height of the lance is fixed between 1300 mm (for decarburization) and 1500 mm (for scorification).

4030 observations (cards of fusion) were collected arbitrarily; each observation corresponds to 12 data with knowing (cast iron(t), (%C, %Mn, %Si, %P, %S, T°) Cast iron, (%C, %Mn, T°) Steel, Gueuese(t), Iron ore (Feo_3) (t), Volume Puffed up O_2 (Nm^3)).All the other parameters are considered fixed (as an example: position of the lance (mode of blowing), age of the converter, oxygen characteristics (purity, pressure and flow), quantities of the lime and limestone ($CaCO_3$) added in the converter.

The most significant parameters for the development of detection and diagnosis system are respectively: carbon and manganese Contents, steel temperature. This choice being justified by the number and the percentage of the reblowing fusions for the 2005 year. Table 2 justifies what we has just stated:

Table 3: Test results

	% C	% Mn	T°
Not classified vectors	52	88	46
Error of generalization	0.000015	0.000302	53.376
% of classification	96.664	94.355	97.049

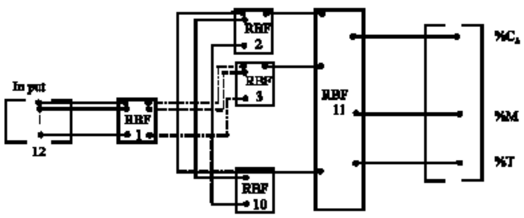

Fig. 5: Network architecture multi-neurons adopted

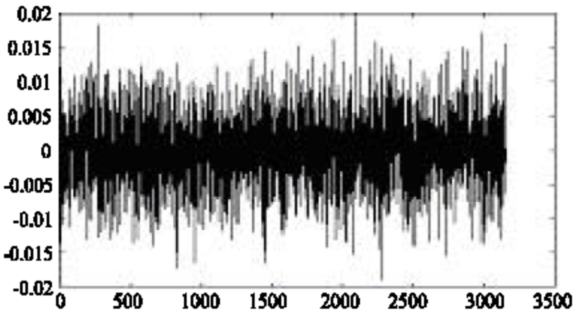

Fig. 6: Training error (Oxygenate)

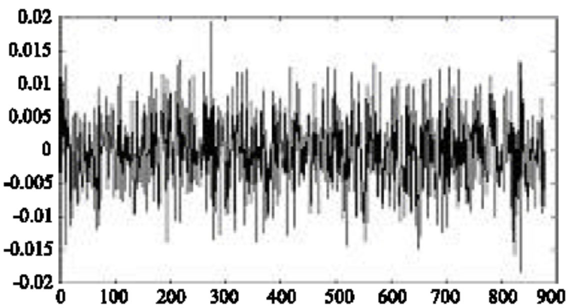

Fig. 7: Validation error (Oxygenate)

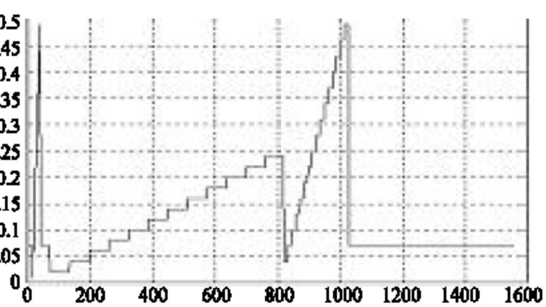

Fig. 8: Real carbone content

RESULTS

Adopted architecture is a multi homogeneous neural network; it is composed of eleven RBF networks arising according to the below architecture.

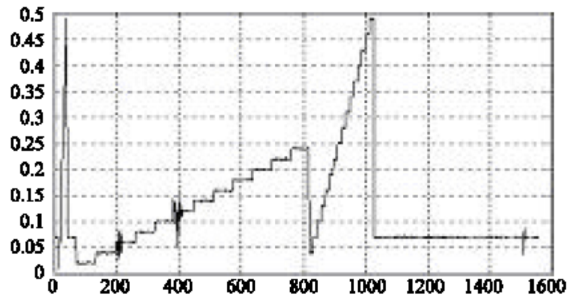

Fig. 9: Estimated carbone content

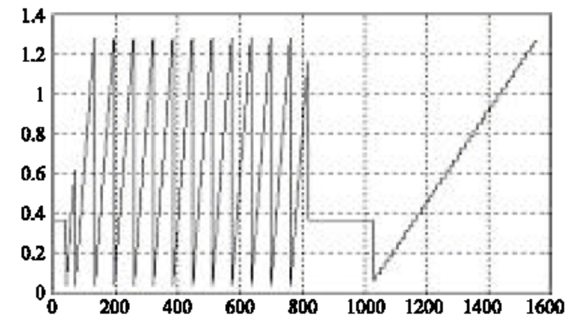

Fig. 10: Real manganese content

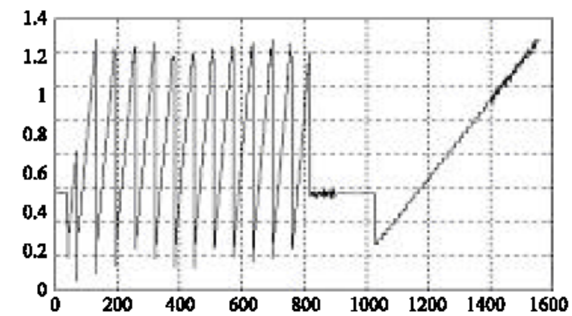

Fig. 11: Estimated manganese content

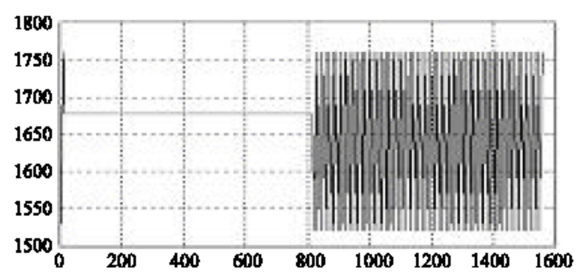

Fig. 12: Real temperature

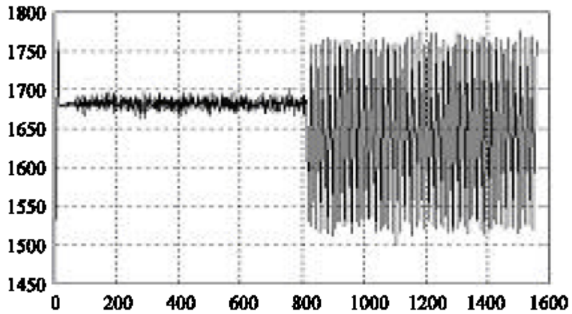

Fig. 13: Estimated temperature

The first network receive an input vector (12 parameters) for each fusion and makes it possible to classify the total base made up of 4030 cast (3150 for the training and 880 for the validation) in nine models distinct according to the steel nuance aimed. The output of each one of these models makes it possible to define the oxygen volume for each casting (vector) and is used as entry for the last networks which allows the monitoring of the parameters (%C, %Mn, T). The Figs 6-12 present the training and validation error, of the volume of puffed up oxygen, the real and estimated values of steel carbon and manganese content, steel Temperature.

After the phase of training, the error of generalization as the percentage of classification for the (1559) vectors composed by total base are presented in Table 3.

CONCLUSION

This study presents a multi homogeneous neural network system based fault detection and diagnosis scheme for parameters failures in a steel refining process (oxygen steel mill N°1 MITTAL STEEL ALGERIA). The adopted configuration is a serial / parallel architecture. The results of simulation proved that the capacity of classification of the systems containing networks is rather excellent. In our case a percentage of (94%÷97%) of vectors constituting the all base were classified in a correct way.

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