ADVANCED CONTROL OF THE AGGLOMERATING PROCESS OF THE FERROUS ORES

Stela Anghel, Nicolae Rusu

The "Politehnica" University of Timişoara, The Engineering Faculty of Hunedoara
5 Revolutiei Str. 331128 Hunedoara, Romania
Tel. +40(0)254 207 500 Fax: +40(0)254 207 501,. e-mail: decan @fih.utt.ro

Abstract: The Process of iron ore agglomeration is highly complex, its productivity and the product quality depending on several factors, some of which having an unpredictable and uncontrollable evolution. For this reason, its mathematical modeling is difficult and the control of the process by classical methods leads to mediocre results.
The paper introduces an expert system, based on the fuzzy logic, which, taking into consideration the experience of some human operators (materialized into a system of rules including all the possible work conditions of the installation), controls the process in such a way that it leads to the best results for a given situation.
The experiments carried out starting from this system lead to a 15% increase in productivity and a reduction of rejects (insufficiently agglomerated material) by 7%. The results can be improved by a continuous improvement of the rule base.

Key words: expert system, ore agglomeration.

1. INTRODUCTION

Of all the methods of iron ore preparation, agglomeration is the most complex one. The physical-chemical phenomena taking place in the layer of ore and additional materials are influenced by a multitude of factors, some uncontrollable, with random variations [1]. This is why mathematical modeling is always imprecise and the classical control methods lead to mediocre results.

One basic parameter is the ferrous mixture vertical rate of sintering, which determines the point of process ending and according to which the sintering belt horizontal advance rate is calculated. At present, the sintering ending point is calculated taking into consideration the temperatures in the last three depression chambers (figure 1) and on condition that the apex of the temperature curve correspond to the last but one depression chamber. The experimentally determined temperature curve [1] looks very much like a parable. A computing system feeds the rotation regulator of the driving motor of the sintering belt with the values needed by the rotation rate in accordance with the measured values t_1, t_2, t_3, and according to a simple algorithm.

This method, extensively used in practice, has a series of disadvantages, among which:

- by controlling the process in accordance with only the temperature measurements in the last three depression chambers, without considering the previous evolution of the sintering

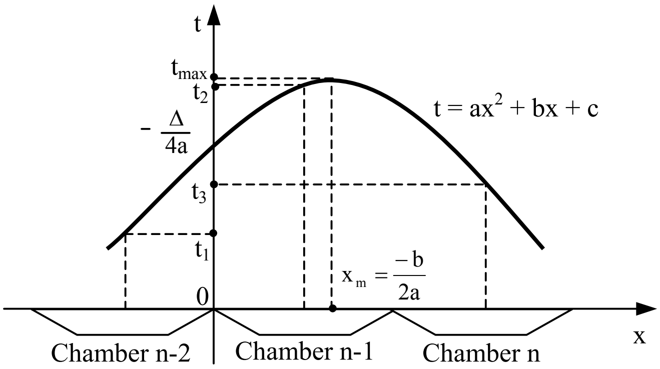

Figure 1

process, the quality of the agglomerate is poor (resulting in a large amount of rejects) and if high quality is aimed at, the productivity is low. Taking into consideration the fact that the process is high energy and raw material consuming, the economical implications are serious;

- the unforeseeable factors, sometimes highly variable, such as moisture, grain size, the chemical composition of the agglomeration mixture, only worsen the output of the process and are hard to mathematically modeling.

In order to obtain a maximum output at a certain quality of the agglomerate, advanced automation of the process is needed.

For the reasons given above, the paper introduces a new method of controlling the agglomeration process, which does not resort to mathematical modeling and which, based on the methods of artificial intelligence, on its real development and on the experience of human experts can lead to best results at a given moment.

In order to apply the method experimentally and draw up the rule base we consulted the best experts and technology specialists of the beneficiary, some of them having many years of practice in the exploitation of agglomeration installations. From the technical point of view, we used two fuzzy controllers (each using a PIC 16C74 microprocessor and the afferent circuits) the existent magnitude transducers and some supplementary ones, the driving system of the belt allowing the rate corrections determined by the expert system.

2. EXPERT SYSTEM FOR THE CONTROL OF THE AGGLOMERATION PROCESS

We suggest the use of an expert system based on the fuzzy logic, whose structure is given in figure 2.

As one can notice, we preserved the classical system of the sintering belt advance correction, based on the temperature analysis of the burned gases in the last three depression chambers and this is illustrated in figure 1. But the value of the advance rate is corrected by the expert system, based on two fuzzy controllers that continuously analyze the values of several magnitudes, as follows:

Fuzzy regulator 1: - Input variables: Temperature in aspiration chamber 11; Temperature in the gas collecting pipe; The ratio of the pressure differences in the last three aspiration chambers $\mathrm{DSlope} = \frac{d_{21} - d_{22}}{d_{20} - d_{21}}$ where d_x – the depression in chamber x

- Output variables: The belt advance rate correction Δv_1

Fuzzy regulator 2: - Input variables: Temperature in aspiration chamber 20; Temperature in aspiration chamber 21; Temperature in aspiration chamber 22

- Output variables: The belt advance rate correction Δv_2

The first fuzzy controller analyzes three magnitudes whose values contain important information on the process development trend, therefore having a predictive character.

The second fuzzy controller analyzes three magnitudes in the final stage of the process, generating the final advance rate correction.

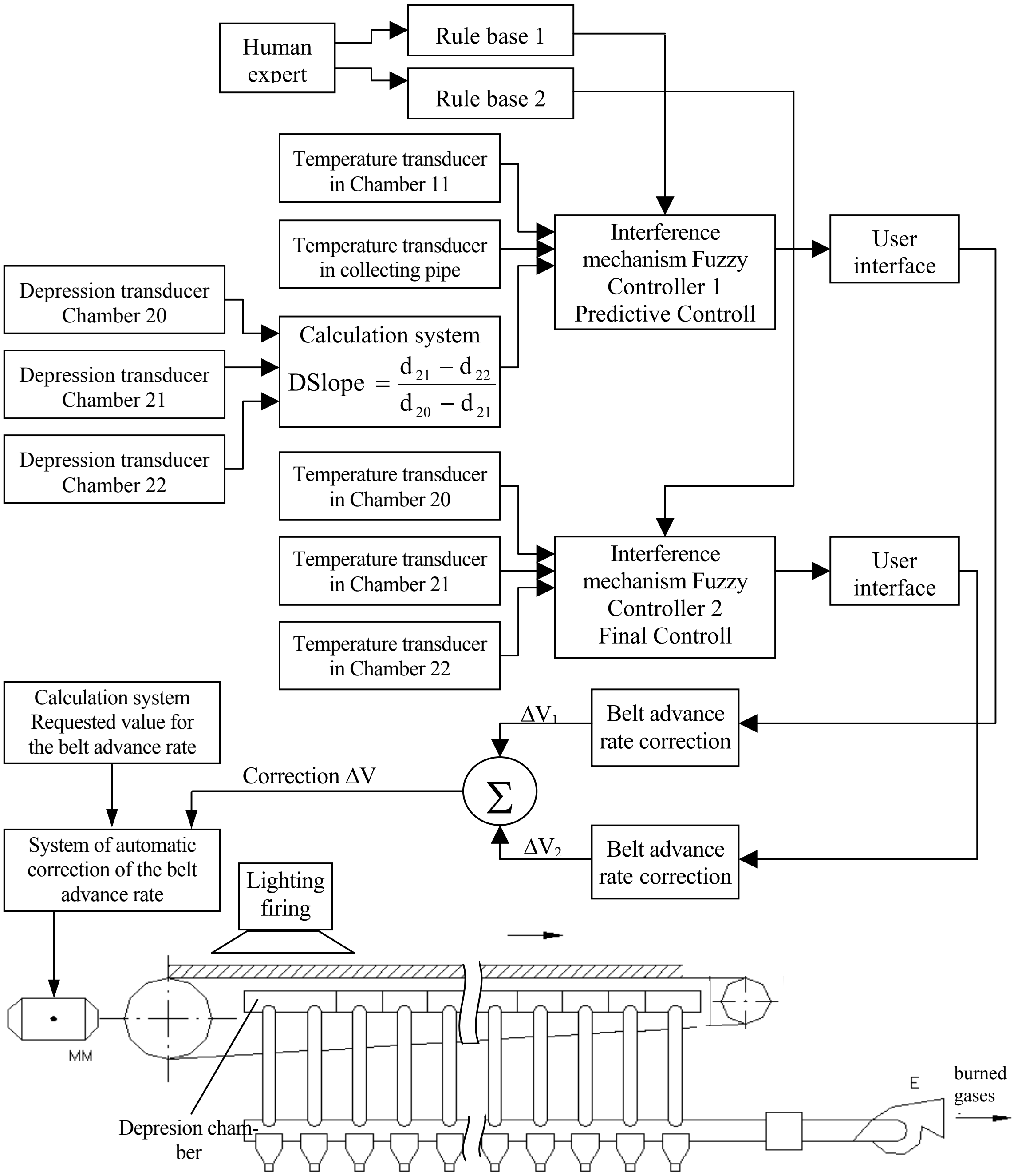

Figure 2. Expert system for the correction of the agglomeration belt advance rate, based on the fuzzy logic

The two advance rate corrections are summed up and applied to the regulator afferent to the classical control system.

In order to draw up the rule base, essential to obtaining high performances, the following technological considerations have to be taken into consideration:

For a high of the agglomeration layer of H_{layer} = 400 mm, the requested advance rate of the agglomeration belt ranges within v = 2 ÷ 2.5 m/min.

The recommended mean temperature for vacuum chamber no. 11 ranges around 55^0C ± 5^0C. If T11 is lower than the requested mean temperature domain, the rate correction is Δv_1 = - 0.1 m/min. If T11 ranges within the requested mean domain, the rate correction is Δv_1 = 0 m/min. If T11 is higher than the requested mean temperature domain, the rate correction is Δv_1 = + 0.1 m/min.

The recommended mean temperature in the collecting pipe ranges around $105^0C \pm 15^0C$. If the temperature of gases in the collecting pipe is lower than the requested domain, the belt advance rate is $\Delta v_1 = -0.1$ m/min. If the temperature of gases in the collecting pipe is within the requested domain, the belt advance rate is $\Delta v_1 = 0$ m/min. If the temperature of gases in the collecting pipe is higher than the requested domain, the belt advance rate is $\Delta v_1 = +0.1$ m/min.

$\Delta = \frac{d_{21} - d_{22}}{d_{20} - d_{21}}$ where $d_{20} = 650$ mm water column, $d_{21} = 600$ mm water column, $d_{22} = 500$ mm water column, are the prescribed values of the depressions in the three vacuum chambers. If $\Delta > 2 \Rightarrow$ the advance rate correction $\Delta v_1 = +0.1$ m/min. If $\Delta \in (1{,}5 \div 2)$ the advance rate correction $\Delta v_1 = 0$ m/min. If $\Delta < 1.5 \Rightarrow$ the advance rate correction $\Delta v_1 = -0.1$ m/ min.

On establishing the rule base for the second fuzzy regulator we took into consideration the following: If T20 < T21 and T20>T22 $\Rightarrow$ the advance rate correction $\Delta v_2 = +0.1$ m/ min. If T20 < T21 and T20=T22 $\Rightarrow$ the advance rate correction $\Delta v_2 = 0$ m/min. If T20 < T21 and T20<T22 $\Rightarrow$ the advance rate correction $\Delta v_2 = -0.1$ m/ min

2.1. The design of Fuzzy regulator 1

1. Information on input magnitudes

T11
(Temperature in vacuum room 11, [^{0}C])
Number of states = 3

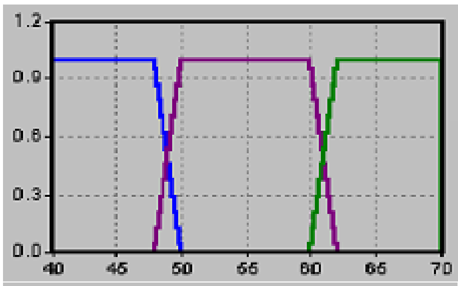

Figure 3. Representation of the affiliation functions for T11

Tcolleting_pipe
(the temperature of gases in the collecting pipe[^{0}C])
Number of states = 3

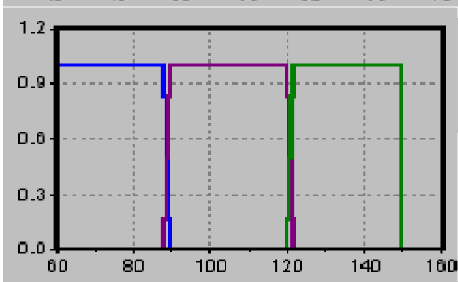

Fig. 4. Representation of the affiliation functions for Tcolleting_pipe

The DSlope
(ration of the depressions in the last three aspiration chambers $\Delta = \frac{d_{21} - d_{22}}{d_{20} - d_{21}}$).
Number of states = 3

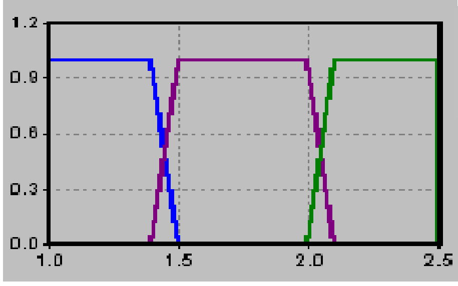

Fig. 5. Representation of the affiliation functions for DSlope

2. Information on the output magnitudes

Correction Δv_1
(the belt advance rate correction, [m/min])

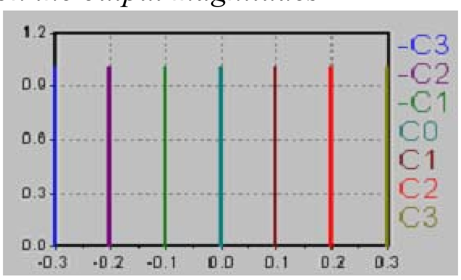

Fig. 6. The representation of the affiliation functions for Correction Δv_1

3. Control rules

For the belt advance rate correction according to temperatures T11, DSlope and Tcollecting_pipe : Number of rules = 3*3*3*1 = 27. Part of these rules are given below:

IF T11 = low AND Tcollecting_pipe = low AND DSlope = low THEN Correction_v1 = -C3 (100%)
IF T11 = low AND Tcollecting_pipe = low AND DSlope = optimal THEN Correction_v1 = -C2 (100%)
IF T11 = low AND Tcollecting_pipe = low AND DSlope = high THEN Correction_v1 = -C1 (100%)
IF T11 = low AND Tcollecting_pipe = optimal AND DSlope = high THEN Correction_v1 = C0 (100%)
IF T11 = low AND Tcollecting_pipe = high AND DSlope = optimal THEN Correction_v1 = C0 (100%)
IF T11 = low AND Tcollecting_pipe = high AND DSlope = high THEN Correction_v1 = C1 (100%)
IF T11 = optimal AND Tcollecting_pipe = low AND DSlope = low THEN Correction_v1 = -C2 (100%)
IF T11 = optimal AND Tcollecting_pipe = low AND DSlope = high THEN Correction_v1 = C0 (100%)
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The shape of a correction surface for a practical case is given in fig. 7

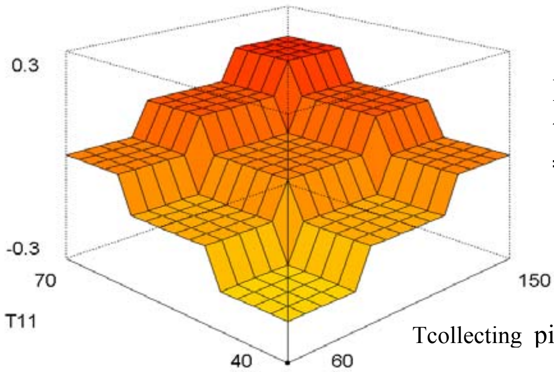

Figure 7. The correction surface of DSlope = 1.75 (optimal)

2.2. The design of Fuzzy regulator 2

1. Information on input magnitudes

T20
(Temperature in vacuum room 20, [^{0}C])
Number of states = 3

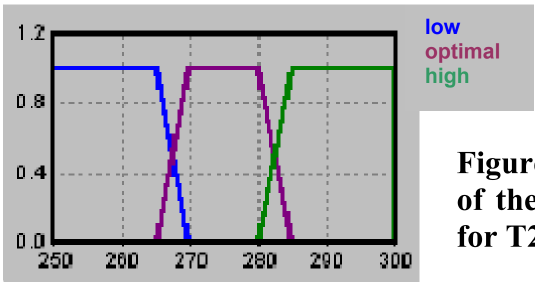

Figure 8. Representation of the affiliation functions for T20

T21
(Temperature in vacuum room 21, [^{0}C])
Number of states = 3

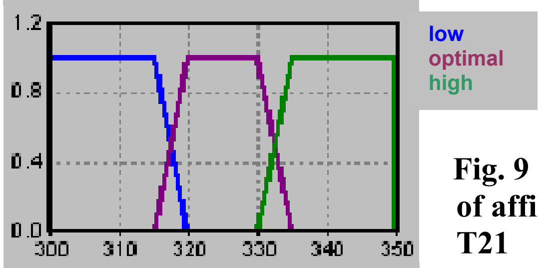

Fig. 9 The representation of affiliation functions for T21

T22
(temperature in vacuum chamber 22, [^{0}C]
Number of states = 3

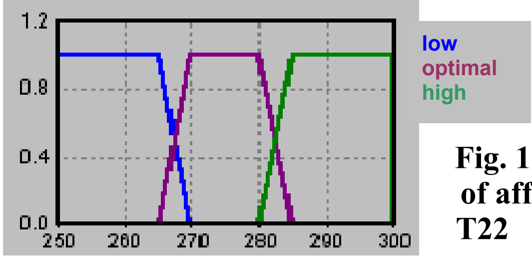

Fig. 10 The representation of affiliation functions for T22

2. Information on the output magnitudes

Correction Δv_2
(the belt advance rate correction, [m/min])

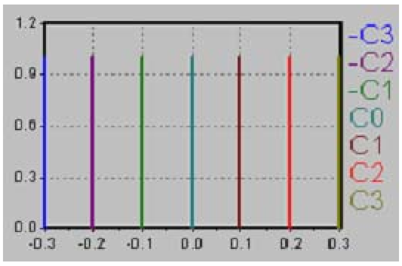

Fig. 11 The representation of affiliation functions for Correction Δv_2

3. Control rules

For the correction of the belt advance rate according to temperatures T20, T21 and T22: Number of rules = 3 * 3 * 3 1 = 27

We give below a few rules as example:

IF T20 = low AND T21 = low AND T22 = low THEN Correction_v2 = -C1 (100%)
IF T20 = low AND T21 = medium AND T22 = low THEN Correction_v2 = C0 (100%)
IF T20 = low AND T21 = medium AND T22 = high THEN Correction_v2 = -C2 (100%)
IF T20 = low AND T21 = high AND T22 = low THEN Correction_v2 = C3 (100%)
IF T20 = low AND T21 = high AND T22 = medium THEN Correction_v2 = C2 (100%)
IF T20 = medium AND T21 = low AND T22 = low THEN Correction_v2 = -C1 (100%)
IF T20 = medium AND T21 = low AND T22 = high THEN Correction_v2 = -C3 (100%)
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The shape of a correction surface for a practical case is given in fig. 12

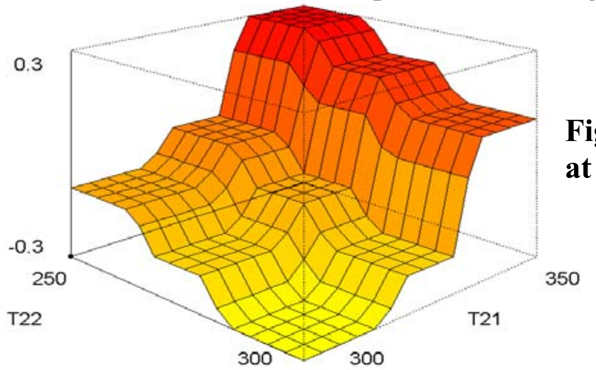

Fig. 12 The correction surface at T20 = 250^{0}C

3. CONCLUSIONS

The expert system presented in the paper, staring from the analysis of a large number of process items of information leads to obtaining higher performances as compared to the classical systems. Thus, its turning into account lead to an increase in productivity of the agglomeration belt by 15% and to a reduction of rejects by 7%. By optimizing the rule base during a longer period of functioning of the installation, these performances can be improved without any extra investment. The conception of the system and that of the rule base are original and can be used in steel making industry for all the installations of ferrous ore agglomeration.

4. REFERENCES

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