15th Triennial World Congress, Barcelona, Spain

CONTROL OF COATING THICKNESS IN A TINPLATE LINE

H. López * A. M. López * G. Ojea * I. Machón * N. de Abajo **
V. Torre **

* *University of Oviedo. Electrical Engineering Department.*
C. Universitario de Viesques, Ed. Departamental Nº.2, 33203, Gijon,
Asturias, Spain.
e-mail: hilario@isa.uniovi.es
** *Centro de Desarrollo Tecnológico.*
Aceralia Corporación Siderúrgica
Avilés, Apdo. 90, 33480, Asturias, Spain
e-mail: nabajom@aceralia.es

Abstract: In a tinplate line the coating thickness can be controlled by means of the line speed and current applied. A control strategy has been developed that calculates the maximum possible speed and the total necessary current, distributing it into the available rectifiers. The equations used for the calculations are based on a mathematical model obtained using Genetic Programming. *Copyright ©'2002' IFAC.*

Keywords: Factory Automation, Industrial Control, Model Based Control, Steel Industry

1. INTRODUCTION

This work is part of the CECA project *Development and Implementation of Intelligent Systems for the Real Time Optimization of Product Quality in Rolling and Process Lines* (de Abajo *et al.*, 2000). This project is part of the continuous effort of Aceralia to achieve the highest standards of quality and customer satisfaction. One of the objectives of the project is the optimization of the thickness of tin coating in a tinplate production line.

Tin coating is a very complex electrolytic process in which a large number of variables take part. The coating process consists on the deposition of a tin layer on the surface of a steel strip, created by the joining of several steel coils.

The strip passes through several tanks (see figure 1) that contain an electrolyte with stannum ions. To increase the deposition of ions on the strip, which acts as a cathode, a set of anodes located in every tank supply a certain amount of current. Each anode is connected to a rectifier that provides the necessary current. These rectifiers are independent, that is to say, it is possible to select which rectifiers are to be used and the current they must supply.

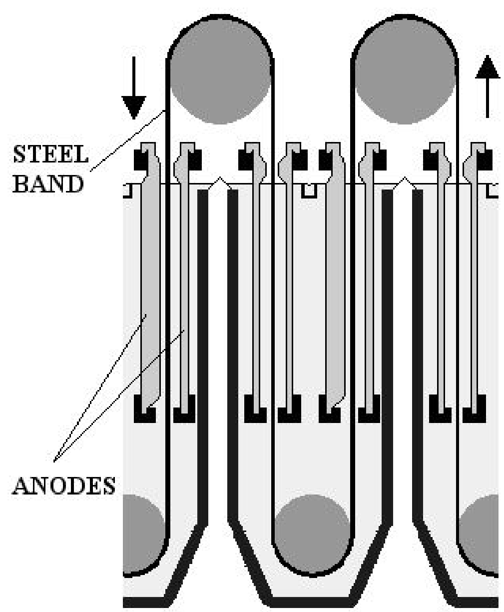

Fig. 1. Plating Tank

Up to now, the control strategy applied in the process is based on a model developed around Faraday's law (López *et al.*, 2000; López *et al.*, 1999) (see equation 1), corrected by means of an efficiency factor K_1 (see equation 2). For the processing of a tinplating task, total current and line speed values are previously calculated. Current is uniformly distributed among a set of manually selected rectifiers. Once determined, unless line speed must be changed, these preset calculations will be used to process all the coils in the task, and only eventual modifications are carried out during the process.

$$m = \frac{\frac{A}{z}}{F} \times I \times t \quad (1)$$

$$I = \frac{K_2}{K_1} \times \frac{m}{t} \quad (2)$$

$m =$ Tin weight

$A =$ Stannum atomic mass

$z =$ Stannum valence

$F =$ Faraday constant

$I =$ Current intensity

$t =$ Time current attacks strip

$K_1 =$ Efficiency factor

$$K_2 = \frac{F}{A/z}$$

This mathematical model considers only a reduced set of the variables involved in the process, so it introduces an error when calculating line references for a given coating thickness. Under certain conditions, this error could be greater than the maximum allowed, which forces the processed coil to be rejected.

In order to avoid tin thickness below minimum customer requirements, a way to handle with the imprecision of the model could be to slightly oversize the desired coating thickness at the beginning of the task. According to the thickness measures sampled during the process, line speed and current applied could be on-line tuned if necessary. Nevertheless, oversizing policies are nowadays being penalized due to ecological considerations. Also, customers sometimes experiment problems when shaping wide tin coils. Finally, tin is an expensive product, and wasted material affects economical profit of the company.

The variables that have influence on the coating thickness can be classified into four groups:

- Variables related to the steel strip and the coil quality to produce: width, coating thickness, etc.
- Variables related to the line. Some of them (such as length of anodes or total number of tanks) can not be modified, and the rest (e.g. temperatures and concentrations) are difficult to control due to the time needed to change their values.
- Parameters selected by the operator, which determine the way the coating process should be performed.
- Line speed and current applied. These two variables (three in fact, because different currents can be applied for each side of the strip) are the basis of the control strategy.

To enhance the control strategy, a new model model calculation module based on Genetic Programming (Banzhaf *et al.*, 1998; Koza, 1992) has been developed (López *et al.*, 2001). It considers all those variables that have been found relevant for the process, and provides models to be used for the control strategy.

This model is not fixed. The operator can decide to calculate a new model in the basis of the observation of the real and the model predicted coating thickness for a set of previously processed coils. But handling this unknown obtained model is more difficult than handling the previous one. So, the control strategy developed tries to mix the well known methods used along the years with new ideas to enhance the quality of the final product while considering a new automatically generated process model.

This paper mainly focuses on the description of the control strategy, although providing some comparative results of the modeling tool in comparison with the Faraday's based model.

According to the process model, the maximum line speed for a given thickness is calculated, taking into account a set of conditions composed of those selected by the user (operation conditions) and the values of the variables sampled from the line. In a next step, based on this speed, the total necessary current for each steel strip side will be calculated. This current has to be distributed into the available rectifiers, so it is necessary to determine a set of rectifiers for each coating side ("pattern of rectifiers"), as well as the current each one must supply.

For all the coils involved in a coating task but the first, coating thickness errors for the previous coils are considered in order to make corrections over the line parameters to accurately fit the objective coating thickness.

An application that performs these calculations has also been developed. It acquires data from the line, the user and the next coils to be processed, and, when the calculations finish, sends back the results.

2. CONTROL STRATEGY

The control strategy departs from a set of operational conditions. This name is given to those parameters that can be selected by the user (Zubimendi *et al.*, 1996). They define the way the calculations are performed. Three parameters are critical:

Type of current density It indicates if all the rectifiers have to supply the same current (uniform) or a current proportional to the maximum current they can provide (not uniform), which could be not the same (see equation 3) for all the rectifiers due to degradation.

$$RC_i = TC \times \frac{RC_{maxi}}{\sum_{j \in P} RC_{maxj}} \quad (3)$$

$RC_i =$ Current for rectifier i

$RC_{maxk} =$ Available Current for rectifier k

$TC =$ Total necessary current

$P =$ Pattern of rectifiers

Pattern of rectifiers Includes different options, such as a manual selection of the rectifiers considered to set up the pattern, the inclusion or exclusion of a specific rectifier in every pattern, etc.

Rectifier selection criteria Several criteria may be considered to select the rectifiers that have to be included in a pattern: try to minimize the number of rectifiers, group used rectifiers at the end of the line, etc.

This point, although decisive to resolve the rectifiers that are included in a pattern, is in fact secondary, that is, it is only considered after the line speed and the total current have been fixed.

The control strategy is divided into a feedforward and a feedback control:

Feedforward control. It is composed of the *Precalculation* and *Recalculation* steps:

- Precalculation. Before the first coil of a new task enters the line, maximum line speed and most suitable pattern of rectifiers are calculated.
- Recalculation. When the first coil of a task (the same as in the previous step) is about to be processed, some values may have changed from the moment the precalculation was done, so the speed and the patterns are adjusted according to these changes.

Feedback control. For the rest of the coils of the same task, the real coating thickness for the previous coil are compared to the estimated ones and the calculations for the next coil take into account the difference.

The equations used for these calculations are based on a mathematical model of the line generated by means of the Genetic Programming modeling approach. Nevertheless, this model is generated from data that include just a reduced set of the possible values that each variable can take, so under certain conditions, it could also introduce errors great enough to make the model unacceptable. Since the conditions that cause these problems can not be determined in advance, it is necessary to check the results after every calculation that involves the Genetic Programming based model and, if they are not valid, discard them and repeat all the calculations using the classical model based on Faraday's law, always valid.

2.1 *Precalculation*

As speed and current are directly related, it is not possible to calculate both of them at the same time. First, the maximum speed is calculated using the maximum available current according to the conditions specified by the user. Sometimes, this speed is higher than the limit imposed by other reasons, so the total necessary current is less than the maximum one and needs to be recalculated. Then, this total current has to be distributed into the available rectifiers.

The precalculation involves a sequence of steps (see figure 2):

- Determination of the objective coating thickness.
- Determination of an initial pattern of rectifiers.
  - Determination of the available rectifier set.
  - Determination of the maximum available current for each rectifier.
  - Rejection of non-valid rectifiers based on the minimum current density.
  - Adjustment of the maximum current per rectifier in basis of the maximum current density.
- Calculation of the maximum line speeds.
  - Calculation of the available total current.
  - Calculation of the maximum line speed (uniform current density).
  - Calculation of the maximum line speed (non-uniform current density).
- Selection of one configuration (line speed and pattern of rectifiers).

Up to this point, the calculations described have to be made separately for both coating sides. Once the limits for the line speed are known, it is possible to determine a common speed for both sides and make the rest of the calculations for both coating sides at the same time:

(1) Determination of line speed. It is the minimum (see equation 4) among the two speeds selected for each coating side and the maximum line speed allowed in the line:

$$v = \min(v_{top}, v_{bottom}, v_{max}) \quad (4)$$

$v_{top} =$ Available speed for top side

$v_{bottom} =$ Available speed for bottom side

$v_{max} =$ Available speed for the line

(2) Calculation of every possible pattern of rectifiers with non-uniform current density.

(3) Calculation of every possible pattern of rectifiers with uniform current density.

The last two steps are iterative processes, that, depending on the operation conditions, produce several

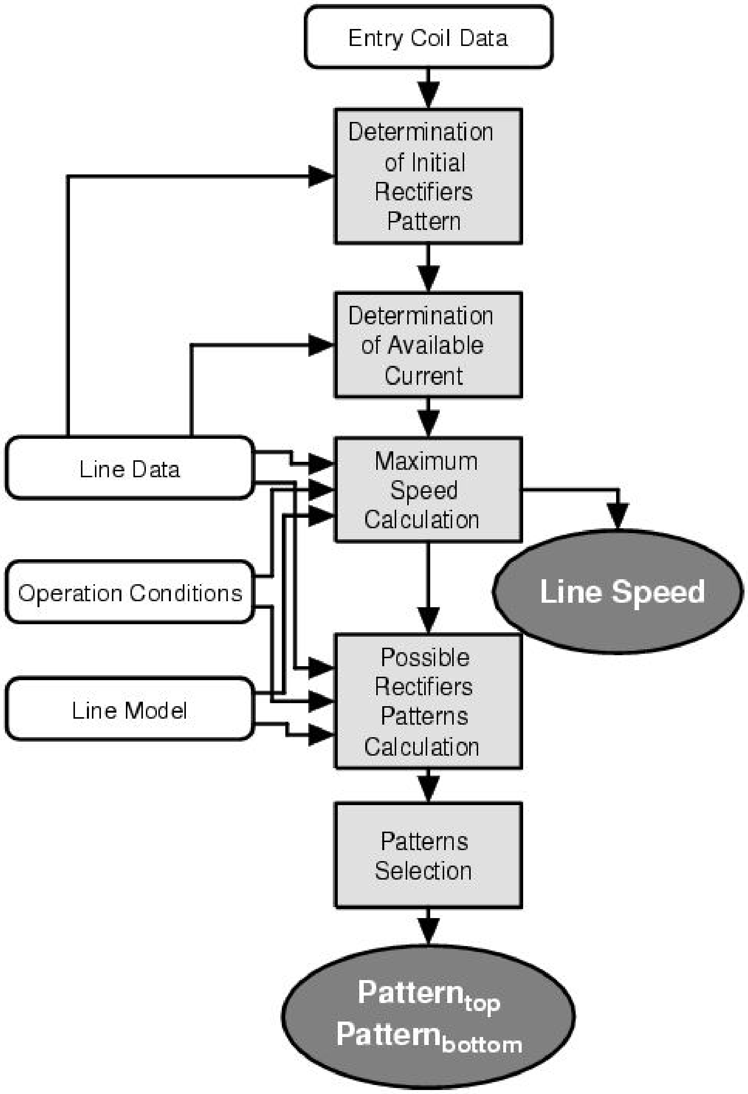

Fig. 2. Precalculation

patterns of the same type for each coating side. Before finishing this stage, the user must select one pattern of rectifiers for each side.

2.2 *Recalculation*

The precalculation may take a long time, so it has to be performed before the coil arrives to the plating section. However, some of the variables involved in the calculations may have changed from the moment the precalculation was done when the task is about to begin.

Although changes are usually very slight, the results from the precalculation have to be adapted to the new values. The line speed is kept, so it is only necessary to recalculate the total current and its distribution into the rectifiers, modifying as little as possible the previous calculated pattern of rectifiers.

2.3 *Feedback*

This stage is quite similar to the previous one, excepting the fact that this one applies to every coil bat the first of a task. Therefore, the real tin thickness for at least one coil processed using the results of the precalculation is known.

The first step is to calculate the coating error for the previous coil. If it is less than a certain percentage, the hypothesis are valid and the steps to perform are:

(1) Adjustment of parameters based on the real values.
(2) Determination of the available rectifiers set.
(3) Calculation of the available current for each side.
(4) If the available current is not high enough to keep the previous line speed, the new maximum line speed has to be calculated. Otherwise, the old one is kept.
(5) Calculation of patterns of rectifiers using the operation conditions specified in the precalculation.

It is necessary to recalculate the line speed, which involves repeating the whole precalculation just in case some of the values have changed more than a certain percentage. As most of the variables change very slowly (temperatures, concentrations...), this case very seldom occurs.

3. IMPLEMENTATION

The application developed for this work is composed of five main modules:

- Communication module.
- Calculation module.
- Model recalculation module.
- Interface.

3.1 *Communication Module*

There are two ways the application can acquire data from the line: via a database or directly from the line. In both cases, to prevent the application from having a polling loop, the communication has to be asynchronous, e.g., the application must be notified whenever certain events take place in order to retrieve the necessary data and perform the appropriate calculations.

The main advantage of using a database is that it allows the application to work with historical data, as well as with present values, which is very useful to test its behaviour. On the other hand, direct communication is faster than the other one, avoiding the delay introduced by the database and being more appropriate for the on-line control of the process.

In a similar way, this module sends to the line the setup calculated by the application so that it is fixed for the next coil.

3.2 *Calculation Module*

This is the main module of the application. Using data obtained from the line, the coil to be processed and the operation conditions selected by the user, it performs the calculations as set out above.

Fast computation is required. As sometimes data are not available until a few seconds before the coil starts to be processed, there is a time limit (depending on line speed) for the calculations to be taken.

Another relevant point is that calculations have to continue even if the operator does not act when it is required. In such cases, default values are selected and the calculations go into the next step when any event in the line forces it. Although it is undesirable, because the system does not take advantage of the knowledge of the operator, the use of default values allows the application not to stop in any case.

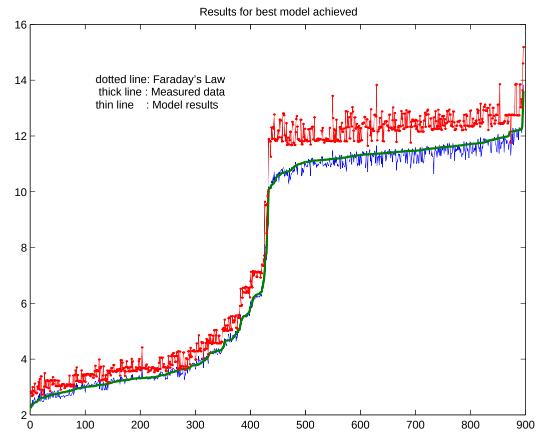

Fig. 3. Genetic Programming Modeling

3.3 *Model Recalculation Module*

The application has to provide a way to replace the mathematical model when it does not fit the behaviour of the line. The decision has to be taken by the operator. To help him, the application shows some indicators of the model fitness.

If the mathematical model has to be replaced, the first step is to obtain some data from the database. The query can be modified by several parameters defined by the user (such as dates or thickness values). These data and the parameters selected by the operator are used to generate a new model.

As an example, figure 3 contains a comparison between actual used mathematical model predicted values (based on Faraday's law), real sampled values and Genetic Programming model predicted values. As it can be seen, model fits better the real value of thickness of tin.

When that application finishes, the new model is shown to the user, who, comparing the fitness of the new and the former model must, finally, select better of the two.

3.4 *Interface*

As this application is the only way the user can interact with the whole system developed, it has to show him all the information he needs.

Figure 4 shows the main screen of the application. The middle and the left areas of the screen display the intermediary data and results and the previous ones, respectively, while the bottom area displays messages about the calculations performed.

It is important to note that the buttons and controls are only active when there are enough data for the calculations they perform. This prevent the user from performing a calculation before the data it needs is ready.

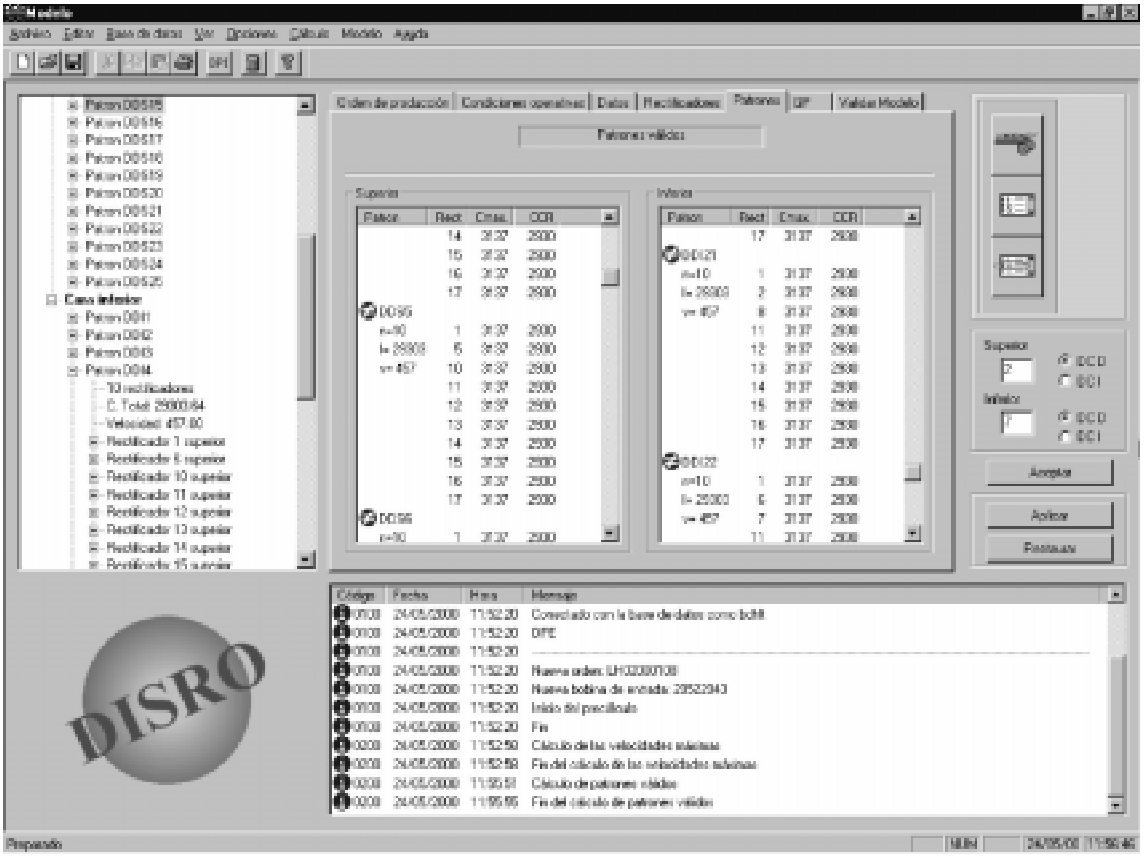

Fig. 4. Main Screen

4. CONCLUSIONS

The system developed permits the calculation of the necessary current for a given coating thickness, with the maximum line speed.

Calculations are performed using the equations generated by means of Genetic Programing. They are more accurate than the classical ones, based on Faraday's law. Therefore, the error on the coating thickness is reduced.

In addition, it determines the best way of distributing the total current into the set of available rectifiers according to the operation conditions selected.

This is an important improvement over the former method: it is possible to select the set of conditions that provide the best results for every task. Unlikely this, up to this moment the distribution of current is made in the same way for all the tasks.

5. REFERENCES

Banzhaf, Wolfgang, Peter Nordin, Robert E. Keller and Frank D. Francone (1998). *Genetic Programming – An Introduction; On the Automatic Evolution of Computer Programs and its Applications*. Morgan Kaufmann, dpunkt.verlag.

de Abajo, N., S. Peregrina, J. A. González, A. López, R. C. González and H. López (2000). Development and implementation of intelligent systems for the real time optimization of product quality in rolling mills and process lines. Workshop CECA "On Line Control of Flat Product Rolling".

Koza, John R. (1992). *Genetic Programming: On the Programming of Computers by Means of Natural Selection*. MIT Press. Cambridge, MA, USA.

López, A., H. López, G. Ojea, J.A. González, N. de Abajo and S. Peregrina (1999). Modelo matemático para la optimización del espesor de recubrimiento de estaño en una línea de hojalata. In: *SAAEI 99*. Madrid. pp. 637–640.

López, A.M., V. Torre, H. López, J.A. González and N. de Abajo (2000). Control de espesor de recubrimiento de estaño en una línea de fabricación de hojalata. Jornadas de Automática, Sevilla 2000.

López, A.M., R. Jáñez, R.C. González, H. López and V. Torre (2001). Adaptive system based on genetic programming for the coatin thickness optimization ina a tinplate production line. In: *Proceedings of the European Control Conference 2001*.

Zubimendi, J.L., C. Baieli, W. Egli, M.R. Chara, G. Andreasen, P. Schilari, R. Savarezza and S. Marchiano (1996). The influence of operating conditions on the morphology of tin electrodepositions and tinplate quality. In: *Proceedings of the Sith Timplate Conference*. p. 85.