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Mathematical model based control system for Silicon Steel Mill of Rourkela Steel Plant

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Abstract

Reactive annealing of semi-processed electrical steels is an important process to reduce electro-magnetic losses. The annealing process involves heating of the steel strip, which is passed continuously through the furnace, to a certain temperature. The heated steel strip gets decarburised and annealed in a warm gas atmosphere containing N_2-H_2-H_2O-CO-CO_2 mixture. The composition of the warm gas atmosphere plays a major role in both the decarburisation and selective oxidation of carbon from the steel strip. The furnace settings are often changed to cater for products with different metallurgical properties and varying dimensions. Often the line speed of the process too needs to be changed to cater to varying input parameters of the steel strip such as composition, width, thickness etc. Thus an advanced mathematical model based system is desired to optimize the running of the furnace to achieve the desired properties at improved productivity.For effective control of system, mathematical model for the heating of the steel strip is developed. Decarburisation model for the steel strip has been coupled with the thermal model. The model takes in various inputs like line speed, composition of the steel strip, width and its thickness. Temperatures in the different zones of the furnace along with the decarburising gas flow rate, H_2/H_2O ratio etc, are taken as input parameters. The model predicts the thermal profile of the steel strip inside the furnace. It also predicts the carbon composition in the steel strip along the length of the furnace. Based on optimized temperature and carbon profile for different grades, the model suggests the desired line speed and the temperature settings in the different zones of the furnace. If there is a mismatch in the desired and the actual line speed the model also generates the desired set points of temperature for increasing or decreasing the furnace temperature which is downloaded to PLC in order to control the furnace parameters in real-time.

Keywords : electrical steel; decarburisation; mathematical model; control system

1. Introduction

Silicon Steel Mill of Rourkela Steel Plant (RSP) produces Cold Rolled Non-Oriented (CRNO) Electrical steels which are widely used for motors, generators, alternators, ballasts, small transformers and a variety of other electromagnetic applications. CRNO steel's good electrical conductivity makes it the ideal material for use in refrigerators, domestic irons, light fittings, fans and mixers.

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Electrical steel is produced from a steel melt which is cast as a thin strip, cooled, hot rolled and/or cold rolled into a finished strip. The finished strip is further subjected to decarburization and annealing treatment wherein the magnetic properties are developed, making the steel strip of suitable for use in electrical machinery such as motors or transformers.

The annealing process involves heating the steel, which is passed continuously through the furnace, to certain temperatures and then cooling it, resulting in a change in the crystalline structure of the steel. If the carbon in the steel is more than 0.003%, then the steel needs to be decarburized. For this, the strip of steel sheet is continuously fed into the furnace at the decarburization end and after the de-carburization; the strip enters the annealing zone, where stress relief and grain growth takes place. The decarburization process is very important since it reduces the carbon percentage in strips which determines the quality and grade of the end product. The furnace settings are often changed especially furnace temperature and line speed to cater for products with different metallurgical properties and varying dimensions. In the old system, these settings were changed manually based upon experience of the operator as a result of which the quality of end product varies depending upon operator's skill. The mathematical model based control system helps to optimize the running of the furnace by changing the furnace parameters in real-time based upon the input strip quality to get the desired grade of end product.

2. Decarburization

As, stated earlier, if the carbon in the steel is more than 0.003%, then the steel needs to be decarburized. For this, the steel strip is continuously fed into the furnace where at first it is subjected to de-carburization and later on it is annealed to get the desired properties in strip. Finally the strip is air cooled, coated with inorganic, semi-organic or organic insulation coating and ready for further processing. During this process cycle, the steel undergoes carbon content reduction, stress relief, ferritic grain growth and surface oxidation.

During decarburization, the steel is heat treated at high soaking temperatures between 700 to 850 ^{O}C under moistened synthetic gas (containing hydrogen and nitrogen) atmosphere. Decarburization occurs mainly through the reaction of the humidity (H_2O) in the furnace atmosphere with carbon atoms on the steel surface. The oxidation reaction involves both the iron and carbon atoms, the latter being diffused from the bulk to the steel surface. The carbon oxidation should prevail, since it involves larger changes in free energy than iron oxidation. However, due to the higher iron concentration on the steel surface, both elements react with humidity. The hydrogen present in the atmosphere has an important role in reducing the iron oxides formed during the treatment and allows a prolonged contact between the atmosphere and the steel. [1]

Decarburization kinetics depends fundamentally on four reaction rates associated with:-

- diffusion of carbon atoms from bulk to the steel surface ,
- gas adsorption (water vapour and hydrogen) on the steel surface,
- oxidation of carbon, and
- formation of iron oxides.

All these processes are thermally activated and should be accelerated by an increase in temperature. The carbon diffusion to the steel surface can be calculated using Fick's second law of diffusion and can be given as:-[1]

$$C = \sum_{0}^{\infty} \frac{8C_o}{(2n+1)^2 \pi^2} \exp\left\{-Dt\left[(2n+1)\pi / e\right]^2\right\} \qquad ..... 1$$

Here, it is considered that the carbon content at the steel surface is zero, C_∞ is the initial carbon content, the diffusion coefficient of carbon D at the soaking temperature and the strip thickness. Regarding the adsorption of water vapour and hydrogen on the steel surface, it is well known that this reaction is very fast and certainly does not control the decarburization process. The third reaction, carbon oxidation at the steel surface, is a thermally activated process obeying Arrhenius law, that is, the reaction rate increases when the temperature and/or concentration of C and H_2O are increased. Finally, the water vapour reacts also with iron, leading to scale formation, which may isolate the steel from the oxidizing atmosphere and thus inhibit further decarburization. The slowest reaction among those previously mentioned determines the overall decarburization rate

3. The Process

The method of producing CRNO steels typically involve preparing a steel melt having the desired composition; casting the steel melt into an ingot or slab having a thickness from about 50 mm to about 500 mm; heating the ingot or slab to a temperature typically greater than about 1040°C; and, hot rolling to a sheet thickness of about 1 mm or more. The hot rolled sheet is subsequently processed by a variety of routings which may include pickling or, optionally, hot band annealing prior to or after pickling; cold rolling in one or more steps to the desired product thickness; with decarburization and finish annealing, sometimes followed by a temper rolling, to develop the desired magnetic properties.

Carbon is an undesirable element in the steel. Carbon fosters the formation of austenite and, when present in an amount greater than about 0.003%, the steel must be provided with a decarburizing annealing treatment to reduce the carbon level sufficiently to prevent "magnetic aging". If the melt carbon level is greater than about 0.003%, the non-oriented electrical steel must be decarburization annealed to less than about 0.003% carbon and, preferably, less than about 0.0025% so that the finished annealed strip will not magnetically age.

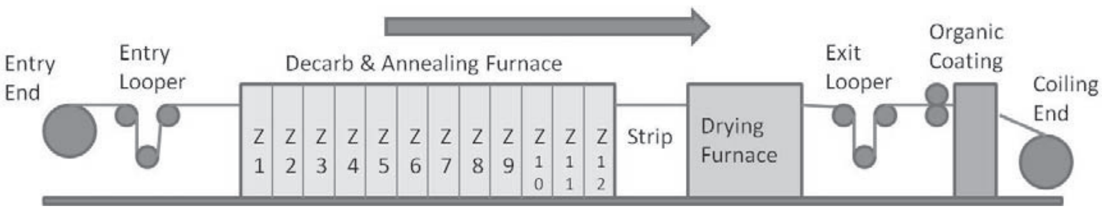

Fig. 1: Decarb and Annealing line of Silicon Steel Mill, RSP

In order to decarburise the strip, it is heated in decarburizing and annealing furnaces. These furnaces are long electric radiant furnace where the steel strips pass at varying line speeds. The temperature along the furnace is controlled by varying the power supplied to the heating elements and by use of cooling tubes. The cooling tubes are located in the last part of the furnace and consist of steel tubes through which ambient air is pumped. It is important that the strip exit the furnace with the correct temperature for coating that is applied at the exit point.

The line speed through the furnace is reduced for strips with higher thickness and width in order to achieve the required temperature. The furnace is divided into different zones with thermocouples fitted to monitor the temperature. The thermocouple temperatures are compared with the desired set-point temperature and the power to the heating elements of each zone of the furnace varied accordingly.

4. The Mathematical Model

In order to improve upon the product quality, and operational efficiency it is desirable that strip temperature and carbon composition profile be predicted to ensure close control on the quality. This can be done by modelling it mathematically for the furnace conditions. The model should predict the strip temperature in the furnace for actual production schedules with the changes in product dimensions, steel grade and furnace temperature settings. This thermal model needs to be clubbed with the metallurgical model of the decarburization to predict the temperature and chemistry of the product during production schedule.

Essentially, the temperature *u* within the strip may be modelled by the heat equation with an advection term corresponding to the strip's speed *v* through the furnace: [2]

$$\rho C_s\left(\frac{\partial\theta}{\partial t}+v\frac{\partial\theta}{\partial x}\right)=k_s\left(\frac{\partial^2\theta}{\partial x^2}+\frac{\partial^2\theta}{\partial y^2}+\frac{\partial^2\theta}{\partial x^2}\right), t>0, \quad (x,y,z)\in S \qquad \text{..... 2}$$

Table 1: Actual final carbon and predicted final carbon by model

Sl. No.	Coil No.	Date of rolling	Width (mm) /Gage (mm)	Speed (m/s)	Zone Temperature (degree C)	Lab Results		End Carbon Predicted by Model
						Initial C (%)	Final C (%)	(%)
1	DJ1067	8/7/2009	0.5/ 1028	21	780/840/840/840/840/880/840/840/820/940/960	0.031	0.006	0.004
2	DJ1242	23/7/2009	DO	22.9	800/820/810/840/840/840/840/860/940/940/960	0.029	0.005	0.003
3	DJ1446	14/8/2009	DO	26	850/840/820/840/840/830/840/930/960/980/990	0.032	0.006	0.005
4	DJ1458	15/8/2009	DO	24	860/840/840/860/840/840/840/900/960/980	0.031	0.006	0.004
5	DJ1496	18/8/2009	DO	26	820/840/820/840/820/840/840/930/960/960/970	0.028	0.005	0.004
6	DJ1501	18/8/2009	DO	22	840/840/840/860/840/840/840/840/900/900/880	0.029	0.006	0.005
7	DJ1513	19/8/2009	DO	22.5	840/840/820/840/840/840/840/930/950/960/960	0.024	0.005	0.003
8	DJ1523	20/8/2009	DO	22.4	820/840/830/840/840/840/840/920/960/960/960	0.029	0.004	0.002
9	DJ1526	20/8/2009	DO	21	840/840/820/840/840/840/840/930/960/960/960	0.024	0.004	0.003

The decarburization kinetics can be predicted by considering the furnace atmosphere to be a mixture of N_2-H_2-H_2O-CO-CO_2-CH_4-O_2 annealing atmosphere. The calculations involve the numerical solution of a system of equations to find the partial pressure of gases. Coupled with mass balance equations for carbon, hydrogen and oxygen on one hand and kinetic rate equations the rate of decarburization

$$\frac{dc}{dt}=D_C\,\frac{d^2c}{dx^2} \qquad \text{..... 3}$$

can be calculated as suggested by Soenen et.al. [3]

5. The Neural Network

Combinations of neural network and classical analytical models are always preferred. A parallel configuration of mathematical model and neural network has been used for the purpose. The mathematical model calculates an approximate value for the target value as accurately as possible, while the neural network produces an estimate of the inherent error in the mathematical model's approximation. The sum of both results should yield an accurate target value.[4]

A model that is based only on neural networks appears as a "black box" to technologists. In contrast, the combination of neural network and mathematical model highlights the analytical relationships within the technical process.

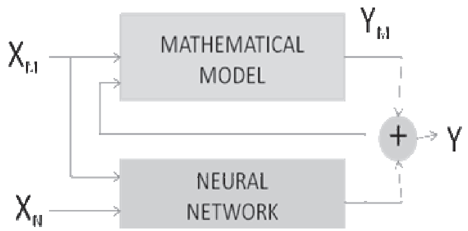

Fig. 2: Parallel configuration of an analytical model and neural network

The effectiveness of a neural network model depends upon the quality and quantity of data with which it is trained with. The spectrum of data with which it is trained must represent each and every aspect of the process. The hybrid model are trained with data representing different parameters like line speed, coil - thickness, temperature of different zones of furnace, initial carbon percentage before processing and final carbon percentage after processing for different grades of steel sampled for about 9-10 months.

6. New Control System

Earlier zone temperatures of the furnace are being controlled trough old generation PID controllers with circular chart recorder. The furnace temperature controller gives an output of 4-20 mA to the thyristor controller from electric heater control and records the temperature continuously in chart. The synthesis gas and nitrogen flows were being manually adjusted by checking flow-scope readings. In the old system temperature of different zones were controlled by providing set-points based on experience/ practice. Thus the manual and inefficient temperature profile control of furnace accounts for about 20% of the total grade diversion in Silicon Steel Mill of RSP.

In the new system the old generation PID controllers are replaced by new generation PLCs which results in much better control of zone temperatures which is desired for effective decarburisation. All the safety interlocks for safe operation of furnaces are implemented through PLC which makes the system much reliable and maintenance friendly. The coil data like coil chemistry, aim grade etc. is downloaded by the system from existing level-2 of plant network, automatically fed into the developed advanced mathematical model which based on aim-grade and coil chemistry predicts the desired temperature profile and suggest the required line speed to achieve the desired grade.

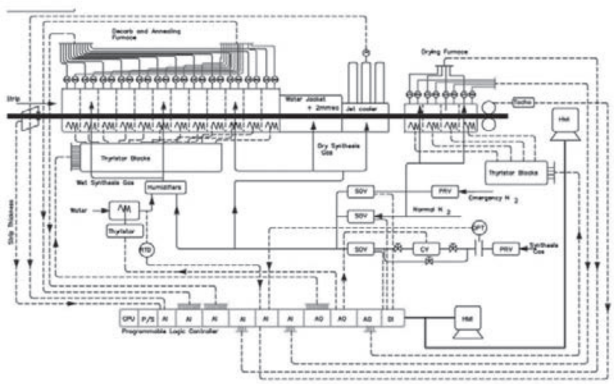
Fig. 3: Schematic diagram of the control system

The new system has three level of controls 1) Auto mode 2) Semi Auto Mode and 3) Manual mode which makes it more flexible from the point of view of operation. In Auto Mode the total control of the system is done by the mathematical model and the set-points for zone temperatures of furnace are directly downloaded to PLC. In semi-auto mode though the set-points are calculated by model but it gives the flexibility to the operator to choose the set-point or to put his own set-point based on his experience. Lastly the Manual Mode gives total control to the operator so that he can put his own set of set-points in order to control the furnace zones.

Conclusion

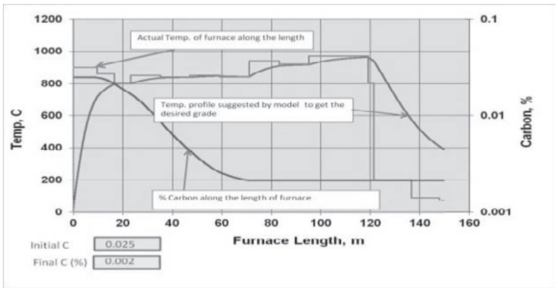

Fig. 4: Actual temp. profile and suggested temp. profile by model

The mathematical model based control system not only provides a better way of controlling the process but it controls the system in a scientific way. The system makes the process less dependent on the expertise of the operator. The PLC based system ensures the control more accurate which results in attaining the desired temperature profile in furnace in order to get the desired grade of electrical steel.

It also allows accurate calculation of strip temperature in changing furnace conditions which further helps us in calculations of furnace settings for the annealing process which provides a tool for optimizing the running of furnace, especially during the transient periods of operation. The better prediction of temperature profile not only ensures better furnace utilization but also conserves energy by restricting unnecessary heating up of furnace zones. Better prediction of temperature profile of furnace by mathematical model along with better controls results in effective decarburization which in turn results in fewer instances of grade diversions.

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References

1. Decarburization Kinetics during Annealing of Semi-processed Electrical Steel, ISIJ International, Vol. 44 (2004), No. 3, pp. 618-622
2. Strip temperature in a metal coating line annealing furnace, M. Guinness and Stephen Taylor, New Zealand Steel, MISG2004 Report
3. Modelling Decarburization in Electrical Steels, Steel Research Int. 76 (2205), No. 6, pp. 425
4. Portmann, N.F., D. Lindhoff, G. Sorgel and O. Gramckow (1995). Application of neural networks in rolling mill automation. Iron and Steel Engineer, 72 (2), 33-36