Fuzzy Inference System Controls in Hot Dip Galvanizing Lines

Ersen Kuru[1], Leyla Kuru[2]

[1]Uzunmustafa Mah. Uzunmustafa Cad. No:20/3 Düzce, TURKEY
ersenkuru@hotmail.com,
[2]Uzunmustafa Mah. Uzunmustafa Cad. No:20/3 Düzce, TURKEY
leylakuru@hotmail.com,

Abstract

Today's manufacturers need high-quality galvanized steel strip. High-quality galvanized steel strip is very important for automotive, building and consumer goods industries. Strip speed and process parameters are continuously changing in production galvanized steel strip. That in turn leads to coating thickness fluctuations, which translate into problems in quality and wastage of coating material. This paper presents a new galvannealing control system to optimize this metallurgical process. Fuzzy Inference System based on new control system enables production to be run safely at lower limit of permissible coating values with a significant improvement in the uniformity and quality of the coating layer. A discussion of simulation results show the improvements achieved by using FIS in comparison to the conventional controller.

1. Introduction

Manufacturers of hot dip galvanized steel strip must pay careful attention to the coating uniformity and thickness in order to maintain quality. In particular, the automotive industry requires products with excellent corrosion resistance, weldability and paintability properties combined with low production costs. Galvannealed steel satisfies all these requirements. In order to produce galvannealed material of excellent quality, economically it is necessary to control the process conditions to fulfill all quality demands [1]. Conventional control concepts of the coating thickness are based on conventional list models that take inadequate account of dead time intervals, strip speed changes and changes of the process parameters. That in turn leads to coating thickness fluctuations, which translate into problems in quality and wastage of coating material. To overcome these problems Fuzzy Inference System (FIS) based controller was developed, enabling production to be run safely at lower limit of permissible coating values with a significant improvement in the uniformity and quality of the coating layer.

The assurance of quality with exact according to international norms (Euronorm 10142), has become a top priority for manufacturers of hot dip coated material. Unfortunately, the coating thickness controls used so far are still mainly conventional solutions with the set points manually adjusted by operating personnel. These manual interventions inevitably result in coating thickness fluctuations and vary with the operating personnel. If the coating thickness falls below the minimum permissible tolerances, the market value of the processed product is reduced, while too thick coating reduces the cost effectiveness of plant operations.

A new coating thickness control model based on Fuzzy Inference System was developed, which features two important improvements: It is more cost-effective than conventional solutions and it delivers a better quality product.

2. Galvannealing Process

Galvanizing section is the main process of galvanizing line. In this section, strip is passed through the hot solution obtained by melting the zinc ingots, the amount of coating is adjusted and it is coated in desired amounts after some serial heating and colding processes depending on the characteristics of the product and it is done usually by galvanize.

Figure 1 provides an overview of galvannealing section of a hot dip galvanizing line.

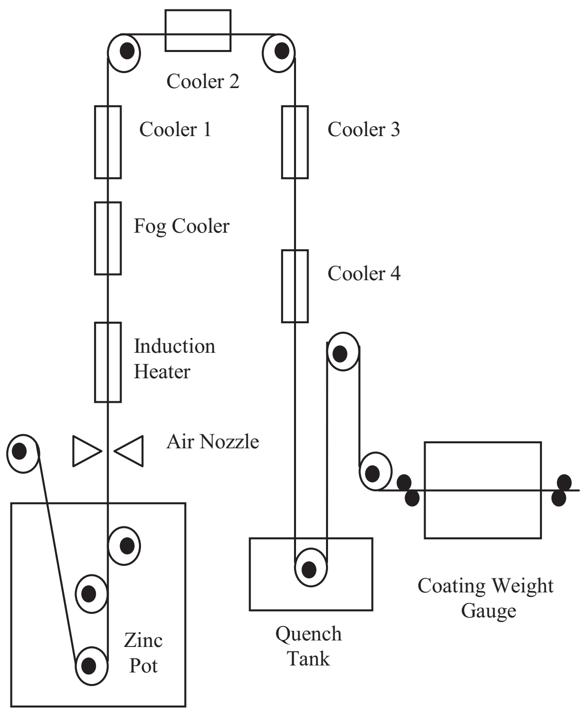

Fig. 1. Galvannealing section of a hot dip galvanizing line

Galvanize coating section has four parts which are Galvanizing pot, Air nozzle, Induction heater, Fog cooler and cooler.

The metallurgy of the galvanizing pot varies depending on the quality of galvanize coating, the thickness of the coating, the capability of the coating to penetrate the strip and the appearance of the surface. The solution in the galvanizing pot is kept at about 460 ^{0}C by using Induction heaters. The belt is to go with the galvanizing pot which is the output from the Galvanizing furnace region at about 500 ^{0}C. Afterwards, the desired coating amount on the belt is adjusted by the air nozzle which is the output part of the galvanizing pot. Depending on the quality characteristics, after adjusting the amount of coating, the belt is heated by induction heater by annealing then it is cooled by fog cooler method by making use of a fan. Finally, after the process of cooling with water is performed, the amount of thickness on the belt is measured by using the equipment Coating Weight Gauge (CWG).

CWG has to be located 80 m. far from the galvanizing pot because the heating and cooling processes at the output of the galvanizing pot takes a long time to finish. Because of this necessity, the amount of coating measured by CWG can't be used as a feedback in the nozzle gap and pressure control. Thus, the nozzle gap and pressure control are performed by the operators manually.

When the desired amount of coating in the successive coils in the Galvanize Coating Process is the same, the operator can perform the nozzle gap and pressure adjustments manually by observing the amount of the actual coating measured by CWG even if some time passes. However, when the desired amount of coating in the successive coils are different, because of the CWG being 80 m. far from the galvanizing pot region, the desired amount of coating in many parts of the coil may not be achieved before the operators perform the necessary nozzle gap and pressure adjustments. Moreover, the thickness of coating may exceed the limits with respect to the deviations of the speed of the line in manual working cases.

In conclusion, all these problems cause the cost of production to increase and the quality to decrease. Thus, these problems should be solved in an efficient and best economic way as much as possible. To overcome these problems, Fuzzy Inference System (FIS) based on controller was developed.

3. Fuzzy Inference Systems (FIS)

Fuzzy logic is an attempt at the representation and utilization of knowledge but in a way more comparable to the way humans think. "Crisp" variables and crisp knowledge are elements in the knowledge-domain that have an exact "truth value" ; either TRUE or FALSE. Another definition of fuzzy logic is that it is a method for easily representing analog processes on a digital computer. These processes are concerned with continuous phenomena that are not easily broken down into discrete segments, and the concepts involved are difficult to model along mathematical or rule-based lines [2-3]

This article involves the development of several fuzzy inference systems that accomplish the following objective: determination Nozzle Pressure and Nozzle Gap as a function of Line Speed and Coating Weight (CW) Set value.
MATLAB Fuzzy Logic Toolbox is used for determination of Nozzle Pressure and Nozzle Gap. In the first part of this research, input variables Line Speed, Coating Weight Set value and output variables Nozzle Pressure, Nozzle Gap are defined. Membership functions (MF) are also defined for input and output variables using actual measurement table shown in table 1. After defining the MF, are also defined fuzzy rules in MATLAB Fuzzy Logic Toolbox Rule Editor. Finally, fuzzy system is tested using different input values. Figure 2 shows the complete determination algorithm proposed [4].

4. Fuzzy Inference System Controls in Hot Dip Galvanizing

In this application there are two inputs and two outputs. Input variables are Line Speed and Coating Weight Set value. and output variables are Nozzle Pressure and Nozzle Gap. They are defined using MATLAB Fuzzy Logic Toolbox. After defining Fuzzy Inference System we tested the system. This shows us that Nozzle Pressure and Nozzle Gap can be determined by using fuzzy inference system.

After defining input and output variables MFs for input and output variables are defined using table 1. During one week, measurements have done on the system based on conventional controle. The results are shown on table 1. Nozzele Pressure and Nozzle Gap settings for different line speed and different CW set values have been taken. The accurate ideal working values depend on the measurement time. The longer the time the more accurate the results of FIS.

According to this table we decided that input variable Line Speed has sixteen MFs and Coating Weight Set value has seven MFs and the output variables Nozzle Pressure and Nozzle Gap have eight MFs. In this application Mamdani inferencing is used.

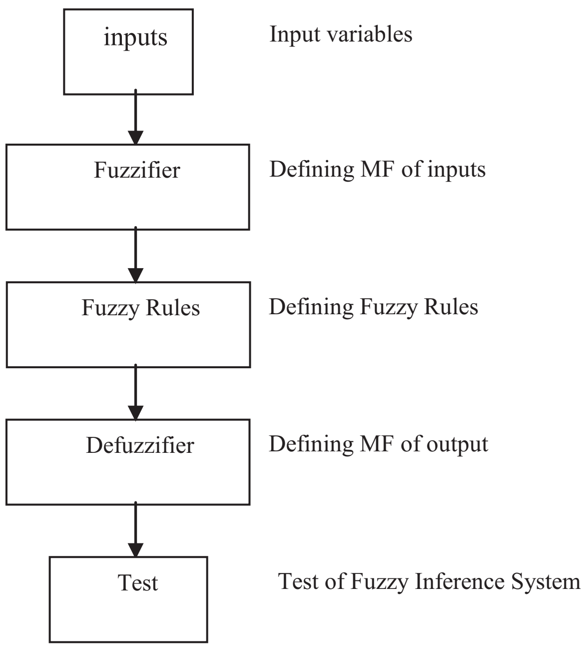

Fig. 2. Determination algorithm

First of all the input variables Line Speed and Coating Weight Set value and output variables Nozzle Pressure and Nozzle Gap are defined by using table 1 for designing of FIS as shown in figure 3.

Membership functions of input and output variables are also defined using table 1. According to this table the input variable Line Speed is changing between 30 to 100 m/mim. This interval can be divided in to 16 parts to define of the Line Speed membership functions. The input variable Coating Weight Set Value is changing between 45 to 225 gr/cm^2. This interval can be divided in to 7 parts. Output variable Nozzle Pressure is changing between 0.17 to 0.9 kg/cm^2 and Nozzle Gap is changing 60 to 225 mm. The output variables' intervals can be divided in to 8 parts.

Membership functions are defined after defining input and output variables. Membership function definition for Line Speed is shown in figure 4, membership function definition for Coating Weight Set Value is shown in figure 5, membership function definition for Nozzle Pressure is shown in figure 6, membership function definition for Nozzle Gap is shown in figure 7. "TRIMF" type membership function is used to define membership function of input variables and output variables.

"If Then" rules are defined for FIS after defining membership functions. Forty six rules are defined to determine of Nozzle Pressure and Nozzle Gap. Defuzzification method is selected as "Centroid" type. OrMethod is selected as "max", ImpMethod is selected as "min" and AggMethod is selected as "max".

Fig. 3. Definition of input and output variables

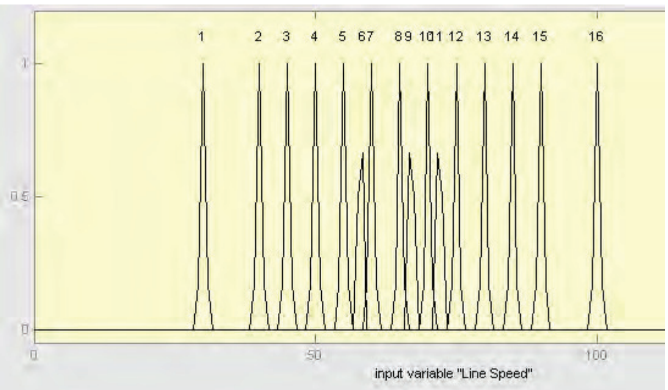

Fig. 4. MF of Line speed

Table 1. Actual measurement

STRIP SPEED	CW SET	M.NOZ PIC	N.Gap Set
mpm	gr/cm2	kg/cm2	mm
30	100	0.6	80
40	100	0.3	195
40	50	0.19-0.2	85
40	70	0.19-0.22	115
45	138	0.18	185
50	50	0.18-0.25	75-90
50	60	0.18-0.24	75-95
50	70	0.2	110
50	138	0.18	150
55	60	0.2-0.26	60-80
55	70	0.18	80
55	100	0.17-0.18	125-130
55	138	0.17-0.2	140-160
58	60	0.18	80
58	138	0.18	150
60	50	0.25-0.3	70
60	60	0.19-0.32	60-80
60	70	0.2-0.24	80
60	100	0.18-0.19	100-110
60	138	0.17-0.2	130-165
60	225	0.17	200
65	50	0.28-0.32	70-80
65	70	0.22	80
65	100	0.18-0.19	100
65	138	0.19-0.22	120-145
65	225	0.19	200-225
67	50	0.35	80
70	50	0.3-0.37	70-80
70	60	0.26-0.36	60-80
70	70	0.24-0.26	80
70	100	0.18-0.25	95-100
70	138	0.18-0.25	130-150
72	50	0.33	70
72	100	0.18	100
75	60	0.36	80
75	100	0.2	80
80	45	0.81-0.9	60-70
80	50	0.38	70
80	60	0.29-0.32	70-80
80	70	0.25-0.26	70
80	138	0.170.19	85-105
85	138	0.18-0.19	95
90	138	0.18	85
100	100	0.22-0.24	70
100	138	0.17-0.19	75-80

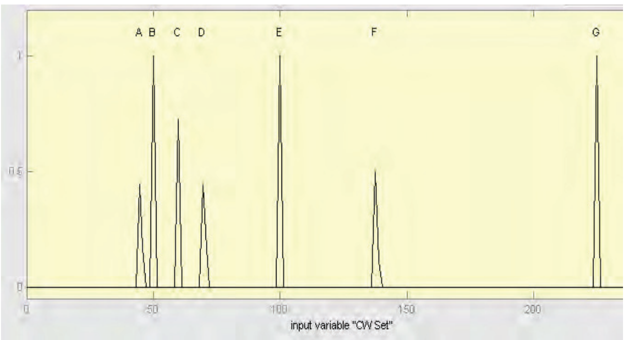

Fig. 5. MF of CW

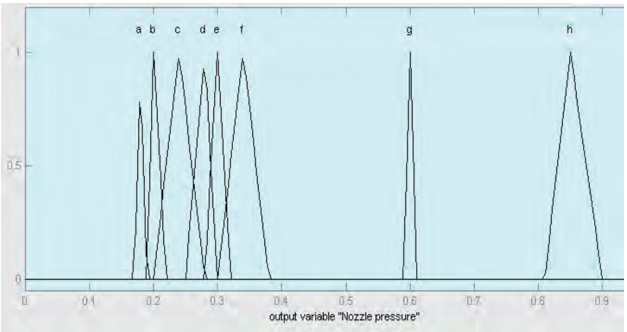

Fig. 6. MF of Nozzle pressure

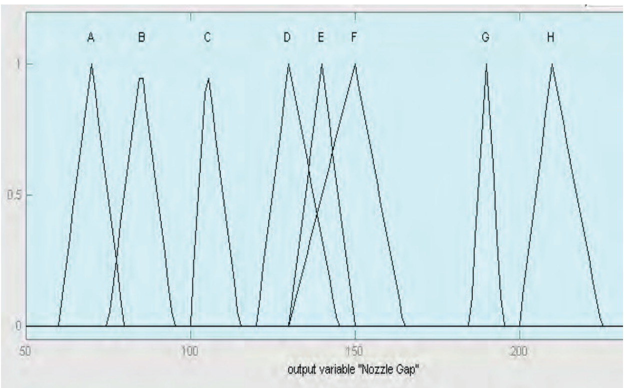

Fig.7. MF of Nozzle gap

5. Test of FIS

After designing the FIS we tested this new method using Rule Viewer for different input values as shown in figure 8. Actual measurement values shown in table 1 are used for testing of the FIS. In this table strip speed, coating weight set, main nozzle pressure and nozzle gap set values are measured. Thus system parameters taken at the production time by experienced operators can be obtained as a list. According to this actual measurement values we designed the FIS. FIS is tested by using measured strip speed, coating weight set, main nozzle pressure and nozzle gap set values and both FIS outputs and actual measured outputs. The results are shown in table 2.

Table 2. FIS outputs

STRIP SPEED	CW SET	M.NOZ PIC	N.Gap Set
mpm	gr/cm2	kg/cm2	mm
30	100	0,6	85
40	100	0,3	190
40	50	0,203	85
40	70	0,203	107
45	138	0,18	190
50	50	0,203	85
50	60	0,203	85
50	70	0,203	107
50	138	0,18	148
55	60	0,24	70
55	70	0,18	85
55	100	0,18	132
55	138	0,18	148
58	60	0,18	85
58	138	0,18	148
60	50	0,277	70
60	60	0,3	70
60	70	0,24	85
60	100	0,18	107
60	138	0,18	148
60	225	0,18	212
65	50	0,3	70
65	70	0,203	85
65	100	0,18	107
65	138	0,203	132
65	225	0,18	212
67	50	0,34	85
70	50	0,34	70
70	60	0,3	70
70	70	0,24	85
70	100	0,203	107
70	138	0,203	140
72	50	0,34	70
72	100	0,18	107
75	60	0,277	85
75	100	0,203	85
80	45	0,853	70
80	50	0,34	70
80	60	0,3	70
80	70	0,24	70
80	138	0,18	107
85	138	0,18	85
90	138	0,18	85
100	100	0,24	70
100	138	0,18	70

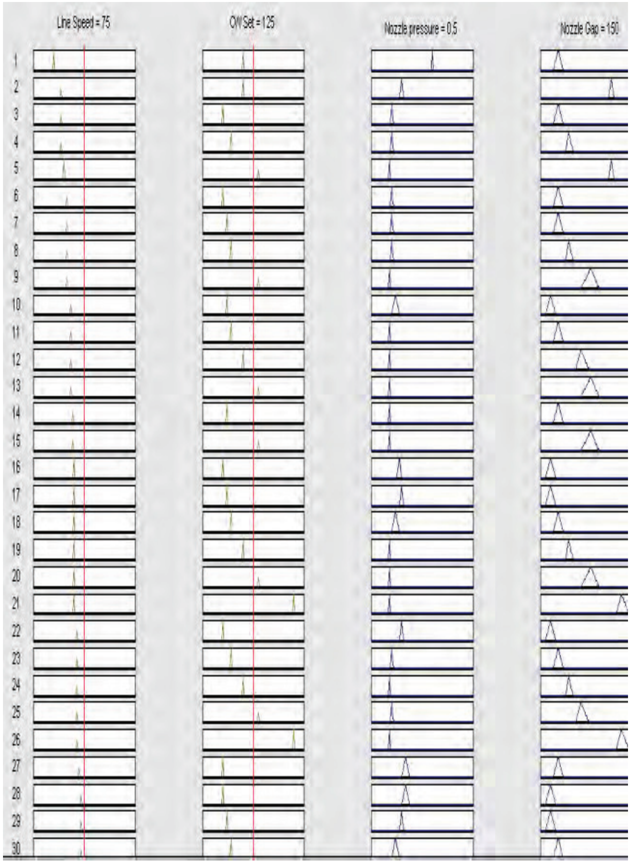

Fig. 8. Rule viewer of FIS

If the results obtained in table.1 and table.2 are compared, it will be seen that the FIS outputs and the manual system outputs based on the experiences of the operators are very close to each other. For example, in case of strip speed being 30 mpm and coating weight set value being 100 gr/cm2, the operators can adjust the desired thickness of coating by adjusting the value of main nozzle pressure to 0.6 kg/cm2 and the value of nozzle gap to 80 mm. In the same working conditions, FIS produces outputs of main nozzle pressure value of 0.6 kg/cm2 and nozzle gap value of 85 mm. Similarly, FIS gives satisfactory results in the experiments performed for the other working conditions. The accuracies of the FIS output will be able to be increased by increasing the period of the measurements performed to obtain the table used in FIS design, i.e., by obtaining much more adjustment parameter for different working conditions

The main nozzle pressure and nozzle gap values which are adjusted by the operators manually by using FIS are adjusted automatically. Thus, it is seen that the problems such as the quality defects due to manual working and high cost of production can be removed. As a conclusion, the usability of Fuzzy Inference System based on Controls in Hot Dip Galvanizing Lines can be seen.

6. Conclusions

This paper presents a new galvannealing control system to optimize metallurgical process. Fuzzy Inference System based on new control system enables production to be run safely and quality of the coating layer. Fuzzy Inference System Controls in Hot Dip Galvanizing Lines is satisfied. The proposed fuzzy inference system approach has been successfully applied to Hot Dip Galvanizing.

A new coating thickness control model based on Fuzzy Inference System features two important improvements: It is more cost-effective than conventional solutions and it delivers a better quality product. A discussion of simulation results shows the improvements achieved by using FIS in comparison to the conventional controller.

By implementing the FIS based coating thickness control model, manufacturers of hot dip coated material reap a number of benefits. These include significant quality improvement through coating uniformity via online adaption of a self-learning model despite coating thickness changes, strip speed changes and changing plant parameters.

Equally important hot dip galvanizing lines are run far more effectively through:

- Optimum operation at the minimum permissible coating thickness specified by the applicable standards.
- Optimization of the minimum coating thickness, independent of operation control personnel.
- Shortest transition time for coating thickness changes.

Automatic adaptation to changed plant parameters without operator intervention.

7.References

[1] Christian Schiefer, Franz X.Rubenzucker, H. Peter Jörgl and Heinrich R. Aberl, “A Neural Network Controls the Galvannealing Process”, IEEE Transactions on Industry Applications, Vol.35, No.1, January/February 1999, pp.114-118.

[2] L.A. Zadeh, “Fuzzy sets,” Information Control,Vol.8, 1965, pp.338-353.

[3] Hung T. Nguyen, Elbert A. Walker, A first Course In Fuzzy Logic, Chapman and Hall / CRC 2000.

[4] Kuru E., Kuru L., Köklükaya E., ”Classification of Harmonic Distortions as a Function of Angle Using Fuzzy Classification In Full-Bridge, Single-Phase Inverter and Active Filter”, International Conference on Electrical and Electronics Engineering, ELECO’ 2003