Improvement of Zinc Coating Weight Control for Transition of Target Change

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The product specification of the Continuous Hot Dip Galvanizing Line (CGL) changes and varies constantly with different customers' requirements, especially in the zinc coating weight which is from 30 to 150 g/m^2 on each side. Since the coating weight of zinc changes often, it is very important to reduce time spent in the transfer of target values changed for low production cost and yield loss. The No.2 CGL in China Steel Corporation (CSC) has improved the control of the air knife which is designed by Siemens VAI. CSC proposed an experiment design which is an $L_9(3^4)$ orthogonal array to find the relations between zinc coating weight and the process parameters, such as the line speed, air pressure, gap of air knife and air knife position. A non-linear regression formula was derived from the experimental results and applied in the mathematical model. A new air knife feedforward control system, which is coupled with the regression formula, the air knife control system and the process computer, is implemented into the line. The practical plant operation results have been presented to show the transfer time is obviously shortened while zinc coating weight target changing and the product rejected ratio caused by zinc coating weight out of specification is significantly reduced from 0.5% to 0.15 %.

Keywords *: coating, galvanizing, zinc, CGL*

1. Introduction

The product specification of CSC No.2 CGL, such as the size of steel sheets, annealing temperature, etc., changes and varies constantly with different customers' requirements. Considering the connected conditions of actual operation and production, the zinc coating weight ranges between 30 to 150 g/m^2 on each side. Since the coating weight of zinc diverged greatly and changed frequently, it adds complications to come up to the requirement of customers. The product rejection for over or less - coating raises the cost and reduces the product yield. In the second quarter 2008, the rejection rate of No.2 CGL production was 0.53%. Therefore, to closely match the required zinc coating weight and overcome the effect of the transition delay becomes the most important topic for the operational cost savings.

2. Experiment procedure

CSC designed an experiment to find out the mathematical model of air knife by using SAS Regression Procedure.

2.1 The background of experiment

(1) A 4-factor & 3-level orthogonal array, named $L_9(3^4)$, is used to evaluate the key factor of the coating weight in this experiment. There are totally 9 tests with certain

Table 1. $L_9(3^4)$ Orthogonal Array

Test	A (speed, m/min)	B (pressure, kpa)	C (distance, mm)	D (gap, mm)	CW (g/m^2)
1	70	13	8.5	0.6	y_1=89
2	70	25	12	0.8	y_2=57
3	70	35	15	1.0	y_3=47
4	100	13	12	1.0	y_4=148
5	100	25	15	0.6	y_5=150
6	100	35	8.5	0.8	y_6=39
7	130	13	15	0.8	y_7=200
8	130	25	8.5	1.0	y_8=63
9	130	35	12	0.6	y_9=92

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conditions in $L_9(3^4)$ orthogonal array, and the actual coating weight are listed in Table 1 from y_1 to y_9.

(2) The factors in the experiment are center line speed (Factor A), air pressure of air knife (Factor B), distance between air knife and strip (Factor C), and gap of air knife (Factor D).

(3) The levels of Factor A are 70, 100, 130 m/min; Factor B are 13, 25, 35 kpa; Factor C are 8.5, 12, 15 mm, and Factor D are 0.6, 0.8, 1.0 mm. Please refer to Table 1.

2.2 The results of experiment

According to the results of the experiment, we have

(1) The ground average of coating weight is

$$\bar{y} = (y_1 + y_2 + ... + y_9)/9 = 98.3 \text{ g/m}^2$$

(2) The CW calculation of the effect of factors are following and shown in the Table 2.

A(70)=(89+57+47)/3=64.3
B(13)=(89+148+200)/3=145.7
C(8.5)=(89+39+63)/3=63.7
D(0.6)=(89+150+92)/3=110.3

A(100)=(148+150+39)/3=112.3
B(25)=(57+150+63)/3=90
C(12)=(57+148+92)/3=99
D(0.8)=(57+39+200)/3=98.7

A(130)=(200+63+92)/3=118.3
B(35)=(47+39+92)/3=59.3
C(15)=(47+150+200)/3=132.3
D(1.0)=(47+148+63)/3=86

Table 2. The calculation of the effect of factors

Variables	Levels	Results(y)	*Effect
A	70	64.3	-34
	100	112.3	14
	130	118.3	20
B	13	145.7	47.3
	25	90	-8.3
	35	59.3	-39
C	8.5	63.7	-34.6
	12	99	0.6
	15	132.3	34
D	0.6	110.3	12
	0.8	98.7	0.3
	1.0	86	-12.3

* The definition of effect is $y-\bar{y}$, for example, the effect of A(70) = 64.3 -98.3 = -34

(3) From Table 2, we found that the CW is proportional to the strip speed and distance between air knife and strip, whereas CW is inversely proportional to air pressure and gap of air knife. Therefore, Table 2 and the operation experience point to the same conclusion.

(4) It is assumed that the coating weight is linear to the strip speed, air pressure, distance between air knife and strip, and gap of air knife, we obtain a regression formula by using *SAS Regression Procedure* which is described by

$$\begin{aligned} CW = f(A,B,C,D) &= a_0 + a_1 \cdot A + a_2 \cdot B + a_3 \cdot C + a_4 \cdot D \\ &= 29 + 0.87 \cdot A - 4 \cdot B + 10.5 \cdot C - 56 \cdot D \end{aligned} \quad (1)$$

where a_0 is interception of the regression formula, and a_1, a_2, a_3, a_4 are the coefficient of factor A, B, C and D respectively.

2.3 Confirmation test and *SAS RSREG Procedure*

We applied the linear regression formula to check the prediction in coating weight. Table 3 shows the difference between the prediction and actual coating weight is variant.

In order to obtain the more accurate estimations of the coating weight, a non-linear formula is necessary. A huge mass of production data are used as inputs of *SAS RSREG Procedure*, then the polynomial series is given by

$$\begin{aligned} CW &= f(A,B,C,D) = f(x_1, x_2, x_3, x_4) \\ &= a_0 + \sum_{i=1}^{4} a_{1i} x_i + \sum_{i=1}^{4} a_{2i} x_i^2 + \sum_{\substack{i=1 \\ j=1}}^{4} a_{3ij} x_i x_j \end{aligned} \quad (2)$$

The difference between the actually observed and computed coating weight is much slight when using the polynomial series. And the standard deviation estimated is less than 5 g/m^2.

2.4 Feedforward control system

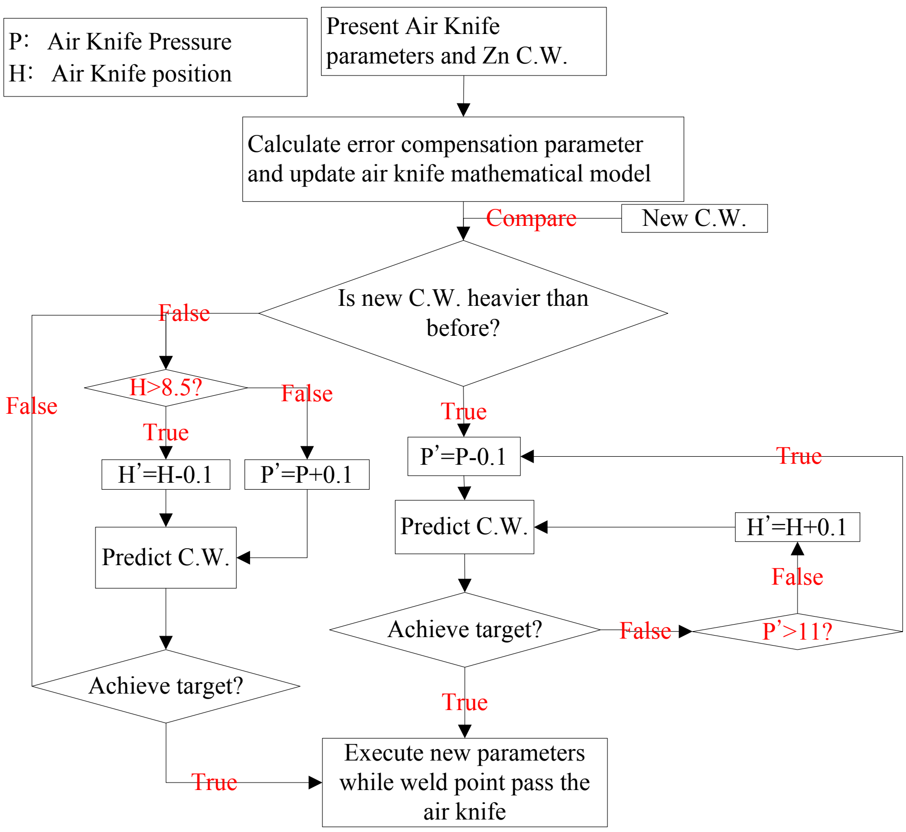
According to the operating experience, the zinc coating quality depends on many parameters. The primary factor is the accuracy of air knife position. Furthermore, the air knife pressure, line speed and lip gap are also important to meet the requirement in terms of coating quality. Therefore, we designed a simple flowchart which is shown as Table 4 and implemented it in the process computer.

Before the target values of zinc coating weight change, the air knife control computer transfers the relative process parameters to the process computer immediately. And then the process computer calculates the error compensation parameter by air knife mathematical model, update the model, predict the air knife parameters to match the new target

Table 3. Difference between the prediction and actual coating weight

Test	A(Speed)	B(Pressure)	C(Distance)	D(Gap)	Act. CW	Predict CW	Difference
1	70	13	8.5	0.6	89	94	5
2	70	25	12	0.8	57	71	14
3	70	35	15	1.0	47	51	4
4	100	13	12	1.0	148	134	-14
5	100	25	15	0.6	150	140	-10
6	100	35	8.5	0.8	39	20	-19
7	130	13	15	0.8	200	203	3
8	130	25	8.5	1.0	63	75	12
9	130	35	12	0.6	92	95	3

Table 4. Predict Flowchart of Air knife parameters



of coating weight and feedback to the air knife. The air knife system will automatically adjust the position and pressure while the weld point of strip passes through. The entire operation procedure is illustrated in Table 4 and Fig. 1.

2.5 Result of application

We can see the dramatic improvement after adopted the air knife feedforward controller, Fig. 2 shows the coating weight target only missed 0.28% in 95% confidence interval. Applied the refined air knife controller, the operators just need to confirm data of air knife computer. The computer systems could calculate dynamically and automatically instead of manual operations. The major improvement is solving the problems caused by coating weight changed frequently and decreasing the ratio of product rejection.

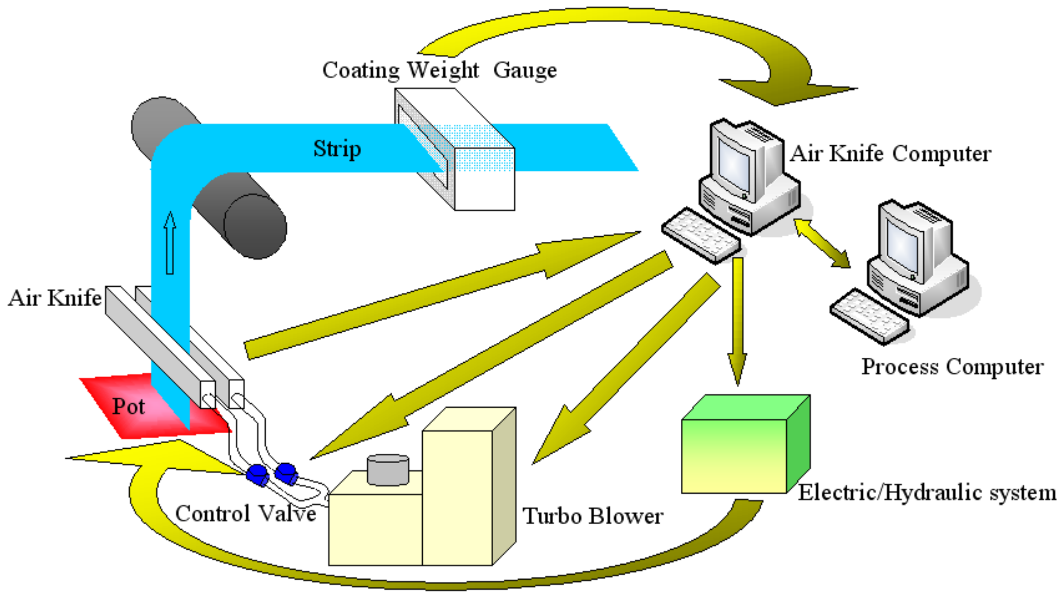


Fig. 1. Air Knife Control System.

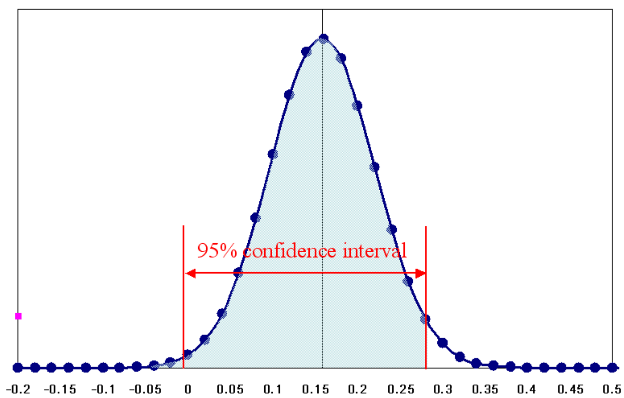


Fig. 2. Distribution of coating weight missed.

3. Conclusions

It is difficult to match the target values while zinc coating weight changed with the conventional feedback control in short time. Solving the Air-Knife mathematical model by using the results of the experiment and regression analysis, CSC developed the model based feedforward controller to automatically controls air knife to supplement the original control system. Another significant benefit involves savings in zinc consumption by avoiding excessively heavy coatings, which has greatly increased productivity and decreased the cost of production.

References

1. Zhao-Ying Peng, *SAS and Statistical Analysis* (2007).