KAWASAKI STEEL TECHNICAL REPORT
No.34 (March 1996)
Highly Efficient Production and
Application of sheet Produts,and
Application Development in Open System's Age

Techniques of Automatic Operation in Continuous Galvanizing Line

Takanori Adachi, Yasuo Tomura, Takayuki Yoshioka

Synopsis :
Operation at the entry section, zinc coating weight control, and galvannealing control are main techniques of automatic operation in continuous galvanizing lines at Kawasaki Steel. These techniques contribute to quality improvement and labor saving. The coil transport and threading equipment in the entry section have been automated by a process computer. Automatic zinc coating weight control, which uses a physical model, has achieved high accuracy of a standard deviation of 3.0 g/m2 of the zinc coating weight, when the zinc coating weight target is changed. Automatic galvannealing control, which uses emissivity changes when Fe diffuses in the zinc coating layer, has also reduced the standard deviation of the Fe contents by half, achieving a high accuracy of 0.3%.

The body can be viewed from the next page.

Techniques of Automatic Operation in Continuous Galvanizing Line*


Takanori Adachi
Cold Rolling Technology Sec., Cold Rolling Dept. II, Chiba Works


Yasuo Tomura
Staff Assistant Manager, Plant Control Technology Development Sec., Process Development Dept., Chiba Works


Takayuki Yoshioka
Facilities & Distribution Equipment Marketing Sec., Construction Marketing Dept., Engineering & Construction Divisional Group

Synopsis:

Operation at the entry section, zinc coating weight control, and galvannealing control are main techniques of automatic operation in continuous galvanizing lines at Kawasaki Steel. These techniques contribute to quality improvement and labor saving. The coil transport and threading equipment in the entry section have been automated by a process computer. Automatic zinc coating weight control, which uses a physical model, has achieved high accuracy of a standard deviation of 3.0 g/m² of the zinc coating weight, when the zinc coating weight target is changed. Automatic galvannealing control, which uses emissivity changes when Fe diffuses in the zinc coating layer, has also reduced the standard deviation of the Fe contents by half, achieving a high accuracy of 0.3%.

1 Introduction

No. 1 CGL[1,2] (continuous galvanizing lines) began operation at Mizushima Works in May 1989 and No. 2 CGL[3] at Chiba Works in August 1991. In order to meet the recent needs of customers for higher quality, as well as to improve our competitiveness in the international market, these CGLs have been designed to ensure a high automatic operation ratio. Especially the automatization of three functions, the coil transport and threading equipment in the entry section, zinc coating weight control, and galvannealing control, has substantially contributed to the improvement of quality and labor-saving.

This paper presents an outline of this automation technology.

2 Outline of Production Process

Figure 1 shows the layout of No. 2 CGL at Chiba Works. Strip coils rolled by the cold rolling mill are automatically mounted on the pay-off reel. After subsequent welding, the strip is passed through an automatically controlled annealing furnace to be heated to a specified temperature, and then dipped in a Zn bath.

A wiping nozzle provided immediately above the Zn bath "sandwiches" the strip, and controls the zinc coating weight to the specified value by the discharged gas. With galvanneald steel (GA), the coated strip is heated in the galvannealing furnace, where the degree of alloying between the zinc coating layer and substrate is controlled.

After passing through the temper mill and tension leveler, the strip is subjected to chromate treatment and oiling, as necessary, and rolled on a tension reel.

3 Automation of Entry Section

Kawasaki Steel's CGLs were constructed in expectation of unattended operation of the entry section from the beginning. Improved functions of the respective automatic equipment have permitted unattended operation of the entry section in No. 1 CGL at Mizushima Works since May 1992 and in No. 2 CGL at Chiba Works since September 1994.

3.1 Coil Storage Equipment

The coil rolled by the cold rolling mill is carried on a coil car to the coil storage yard at the entry section of the CGL, and stored in a section with a specified coil address. Coils stored in the coil storage yard are loaded into the main unit of the CGL in accordance with a load-

* Originally published in *Kawasaki Steel Giho*, 27(1995)3, 149–155

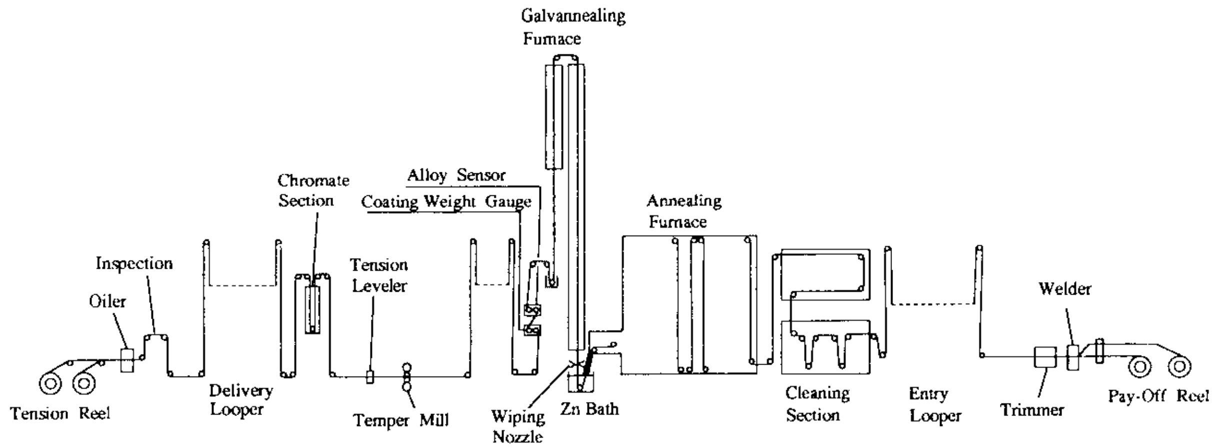

Fig. 1 Layout of Chiba No. 2 continuous galvanizing line (CGL)

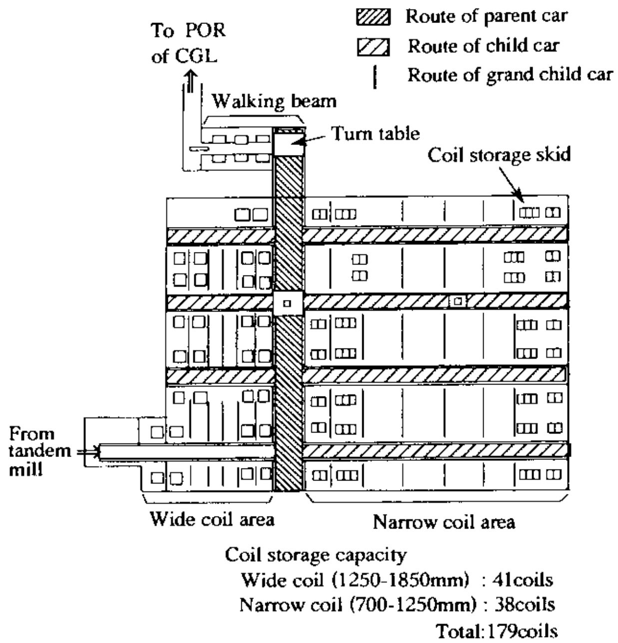

Fig. 2 Top view of entry coil storage yard

ing schedule.

Coil yard management, carrying-in, and carrying-out are all controlled by a dedicated process computer to permit automatic, unattended operation. **Figure 2** shows the top view of entry coil storage yard of No. 1 CGL at Mizushima Works.

3.2 Coil Carrying Equipment

The arrangement and carrying of coils in the entry section are automated. Major automatic equipment includes the following:

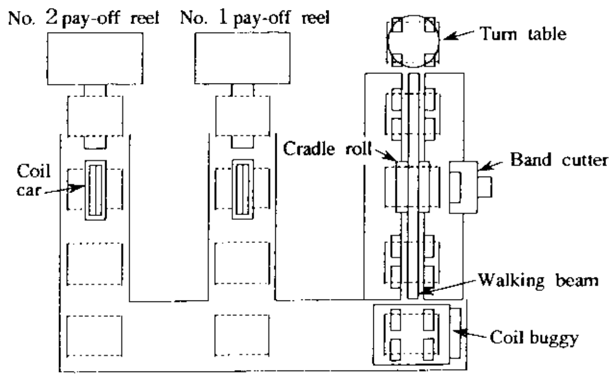

Fig. 3 Outline of coil carrier equipment in the entry section

(1) Turntable (for changing the coil leading-end direction)
(2) Band cutter (for removing bands)
(3) Walking beam and coil buggy (for coil carrying)
(4) Coil car (for receiving coils, height adjustment/centering, and coil mounting)

Figure 3 shows the outline of the coil carrier equipment in the entry section of No. 1 CGL at Mizushima Works.

3.3 Threading Equipment

Figure 4 shows the major automated parts of the threading equipment in the entry section. Detection of the coil leading-end, correction of strip shape by a rough leveler, cutting off-gauge, and welding are all automated, and remote monitoring and control is possible from the central operation room via monitor TVs.

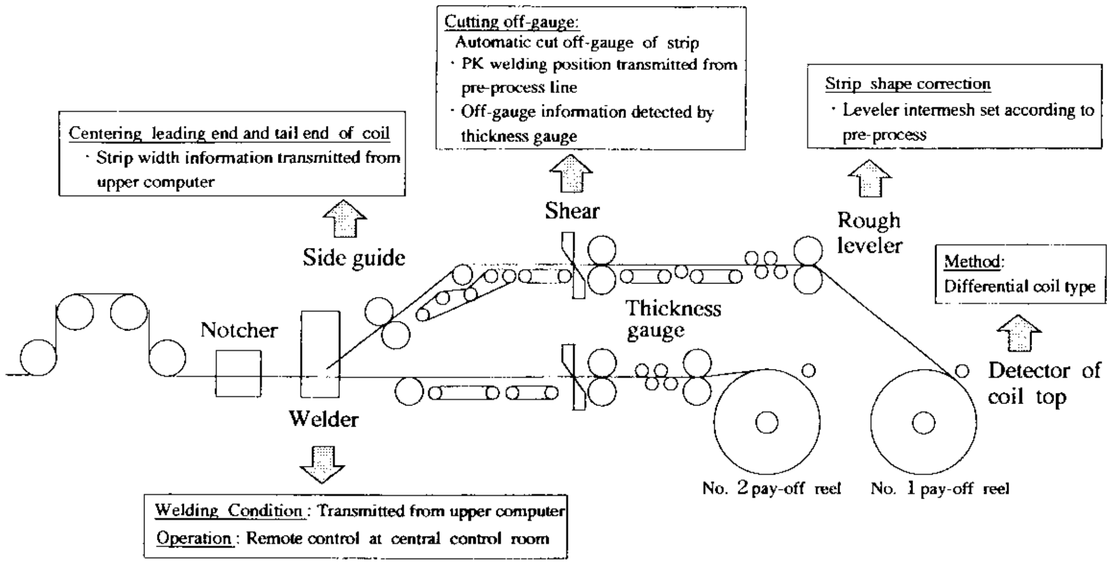

Fig. 4 Outline of automatic operation in the entry section

4 Automatic Zinc Coating Weight Control

The zinc coating weight is controlled by changing the pressure of wiping gas emitted through the wiping nozzle, as well as by changing the nozzle distance. To ensure the target coating weight by controlling the said pressure and distance, it is necessary to formulate an accurate model that permits establishment of optimal setting values based on the present operating conditions. In automatic zinc coating weight control, a physical model that correctly represents the wiping phenomenon has been developed to quantitatively determine the relationship between the respective operating conditions and zinc coating weight. To realize a control system that follows the changes in the pass line of strip, a distance sensor that measures the nozzle distance has been introduced, etablishing the high-precision automatic coating weight control system shown in **Fig. 5**.

The application of the above technology to No. 1 CGL at Mizushima Works is discussed below.

4.1 Zinc Coating Weight Model

Use of the physical model to which the two-dimensional free jet theory[4)] is applied has improved coating weight prediction accuracy to ± 1.5 g/m^2 in the coating weight range of 60 g/m^2 or less. The effect of the nozzle distance on the coating weight differs according to the wiping gas jet range. The physical model is therefore composed of the following two equations in accordance with the distance between the strip and nozzle, as well as the nozzle slit thickness.

- Developing range ($D/B \leq C$)

$$M = L_1 \cdot a_1 \cdot \frac{1}{\sqrt{\eta}} \cdot \sqrt{D} \cdot \sqrt{\frac{\mu_z \cdot L_s}{\left(\frac{P}{P_a}\right)^{\frac{\gamma-1}{\gamma}} - 1}} \quad \cdots\cdots\cdots\cdots\cdots (1)$$

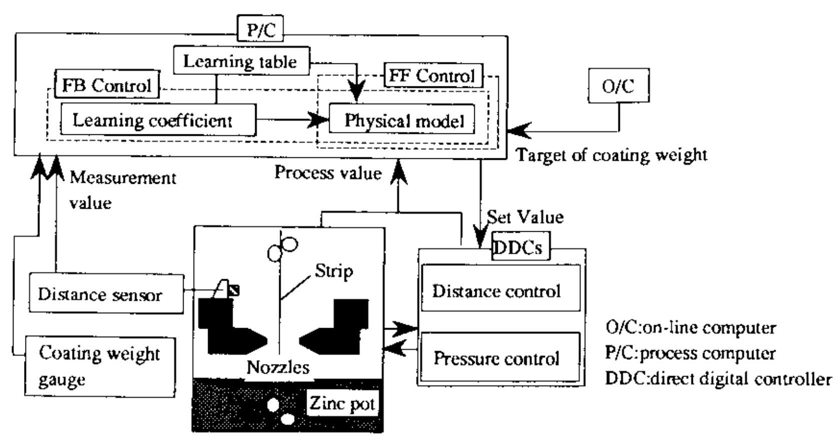

Fig. 5 System configuration of coating weight control

- Fully developed range ($D/B > C$)

$$M = L_2 \cdot b_1 \cdot \frac{1}{\sqrt{\eta}} \cdot \frac{D}{\sqrt{B}} \cdot \sqrt{\frac{\mu_Z \cdot L_s}{\left(\frac{P}{P_a}\right)^{\frac{\gamma-1}{\gamma}} - 1}} \quad \cdots\cdots (2)$$

M: Coating weight (g/m^2)
η: Nozzle efficiency
D: Distance between strip and nozzle
μ_Z: Zinc viscosity (Pa · S)
L_s: Line speed (m/min)
P: Gas pressure (Pa)
γ: Ratio of specific heat
P_a: Atmospheric pressure (Pa)
B: Nozzle slit thickness (mm)
L_1, L_2: Learning factor
a_1, b_2, C: Constant

4.2 Nozzle Distance Sensor

The distance between the strip and wiping nozzle is dynamically controlled by an eddy current type distance sensor installed on the wiping nozzle, which measures the fluctuation of the strip pass line on a real-time basis.

An eddy current type distance sensor is not influenced by Zn powder or splashes in the vicinity of the wiping nozzle, and its measuring range is wider than that of other types of distance sensor; therefore, it averages local warpage of the strip to provide optimal control. However, an eddy current type distance sensor is subject to the influence of temperature change. Therefore, in this sensor[5] described here, a ceramic material with a small coefficient of thermal expansion is used, and a Pd alloy which remains stable irrespective of temperature change is used as an internal coiling wire. Furthermore, the main unit of the sensor is of thermocouple construction for temperature compensation to ensure stable characteristics irrespective of temperature change, as shown in **Fig. 6**.

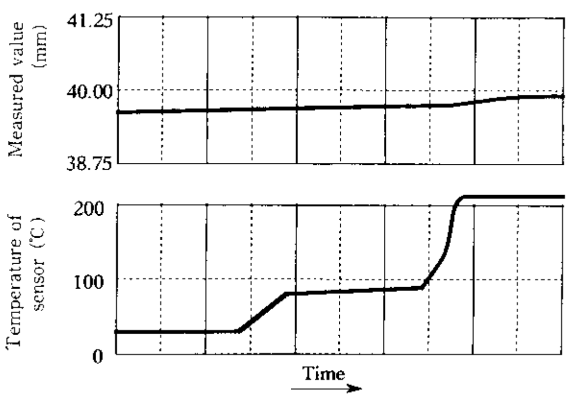

Fig. 6 Characteristics of distance sensor

4.3 Coating Weight Control Method

The coating weight is affected by the line speed and changes in the temperature of the Zn bath. Since the coating weight gauge is installed at a distance of approximately 130 m from the wiping nozzle in terms of strip length, dead time will be so great, if feedback control alone is used, that control will be delayed when chnages in the line speed or other disturbances occur.

To ensure a uniform coating weight over the entire length of the strip, the coating weight control method is provided with the respective functions described below.

4.3.1 Feedforward (FF) control

The actual values of line speed and nozzle distance are collected every five seconds, and when change of coating weight target or manual intervention occurs, the set value of the nozzle distance and wiping gas pressure are dynamically calculated based on the physical model for control.

Equations (1) and (2) are switched in accordance with the next set value of the nozzle distance.

4.3.2 Feedback (FB) control

When operating conditions are in the steady state, the learning factor L_n (n = 1 or 2) is calculated according to the following equation immediately after the actual coating weight is measured:

$$L_n = M_p/M_c \quad \cdots\cdots (3)$$

M_p: Actual coating weight (g/m^2)
M_c: Calculated coating weight (g/m^2)

Here, M_c is obtained by substituting $L_n = 1$ and the actual operating results into Eqs. (1) and (2). Calculated L_1 and L_2 are incorporated into Eqs. (1) and (2) to reset the nozzle distance and wiping gas pressure. L_n is stored in a learning table that is hierarchically classified according to the operating conditions and type of steel.

4.3.3 Learning control

To change the set value at the weld point, where the target coating weight and sheet thickness change, learning factors L_1 and L_2, which are stored in the learning table, are set in the physical model and used to calculate and set the nozzle distance and wiping gas pressure.

4.3.4 Front and back gas equalizing function

When there is a difference between the front and back wiping gas pressures, there is a possibility of splash and other quality defects occur. In this system, therefore, the values of the nozzle distance and wiping gas pressure are set by the flow in **Fig. 7** so that the difference between the front and back wiping gas pressures will be less than a certain value, thereby suppressing the occurrence of quality defects due to splash.

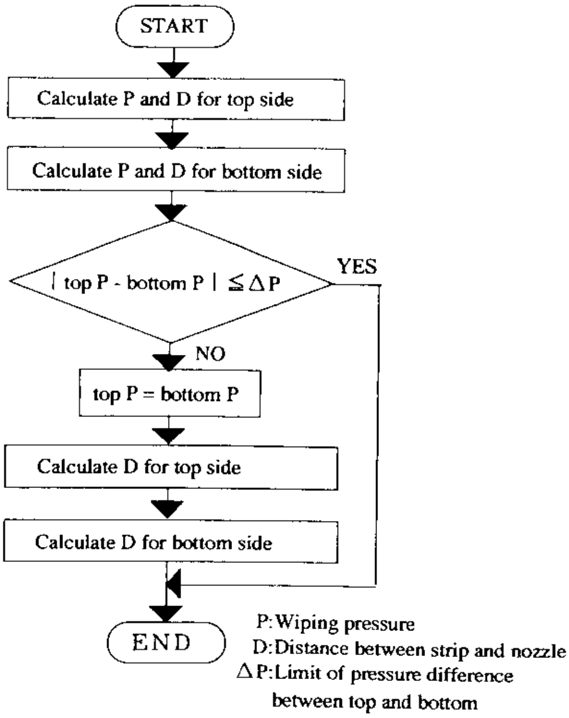

Fig. 7 Flow of equal pressure control

4.4 Status of Implementation

Figure 8 shows the correlation between the calculated and measured coating weight based on the physical model. The standard deviation of error is 1.5 g/m^2, achieving sufficient accuracy. **Figure 9** shows examples of control when the setting changes from a uniform coating weight to a differential coating weight between top and bottom side. While the top and bottom gas pressures are equalized and the nozzle distance is controlled simultaneously, the top and bottom coating weight is so controlled that it will conform to the target coating weight.

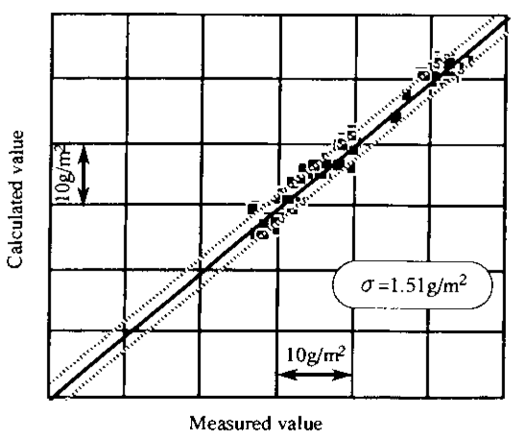

Fig. 8 Correlation between calculated and measured coating weights

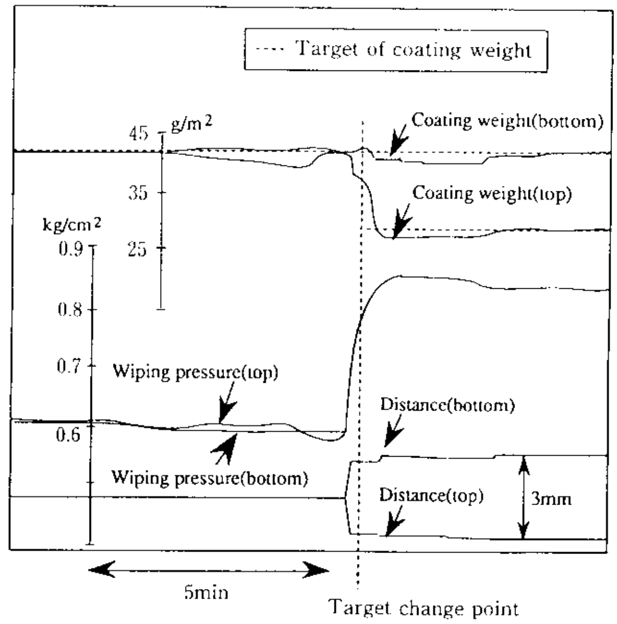

Fig. 9 Example of coating weight change by the automatic control

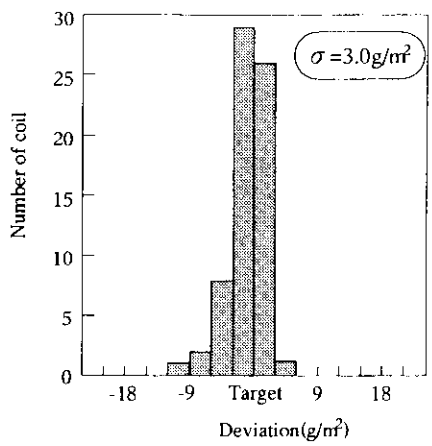

Fig. 10 Deviation of coating weight (results of automatic control)

Figure 10 shows the distribution of the actual coating weight at the leading-end of a coil, which is used as the basis for evaluating the FF control when the target coating weight is changed. The standard deviation (σ) is 3 g/m^2, indicating that favorable results are obtained.

5 Automatic Galvannealing Control

GA is produced in a galvannealing furnace by diffusing the iron in the zinc coating layer. The workability of GA varies according to the quantity of diffused iron (Fe content of the zinc coating layer). It is vital to constantly maintain an optimal Fe content in the zinc coating layer for better workability.

Kawasaki Steel has already developed an on-line alloy sensor[6] (Kawasaki Alloy Sensor: an instrument used to measure the Fe content of the zinc coating layer), which operates on the principle of X-ray diffraction, and put it into practical use. Further, attention has been paid to the change in the emissivity of steel due to the diffusion of Fe in the zinc coating layer, and a technique has been developed to grasp the progress of alloying in the galvannealing furnace, and thus to estimate the Fe content of the zinc coating layer.

Furthermore, practical use of the feedback control technique, in which the above-mentioned estimated values are used, as well as the feedforward control technique at points where coating conditions change, has enabled the production of high-quality GA and automatic galvannealing furnace operation.

The application of the above-mentioned technology at No. 2 CGL of Chiba Works is discussed below.

5.1 Estimation of Fe Contents in Zinc Coating Layer

The Fe content of the zinc coating layer is estimated by determining the progress of alloying of the diffused Fe in the zinc coating layer in the galvannealing furnace from changes in emissivity due to the diffusion of Fe in the zinc coating layer.

It is known that the emissivity on the surface of steel inside a galvannealing furnace suddenly changes from approximately 0.20 to 0.65[7]. Such a change in the emissivity is detected by arranging infrared thermometers in the direction of strip travel in the soaking section of the galvannealing furnace (**Fig. 11**). The point at which emissivity changes suddenly is regarded as the galvannealing point (GP). The GP is represented by the distance from the inlet of the soaking section and is considered to be a point at which the η phase in the coating layer disappers.

Figure 12 shows the relationship between the GP of ultra-low C steel and the value measured by the on-line alloy sensor. As shown in Fig. 12, there is a correlation between the GP and the value measured by the on-line alloy sensor. In other words, the Fe content of the zinc coating layer can be estimated from the GP.

The Fe content of the zinc coating layer is estimated based on a recurrence formula, where the soaking time (Fig. 11) determined by the GP and the strip temperature inside the galvannealing furnace are represented by

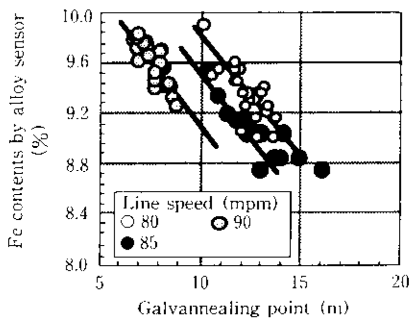

Fig. 12 Relationship between galvannealing point (distance from entrance of soaking section) and Fe contents in coating layer as measured by Kawasaki Alloy Sensor

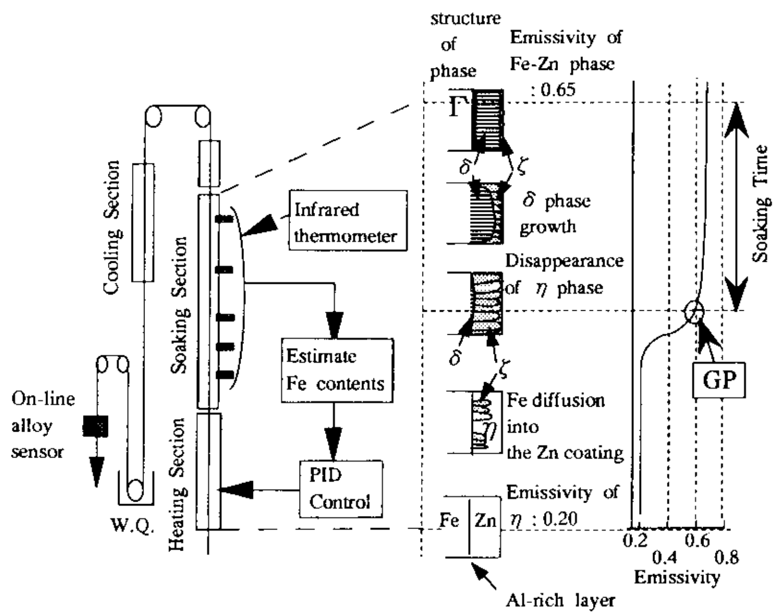

Fig. 11 Change in the coating structure during galvannealing

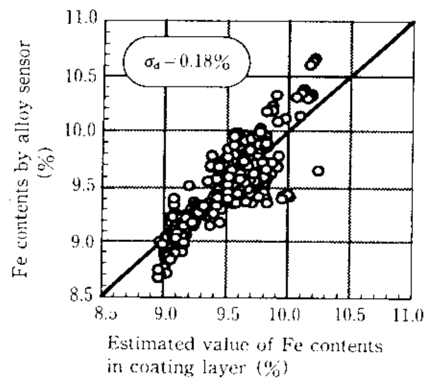

Fig. 13 Correlation of the estimated Fe contents in coating layer evaluated from galvannealing point and that measured with Kawasaki Alloy Sensor

parameters.

Figure 13 shows the relationship between the estimated Fe content of the zinc coating layer and the value measured by the on-line alloy sensor. As shown in the figure, there is a correlation between the estimated Fe contents in the zinc coating layer and the reading of the on-line alloy sensor, and the accuracy (σ_d) obtained with Eq. (4) has reached 0.18%.

$$\sigma_d = \sqrt{\frac{\Sigma (m_i - X_i)^2}{n - 1}} \quad \cdots\cdots (4)$$

m_i: Estimated Fe content of zinc coating layer (%)
X_i: Measured Fe content of zinc coating layer (%)
n: Number of samples

5.2 System Configuration

Figure 14 shows the configuration of the galvannealing control system, and **Fig. 15** shows the block diagram. The Fe content of the zinc coating layer has been controlled by the No. 2 CGL model system P/C (process computer) incorporated in the comprehensive process computer system[8] (CANS: cold autonomous network system) in the multiple production lines in the cold rolling plant of Chiba Works and the EWS (engineering work station) connected to the leased circuit in the No. 2 CGL instrumentation DDC (direct digital controller). The model system P/C provided with an Fe content estimation model performs feedforward control based on the said model. The EWS estimates the Fe content of the zinc coating layer shown in item 5.1 and performs feedback control by PID control. Estimation formulae are subjected to correction based on the values measured by the on-line alloy sensor. One estimation formula is allotted to each type of steel, and the influence of the type of steel is taken into consideration for improved accuracy.

5.3 Status of Implementation

Figure 16 shows examples of the actual use of this control method. In manual operation, the standard deviation (σ) of the Fe content of the zinc coating layer is 0.6%, but introduction of the automatic control system has reduced σ by half, to 0.3%, while eliminating the need for human intervention.

This control system is used in 100% of ultra-low C steel production, contributing to improved quality and stabilized galvannealing furnace operation. Efforts are being made to apply this system for other types of steel.

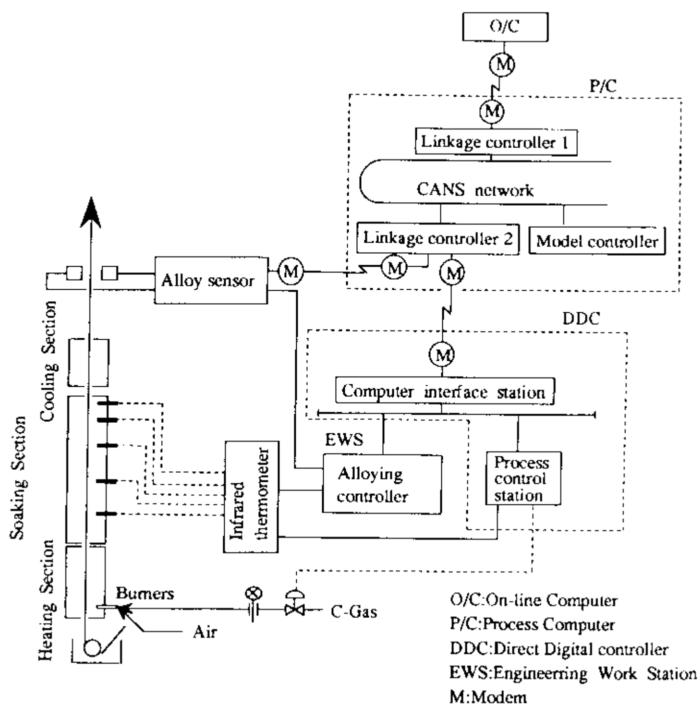

Fig. 14 System configuration of galvannealing control

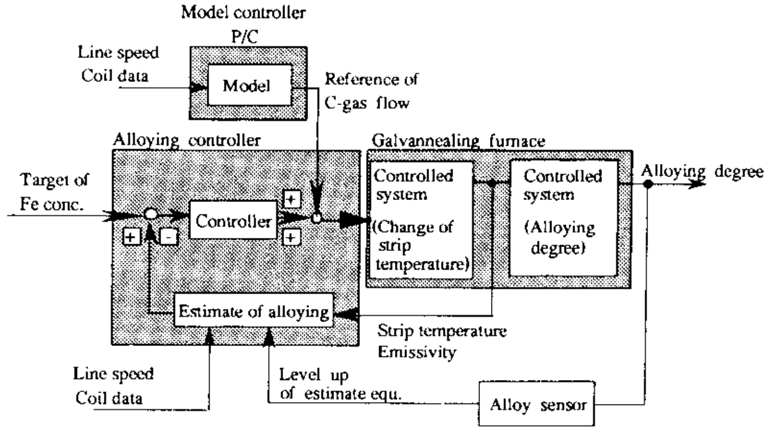

Fig. 15 Block diagram of the galvannealing control system

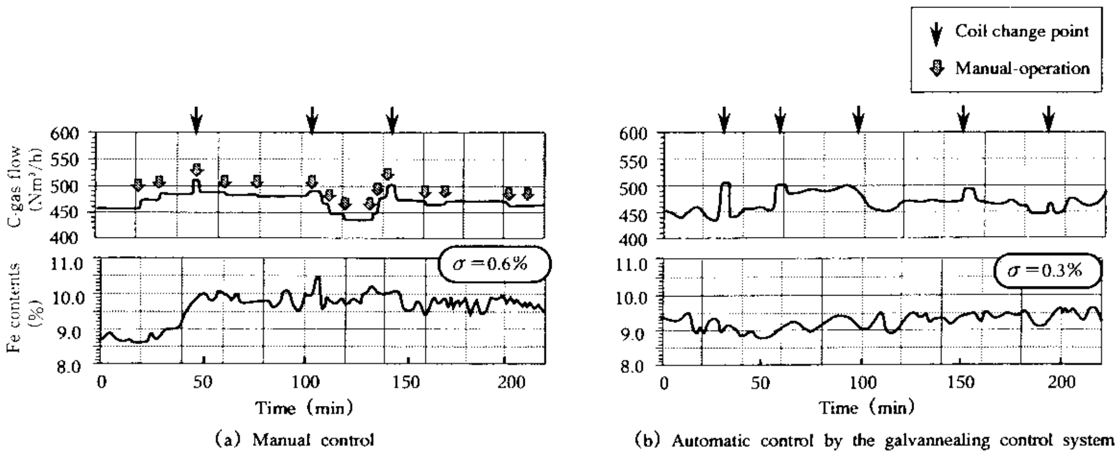

Fig. 16 Comparative results of manual and automatic galvannealing control

6 Conclusions

This paper has introduced the automation of the entry section, automatic zinc coating weight control, and automatic galvannealing control as automatic operation techniques adopted in the continuous galvanizing lines of Kawasaki Steel. The conclusions are shown below.

(1) By upgrading the respective automatic equipment in the entry section and upgrading the process computer, trouble with automatic equipment has been substantially reduced, making it possible to achieve unattended operation of the entry section.

(2) The development of a zinc coating weight model that correctly reproduces the wiping phenomenon and the introduction of a distance sensor to measure the nozzle distance have reduced the standard deviation (σ) of zinc coating weight to 3.0 g/m^2 when the target of coating weight changes, thereby permitting production of products with less zinc coating weight fluctuation.

(3) The development of an automation technique that utilizes the change in the emissivity due to the diffusion of Fe in the zinc coating layer has reduced the standard deviation of the Fe contents in the zinc coating layer by half, to 0.3%, permitting production of products with stable, excellent coating quality.

References

1) T. Kiyasu, S. Iida, H. Shigemoto, N. Suganuma, M. Sakamoto, and S. Iwamoto: "Outline of New Continuous Galvanizing Line for Automobiles," *Kawasaki Steel Giho*, **23**(1991)4, 327
2) T. Sekita, S. Iida, T. Kiyasu, H. Shigemoto, S. Uchiyama, and N. Suganuma: "Development of New CGL at Kawasaki Steel for Automotive Use," 2nd International Conference on Zinc and Zinc Alloy Coated Steel Sheet, Centre de Recherches Metallurgiques, (The Netherlands), (1992), 301
3) M. Arai, K. Akiyoshi, M. Azuma, Y. Ida, Y. Masuno, and M. Kondo: *CAMP-ISIJ*, **2**(1992)5, 666
4) K. Adachi, H. Shigemoto, T. Sekita, and M. Kobashi: *CAMP-ISIJ*, **6**(1993)5, 1560
5) K. Imaike: *Shinkawa Giho*, **2**(1984), 2
6) J. Kawabe, T. Fujinaga, H. Kimura, S. Oshiba, T. Abe, and S. Takahashi: "Continuous Moasuring of Fe Content in Galvannealed Coating," *Kawasaki Steel Giho*, **18**(1986)2, 129
7) N. Saikawa, A. Mori, H. Yokota, S. Yoshinaga, M. Tsukasawa, and K. Hirase: *CAMP-ISIJ*, **1**(1988)2, 592