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Development of numerical model & temperature monitoring system for inductive heater oven

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Abstract: This paper describes numerical model for inductive heating oven and temperature monitoring system for Continuous Coating Line. For induction heating, the heat generation is concentrated within skin depth so exponentially decaying heat distribution was assumed. To calculate and to monitor the oven exit temperature, measurement system was installed on the inductive heater oven including pyrometer and several thermocouples . The experimental result showed the effectiveness of the developed mathematical model.

1. INTRODUCTION

In 2006, the Pohang Coated Steel Co., Ltd. (POCOS) added inductive heater type coater oven on the existing conventional hot air coater ovens in Continuous Coating Line (CCL) Plant, which enables CCL to produce 3C3B (3 coated 3 baked) color sheet to cope with the needs in the marketplace for high-quality home-appliances like outdoor panel of refrigerator. Because of its limited plant space, conventional hot air oven was not applicable, so Inductive Heating Oven (IHO) was selected for its fast heating up capability in relatively short distance to travel.

The coater oven mainly consists of two parts. One is coater and the other is oven. The coater is composed of three rollers to apply liquid paint from bath to the surface of galvanized cold rolled steel sheets, The inductive heating oven consists of three inductive heating chambers in series, each of them was separated by blowers for fume evacuation. The purpose of the oven is to heat and dry the liquid paint on steel sheet and moreover it should be controlled to meet the desired final exit temperature, so called PMT (Peak Metal Temperature).If the final exit temperature is too low the paint is not fully solidified so that it might stick on roller, On the other hand, if it is overheated then the laminated paint become not only brittle but also tarnished. So it is important to monitor the strip temperature in real time.

Infrared radiation pyrometer is commonly used to measure the temperature of continuously moving strip. But it is needed to know the exact emissivity of color film to measure the accurate temperature of coated strip. unfortunately the paint has variety of polymer composition so it is uneasy to cope with. And the pyrometer is also affected by reflected external radiation which makes measurement error quite large. So it is needed to develop numerical model for IHO to estimate final exit temperature.

In this paper, the coater oven in CCL plant was described, the numerical model to estimate exit strip temperature for IHO was developed and the temperature measurement system which gives real time information to operators was described.

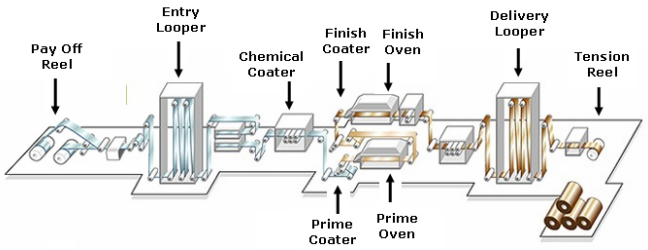

Fig. 1. Layout for Color Coating Line (CCL) with two conventional hot air coater-ovens

2. PROCESS DESCRIPTION

The layout of newly added coater oven is shown in Fig.2. The steel strip travels a distance of 16 (m) of heater with line speed of 40 (mpm) and is heated from room temperature to 200 $\sim$ 270 (C) by three 200 (kW) inductive heaters with the operating frequency of 25 (kHz).

Between the inductive heaters there are four hot air blowers with inlet air temperature about 150 (C), the hot air is used to exhaust the fume during the operation and supplied from the previous Finish Oven. The hot air comes in and flows through the inductive heater and goes out to the opposite side of it.

The strip thickness is ranging from 0.4 to 1 (mm) and width from 700 to 1500 (mm). the final laminated coating film thickness is ranging from 5 to 10 (μm).

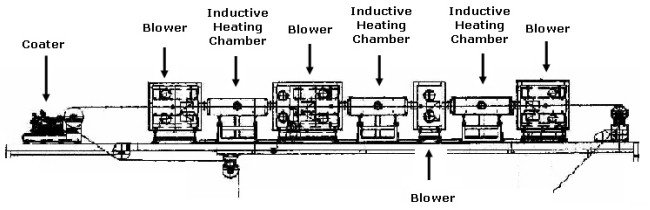

Fig. 2. Layout of inductive heating coater oven installed on CCL plant

3. NUMERICAL MODEL

The numerical model for strip temperature was developed to estimate the exit strip temperature. The governing equation and boundary condition for strip temperature are as follow:

$$\rho C_p \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial y^2} + \dot{q}_g.$$
$$-k \frac{\partial T}{\partial y} = \epsilon\sigma(T^4 - T_\infty^4) + h(T - T_{air})$$

where T is the temperature, t is the time, y is the coordinate in the direction of the strip thickness, and $\dot{q}_g$ is the heat generation in the strip due to induction heating. And ρ,C_p and k are the density, heat capacity, and thermal conductivity, respectively. In induction heating, the power is concentrated within the skin depth which is related with the property and frequency. So the heat generation in the strip has the exponentially decaying distribution from the surface. For the boundary condition at the strip surface, the surface heat flux is composed by the radiation and convection heat transfer.

4. MEASUREMENT SYSTEM

To measure the strip temperature, infrared radiation pyrometer was installed under the exit of inductive heating oven, which has 3.4 (μm) wavelength suitable for paint coated strip temperature measurement, and showed good linearity from 40 to 300(C) . The 'Calibration System' of Williamson. Co. was used to measure the emissivity of various color sheets.

For numerical model calculation,Main computer was installed in the operation room to gather required information such as the input power supplied by inductive heater, hot air temperature of IHO, and process operation informations like line speed and thickness of strip and so on. For that purpose, eight K-type thermocouples were newly installed on three inlets and five outlets of the blower to measure hot air temperature of IHO and the other data were collected by communicating with main control PLC and inductive heater operation inverter. Fig.3. shows the pyrometer and thermocouples installed.

5. EXPERIMENTAL RESULT

Strip of width 800 (mm), thickness 0.8 (mm) was used for experiment, the line speed was 40 (mpm). The coated film material was gray colored epoxy polymer and emissivity was measured by Calibration System and found to be 0.75.

Fig. 3. The pyrometer and thermocouples installed on the inductive heating oven

Before the measurement started, Heat Label was used to check the exit temperature for comparison, which showed that the temperature was around 220 (C). After that the experiment was conducted over 3 hours. Fig. 4 shows the experimental result. The first and second graph shows inductive heater's power input and one of the outlet air temperature change, respectively. The third graph shows pyrometer measurement and we concluded that reflected external radiation error is about 50 (C) when compared with Heat Label. The fourth graph shows model calculated result. Although the calculated result does not use information from the pyrometer at all, it showed very similar pattern with that of pyrometer. The fifth graph shows difference between pyrometer and calculated result without reflected external radiation error, The difference between the two was within 5(c).

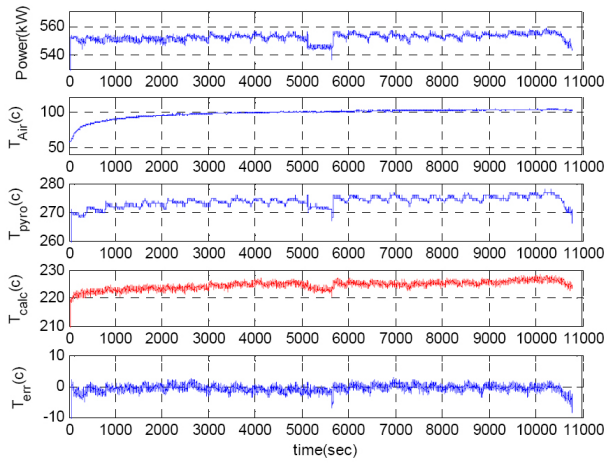

Fig. 4. Experimental Result for inductive heating oven

6. CONCLUSION

We have developed mathematical model for Inductive Heating oven and it was shown that developed numerical model gives very similar pattern with that of pyrometer.

REFERENCES

D.F. Dunn and W.E. Higgins Optimal Gabor filters for texture segmentation IEEE Trans. Image Process., vol. 7, pp. 947-964, 1995.

T. Chang and C.C. Jay Kuo. Texture analysis and classification with tree-structured wavelet transform. IEEE Trans. Image Process., vol. 2, pp. 429-441, 1993.