Model based control of zinc-coating weight on hot-dip galvanizing lines

Fig. 1

The model based controller automatically controls air-knife pressure to give a constant and uniform zinc coating in accordance with customer–order specification. Another significant benefit involves savings in zinc consumption by avoiding excessively heavy coatings. A typical hot-dip galvanizing line is shown in Fig.1.

Two similar but separated controllers, one on each side of the strip, determine set points for the top and bottom air knife pressure. Knife positions and line speed are manually controlled.

For coating weight measurements "cold" gauges are used which are mounted a significant distance downstream from the air knives. This condition introduces a transport lag in the control loop.

Feedforward control is used to overcome the effect of the transport delay. The controller uses a simple empirical nonlinear model for each side of the strip in which deposited mass (m) depends on air knife pressure (p), knife distance (d), strip speed (v) and model parameter K. The parameter K accounts for any systematic modeling errors.

$$\text{Model:} \quad m = K\, d^{\gamma} \frac{v^{a}}{p^{\beta}}$$

The model is used in a predictive mode (inverse model) to determine air pressure p. To the extent that the inverse model depends on measurements of line speed and knife distance it can be regarded as feed-forward control. The parameters α,β,γ are adjusted offline for a particular air knife.

Feedback, in the form of time-delayed measurements of coating weight, is used to drive an adaptation algorithm (**observer**) updating the model coefficient K. The observer satisfies the equation:

$$K(t) = K(t\text{-}1) + k\,[\,y(t) - m(t)\,]$$

where y(t) is the gauge measurement and m(t) the predicted coating weight at the cold gauge. The observer gain k is time-varying.

With the self tuning property of the controller the expected steady-state error is zero. The observer includes an accurate **strip-tracking** system between knife and cold gauge.

The effectiveness of the controller has been demonstrated on full-scale

The controller is available as a software module (language C) to interface with existing scanning gauges and air knife computer systems.

galvanizing lines. A **"hot" gauge** close to the knives is not required.

Block diagram of the control system

The control system consists of two identical self-tuning controllers adjusting top and bottom coating weight.

The block diagram of the system is illustrated in **Figure 2**, where one self-tuning controller is shown. It consists of an observer updating the parameter (K) and an inverse model to determine air pressure (p). The broad line shows the feedback loop with gauge measurements (y). The fine lines show feedforward controls using measurements of line speed (v) and knife distance (d). The parameter λ is to be tuned by the user.

Line speed and knife distance are normally adjusted by the operator to product-specific nominal values.

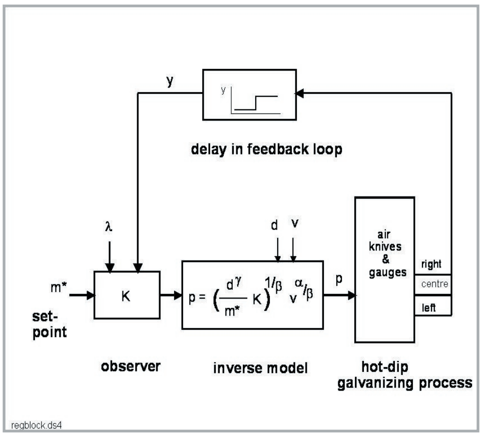

Fig. 2

Closed loop simulation

The response of the controller to a change in coating weight target is illustrated below.

Fig. 3 shows the time-history of 300 seconds including a step change in coating weight target from 100 to 150 g/m² at time 100 sec. It can be seen that the controller is effective and that the pressure has changed from 396 to 175 mbar immediately after the coating weight target was increased. The corresponding increase of the coating weight is measured at the cold gauge after the transport delay of 60 sec. However, the coating weight target has been missed by 4 grams. Every time a new coating weight measurement from the cold gauge is available the K-parameter of the model gets adjusted by the observer if necessary. With the self tuning property of the controller the coating weight is on target in 120 sec.

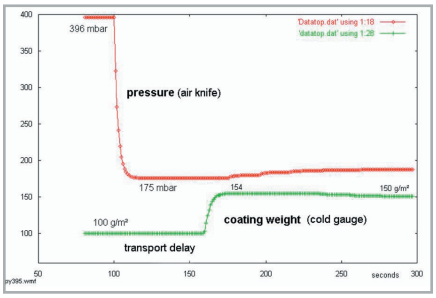

Fig. 3

Offline parameter estimation of the coating weight model

The parameter estimation problem can be formulated as an optimization problem, where the best model is the one that best fits the process data according to the given cost function.

Fitting the coating weight model can be realized by minimizing the cost function

$$J = \sum_{i=1}^{N} \left(y_i - K \, d_i^{\gamma} \, v_i^{\alpha} \, p_i^{-\beta} \right)^2$$

The parameters α, β, γ and the nominal value of K will be adjusted in such a way that the sum of squared errors – the difference between the actually observed y_i and computed coating weight – is a minimum.

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