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Automatic Control System for Snout Positioning in Hot Dip Galvanization Process

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Steel is widely used in various applications due to its resistance to mechanical stress and its ductility, as well as having other important features such as weldability, paint adhesion, easy molding and recycling, low cost and ferromagnetic properties. With exposure to humidity and high temperatures, however, rust occurs on the steel surface, causing the material to deteriorate. There are various techniques used to protect steel against corrosion, including Hot-Dip Galvanization, which consists of heating a metallic steel sheet in an oven to approximately 600 ºC followed by immersing the sheet in a kettle containing an alloy of molten aluminum, iron and zinc. A rectangular metallic structure, known as an electromechanical immersion tunnel (snout), is used for the transfer of the steel metal sheet from the oven to the bath. It is important to prevent the bath oxidation resulting from the contact of the bath with air (dross) because this phenomenon causes a defect visible in the metallic sheet. This can be minimized by controlling the position of the snout. In this study, a mathematical model was implemented to control the angular and linear position of the snout. The automatic reset mode is activated when the rear roller is replaced, while the automatic mode is always used when there are variations in the zinc bath level. The obtained results confirm the effectiveness of the positioning of the equipment showing a minimization of the time required for new adjustments. This proposal reduces the weight of the scrap generated by 27.54 % and 4.75 % for the formation of PGZN (zinc grains) and PBOR (dross), respectively.

1. Introduction

Metal sheets of common carbon steel are frequently used in various industrial applications due to low cost and good mechanical properties. Carbon steel, however, shows low resistance to corrosion in various media, such as the atmosphere. Normally, this material is protected from corrosion by the application of inorganic coatings (chromating, nanoceramic, silanating), metallic coatings (tin, zinc, alloys of zinc/iron, aluminum/zinc) or organic coatings, such as varnishes and paints, to the steel surface. When zinc is used to coat a metallic steel sheet, the coating operation is called galvanization or zinc plating and produces a galvanized steel sheet that is easily moldable, weldable and paintable in addition to showing excellent corrosion resistance (Le and Cui, 2008).

The hot-dip process is a form of galvanization in which the steel sheet is heated in an oven and later is continuously immersed in a kettle containing zinc from an immersion tunnel (snout). The control of the coating thickness applied to the steel sheet is very important in order to obtain a desirable product quality that is competitive and meets the necessities of the market (Linhares et al., 2008). At the end of the zinc bath, a system of blowing air at ambient temperature (air knife) is used to control coating layer deposited on the sheet. Deformations are often removed from the control coating (Campbell et al., 2005). However, an equally important parameter for determining the quality of galvanized steel parts is the evaluation of the appearance of the metallic sheet. There may be high concentrations of different types of metals and other elements in the metallic sheet (silicon, phosphorus, manganese, carbon) causing "spots" or "wrinkling" (Guelton and Lerouge, 2010). It can also be observed the appearance of "lumps" when impurities of the zinc bath (sludge, carbon, oxides, lead) are fixed on the surface sheet at the time of its withdrawal from the bath. The excessive amount of lumps is normally cause rejection because they tend to weaken the coating. Another aspect which leads to rejection of a part constitutes accumulated deposition of zinc. The

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formation of these appearance aspects, characterized as defects which generating scrap is intrinsic to the process. The two interfering (impurities or wastes) that are considered in this work are the dross (PBOR) and grain zinc (PGZN).
The automation and process control systems for hot-dip galvanization is focused on the actuation of the zinc kettle, the kettle exit and the air blade. The process was optimized at the lowest zinc consumption. However, such systems neglected the dross resulting from the contact of the bath with the air and the subsequent generation of dross and zinc grains onto the metal sheet. Once process plants remain under continuous and often intensive pressure to improve throughput and reduce production costs (Gough, 2012), sometimes an operational solution could reduce products outside of specification.
An operational solution to reduce dross consists of manually adjusting the angular and linear position of the electromechanical immersion tunnel (snout) was previously considered. Even well-executed manual control is imprecise, as the occurrence of unwanted transfer (skimmings) is visualized by a video camera inside the snout in an environment with aggressive temperatures, which is verified through a viewing window with metric markings for checking the equipment level relative to the zinc bath in the kettle. Thus, the objective of this study was to implement an automatic control system to position the snout for immersion of the metal sheet in the zinc bath to maximize the final quality of the metal sheet of galvanized steel. Control systems in current use reduce dross by adjusting the sheet thickness rather than the equipment position.

2. Methodology

2.1 The process

In the continuous hot-dip galvanization process, after annealing the sheet in the oven, the temperature of the sheet is controlled to the appropriate value for immersion in the zinc bath or in the aluminum-zinc alloy. The sheet is then guided through the snout into the kettle of molten metal, in which the metallic coating layer is applied, as shown in Figure 1a. The rear roller changes the direction of the sheet such that the sheet leaves the kettle after immersion. The stabilizer rollers guarantee the appropriate tension on the sheet that is leaving the bath. The snout is a rectangular mechanical tube that is connected to the oven exit through a coupling and immersed in the zinc kettle.

2.2 Control system

Prior to the current project implementation, the snout position was adjusted manually. Its position needs to be adjusted in two situations: 1) when the rear roller is replaced, which is known as automatic reset, and 2) when the level of the zinc bath changes and dross (PBOR) appears on the metallic galvanized steel sheet during the production process, which is known as automatic adjustment.
In these cases, the operator changed the linear and angular motion of the snout using a command panel that was located near the equipment. The corrective action was performed by a motor that moves the snout linearly (removal function) and angularly using a video camera installed in the snout with visualization in the operation cabin. A viewing window in the side of the snout was used in loco to determine the best position for the beginning of production. As mentioned, when the linear and/or angular position of the snout needed to be adjusted with the functioning galvanization line, the visualization with the camera was highly problematic (due to lens fogging from the high temperature environment). Consequently, manual control can result in products that are fabricated outside of specifications, which must be minimized.
The snout is similar to a pendulum that rotates around two sliding bearings supported by the metallic structure of a building. The equipment performs two types of motion known as linear and angular positioning. The translational linear motion is characterized by advance or removal in a direction that is radial to the rectangular cross-section of the snout; the angular translational movement is characterized by advance or removal in an angular direction relative to the metallic sheet. Both types of motion are shown in Figure 1b. These two motions are used to adjust the angular position of the snout, as well as the depth (linear position) of the snout, relative to the zinc kettle as needed. As mentioned before, the automatic reset mode must be performed after a component of the bath is replaced (which occurs once a month on average). In the automatic control mode, the system compensates for the advance and removal of the cylinder to center the angular position of the snout based on the sheet position in accordance with the equations above. This mode is activated when the level in the zinc bath changes (which is a process perturbation variable).
Within the proposed mathematical model, the controller calculates new adjustments to define the setpoint for the snout position. These calculations are necessary because dross occurs when the level in the zinc kettle changes or another variable is modified. Once the new value of the setpoint is defined, On/Off

controllers are used to implement the necessary corrective actions. By simulations, it was adjusted the setpoint range for the linear position by 1.00 mm in the front and the rear and for the angular position by 0.5 mm in the front and the rear.

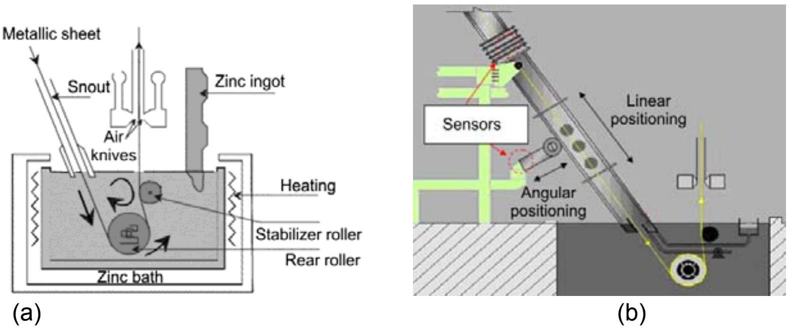


Figure 1: a) Schematic diagram of the zinc bath of galvanization process and b) illustration of the installation of the linear and angular positioning sensors used for position determination.

3. Mathematical model

The mathematical model in this proposal is developed to calculate new setpoints for the snout position that are necessary because dross occurs when the level in the zinc kettle changes or another variable is modified. The automatic reset mode must be performed after a component of the bath is replaced (which occurs once a month on average). In this case, the input data must include the diameter of the rear roller (D) to calculate the new angle (β): the snout is moved to the home position and returns to the necessary setpoint to be used in automatic mode.

Eq. (1) was used to find the angle (β) of the metal sheet as a function of the rear roller diameter (D), which can only range between a maximum allowed diameter (D_{max}) and a minimum (D_{min}), provided by the fabricator. The minimum allowed angle (β_{min}) was calculated as a function of the maximum diameter (D_{max}) and an angle adjustment (β_{max}) which is a value determined for correct reset position of the snout.

$$\beta = \left\{ \left[\frac{(D - D\max)}{(D\min - D\max)} \right] * (\beta\min - \beta\max) \right\} + \beta\max \qquad (1)$$

Two sensors were used in the snout for the linear positioning of the advance and removal motion (H_{sensor}) and for the angular positioning of the largest and smallest angles (CC_{sensor}). These angles were linearized in the minimum (H_{min} and CC_{min}) and maximum (H_{max} and CC_{max}) readers in the controller, which provided information on the distances (in millimeters) within which the proposed mathematical model could be used. With the new value of the angle (β), the setpoint for the linear position (H_{set}) is calculated using Eq. (2) in terms of the distance from of the surface zinc kettle (L) to the joint snout. Using the new calculated value of the linear position (H_{set}) in the automatic reset mode, connected via IHM, the equipment will move itself to the new setpoint value.

$$Hset = {}^{L}\!\!\diagup_{\sin\beta} \qquad (2)$$

As the equipment moves to the new setpoint value for the linear position (H_{set}), the angular position simultaneously moves according to the dynamically calculated angular position (CC_{set}) to maintain the position of the lower extremity of the snout of the metallic sheet at a constant value pre-determined. As the metallic sheet is held fixed, collision between the snout and the metallic sheet is prevented by maintaining a safe distance between the lower part of the snout to the metallic sheet during the linear motion. Thus, the angular length (C) is determined first using Eq. (3) and converted to the angular position (CC_{sensor}), which is the value of the reader at the desired plant by Eq. (4).

$$C = \cos\beta(Hsensor) \qquad (3)$$

$$CCsensor = \sqrt{(tg(\beta) * C)^2 + C^2} \qquad (4)$$

The value of CC_{sensor} is then used to calculate setpoint of the angular position (CC_{set}) in terms of the safety distance (ℓ) and a constant K corresponding to the physical dimensions of the equipment, using Eq. (5).

$$CCset = \left[\left(\int_{CC\min}^{CC\max} CCsensor \right) - \left(K + \ell \right) \right] \tag{5}$$

For automatic mode, first, the linear compensation value is calculated (H_{set}) in terms of the angle (β), the distance from of the surface zinc kettle (L) to the joint snout and an working distance (E), using Eq. (6). This value must meet the pre-defined angle (β) such that part of the snout is always immersed in the zinc bath to ensure a working distance (E), which corresponds to point at which the lower part of the snout is immersed in the zinc bath. Equations 3, 4, and 5 of the automatic reset mode are used in the model to calculate the angular position of the snout.

$$Hset = {(L+E)}/{\sin\beta} \tag{6}$$

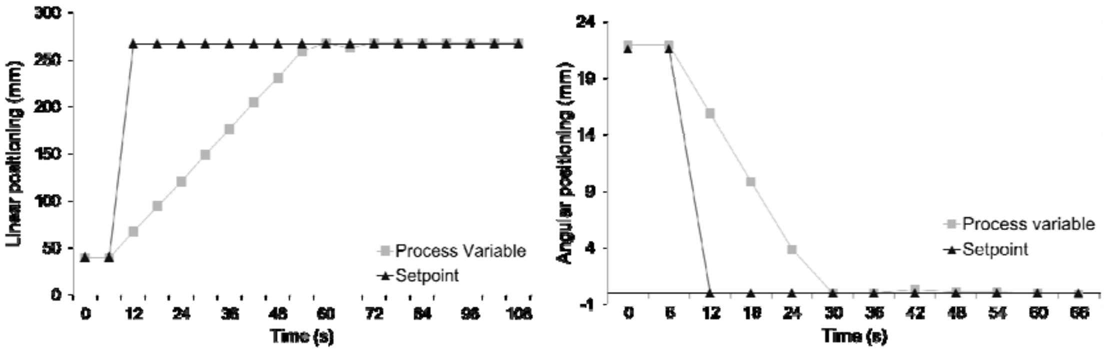
It is important to mention that the process was no optimized for the minimum requirements of zinc because this was not the main objective of the work. The developed model includes only the calculations for new setpoints values.

4. Results

4.1 Tests of automatic reset control

After inputting a new diameter of the rear roller the automatic reset mode was activated. The model calculated the setpoint value for the linear position that was sent to the controller to enact the linear snout motion (266.50 mm). Figure 2a shows the linear motion of the equipment toward the setpoint and it is observed that the reference value was reached at around 60 s, and the real position reader (267.43 mm) stabilized at approximately 72 s.

At the instant that the linear snout motion was initiated toward the desired value, the model dynamically calculated the angular position setpoint. Figure 2b shows the angular motion of the equipment toward the setpoint (0.00 mm in this case); It was observed that the value was reached at approximately 30 s, and the real position reader (-0.07 mm) stabilized at approximately 66 s.



(a) (b)

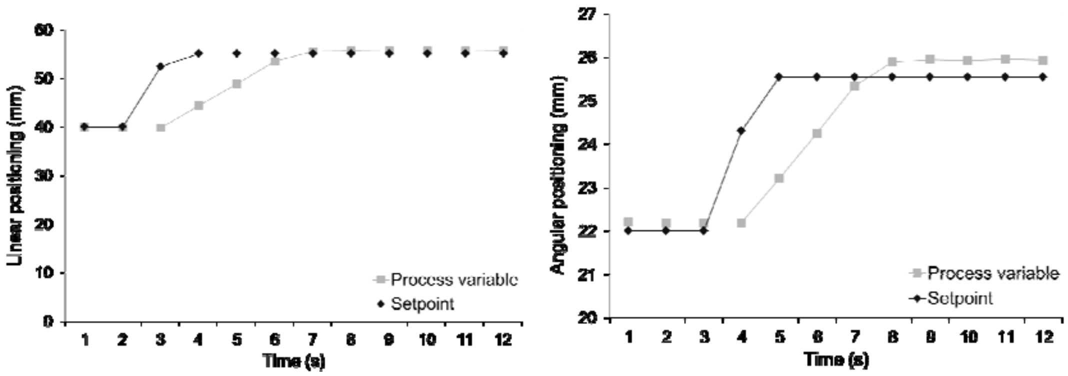
Figure 2: Profile of a) linear and b) angular motion displacement of the process variable relative to the setpoint in relation to the time when the reset automatic mode was tested.

The response times of the controller for the automatic reset mode of the snout based on the model setpoint calculations were satisfactory, where the desired position of the equipment stabilized at approximately 72 s. Previously, the manual snout reset maneuver required a period of approximately 5 min.

4.2 Tests of automatic control

In the automatic control mode for the linear and angular position of the snout, the perturbed variable is the zinc kettle height (L), i.e., the model calculates new setpoint values when L changes. This disturbance occurred by immersing the zinc ingot, which was performed with a speed of 38.40 mm/s.

With these changes in the height of the zinc bath, the setpoint value of the linear positioning was recalculated to 55.10 mm. In Figure 3a is shown the profile of linear movement of the equipment through time. It is observed that the reference change occurs in time of 3 s being reached by the final value in 7 s. That is, it took only 4 s to perform the new adjustment. With the change occurred in the linear positioning it was calculated the new reference value (setpoint) for the angular positioning of 25.54 mm, as shown in Figure 3b. It is observed that the reference change value occurs at time 4 s, being the final value reached at 8 s. That is, it took only 4 s to perform the new adjustment for angular positioning.



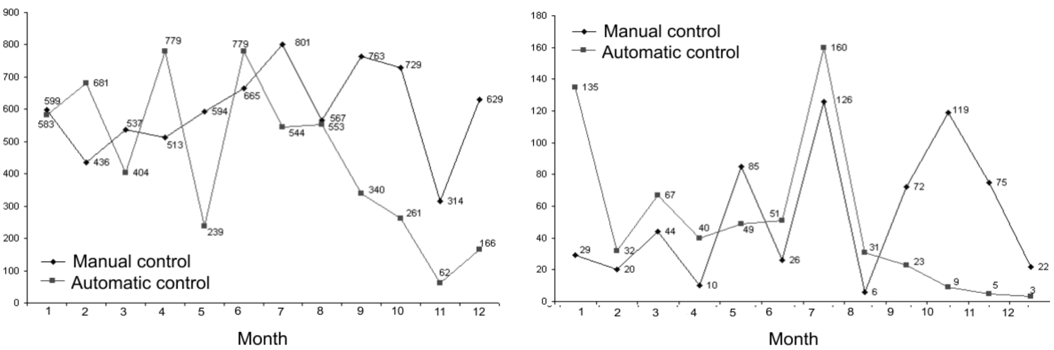
(a) (b)

Figure 3: Profile of a) linear and b) angular motion displacement of the process variable relative to the setpoint in relation to the time when the reset automatic mode was tested.

The results presented for the automatic control mode of the snout showed good adjustments, as observed in the case of automatic zeroing. In fact, the new positions are reached with a significant reduction of time. Since the formation of sludge and grains of zinc in the steel sheet is a characteristic intrinsic to the process, reducing the adjustment time of the new positioning achieved by automating the process incurs reduction of out of spec pieces.

4.3 Evaluation of the quality of pieces/generation of waste

The dross and zinc grains were characterized in keeping with the study objectives. The zinc kettle surface is in contact with atmospheric air. As a result, oxidation occurs and dross is generated on the kettle surface; the PBOR (dross) and PGZN (zinc grain) that are generated in the processed materials must therefore be characterized. So, the viability of the proposed mathematical model and the implemented control system were confirmed by quantifying the occurrences of zinc grain and dross while using the implemented control for a hot-dip galvanization line over one year: during this period, dross generation was recorded along with the number of occurrences and the weight (in tons) of scrap generated. The occurrences of PGZN were reduced by 24.57 % on average (Figure 4a), and consequently, the weight of the scrap generated was reduced by 27.54 % on average.



(a) (b)

Figure 4: Number of occurrences of scrap (weight) before and after the implementation of the control system a) of PGZN and b) of PBOR.

The occurrences of PBOR were reduced by 4.56 % on average (Figure 4b), and the weight of the scrap generated was consequently reduced by 4.75% on average. It was observed average reductions of 2048.85 t per month of PGZN (zinc grains) and 28.95 t per month of PBOR (dross).

5. Conclusions

Once the necessary time to new positioning was reduced, the implementation of the mathematical model for the automatic control of the snout gives a significant reduction in the waste generated in the process thereby increasing the process's efficiency by reducing costs associated with the generated scrap.
It is important to note that the results obtained in one industrial process do not necessarily carry over to other industrial processes; thus, various scenarios should be simulated for each application to evaluate the viability of implementing the application in an industrial process. The results presented in this report suggest that other technologies should be investigated to reduce the dross that was characterized in this study.
Another important consideration is that field experiments should be performed where the constants for other linear and angular positions are changed to identify the optimal operation point for the process, which would further reduce the dross and zinc grains produced in the hot-dip process.

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