

NON-LINEAR CONTROL STRATEGY FOR STRIP CASTING PROCESSES

V. A. Oliveira¹, R. R. Nascimento¹, N. S. D. Arrifano¹
E. Gesualdo¹, J. P. V. Tosetti²

¹Departamento de Engenharia Elétrica, USP São Carlos
CP 359, CEP 13560-970 São Carlos, SP, Brasil

²Instituto de Pesquisas Tecnológicas do Estado de São Paulo, Divisão de Metalurgia
CEP 05508-901 Cidade Universitária, São Paulo, SP, Brasil

Abstract – This paper present a non-linear control strategy to regulate the molten steel level of a strip-casting process. The molten steel level along with the separation force is considered the most critical to the production of high quality steel strips. The molten steel level may be controlled using the tundish output flow or the casting speed. However, the casting speed is usually used to control the roll force separation. To improve the strip thickness uniformity, we propose the introduction of an intermediary tundish submerge into the pool between the rotating rolls. The molten steel level is thus controlled by the intermediary tundish output flow. In this paper, we consider a feedback linearization controller with a selective fuzzy control law for model-estimation error compensation. Stability analysis of the fuzzy Mamdani controller using the Lyapunov direct method is also included. Simulation results are presented considering the real system parameters and both the stopper actuator dynamics and the rolling mill DC motor dynamics. For comparison we include results with the conventional PID.

Keywords – Strip-casters, twin roll, feedback linearization, fuzzy control, Mamdani models.

1. INTRODUCTION

The twin roll strip-casting process belongs to a new generation of casting processes, the called near-net-shape processes. The twin roll strip-casting process was first conceived by Henry Bessemer in the middle of last century [1]. A twin roll casting process is essentially a two rolling mill equipped with three main control loops: the molten steel level control loop, the separation force control loop and the casting speed control loop. The molten steel level along with the separation force is considered the most critical to the production of high quality steel strips. In [2] an adaptive fuzzy controller for the molten steel level in a strip-casting process is proposed. They combine an adaptive fuzzy controller and a switching control strategy to compensate for model-estimation errors and eliminate disturbances. In the pilot plant considered, the feeding of the molten steel into the pool formed between the two rotating rolls is a source of disturbance for the molten steel level. In this paper we consider the use of an intermediary tundish which is submerge into the pool to reduce the steel level fluctuations [3]. The intermediary tundish consists of a refractory recipient with holes to direct the molten steel to the pool formed between the two rotating rolls. Differing from [2], we use a feedback linearization controller and a selective fuzzy controller to take care of the model-estimation errors instead of an adaptation law. As in [2] we use a switching control term to eliminate disturbances. We also include the intermediary tundish in the system modeling. The proposed fuzzy control sheme is simple and follows a conventional fuzzy modeling.

A schematic diagram of a strip-caster pilot plant is installed at IPT São Paulo in Brazil. The main control units are the mill drive, the cooling and the coiler control units [4]. The plant is equipped with a set of Programmable Logic Control (PLC) units to perform the measurements and control. The paper is organized as follows. In Section 2, the components of molten steel level system are described. In Section 3, the Mamdani fuzzy modeling for the molten steel level system along with the stability analysis of the feedback system are given. Also in Section 3, the application of the method of feedback linearization for compensation of modeling errors in the roll gap using a selective fuzzy controller is presented in detail. Finally, Section 4 presents simulation results considering the real system parameters and both the stopper actuator dynamics and the rolling mill DC motor dynamics.

2. SYSTEM MODELING

The molten steel level system may be described as a nonlinear system based on the continuity equation of the steel flow and on the Bernoulli equation. Following, we describe the main components of the molten steel level system.

2.1 Intermediary Tundish Molten Steel Level

The dynamic model of the steel level in the intermediary tundish for input flow rate Q_i and output flow rate Q_{o1} is given as

$$\frac{dh_1}{dt} = \frac{1}{A_T}(Q_i - Q_{o1})$$

where $Q_i = c_f d$; $Q_{o1} = K\sqrt{h_1}$ with h_1 and A_T the steel height and area of the intermediary tundish, respectively; c_f the flow coefficient, d the actuator position; $K = n_f A_f \sqrt{2g}$, A_f the area of the holes, $A_f = \pi r^2$, n_f and r the number and radius of the holes and g the acceleration due to gravity [5].

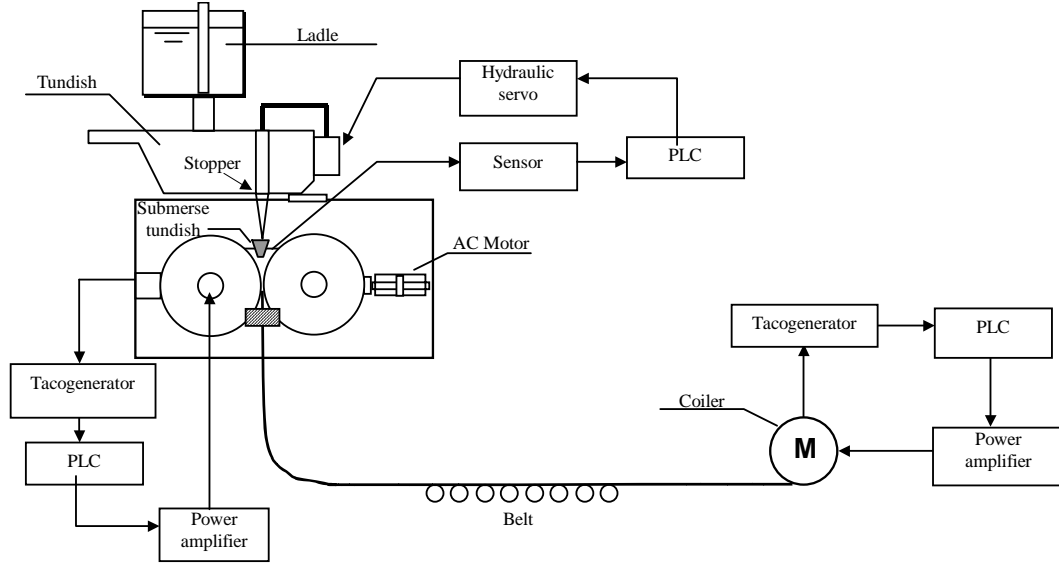


Figure 1: Schematic diagram of the strip-caster pilot plant installed at IPT São Paulo.

2.2 Mill Drive Molten Steel Level

The dynamic model of the input Q_{o1} and output flow Q_{o2} in the mill drive is described as

$$Q_{o1} - Q_{o2} = \frac{dV}{dt}$$

where V is the volume of the molten steel between the rolls, Q_{o2} the output flow from the rolls and Q_{o1} the inflow from the intermediary tundish. In terms of the level in the mill drive, (2) can be written as [2]

$$\frac{dh_2}{dt} = \frac{1}{M(x_g, h_2)} [Q_{o1} - Q_{o2}]$$

where $M := \left[(x_g + 2R) - 2\sqrt{R^2 - h_2^2} \right] L$ and $Q_{o2} = Lx_g v_r$, with v_r the casting speed. The nominal parameters for both the mill drive and intermediary tundish are listed in Table 1.

Table 1: Process parameters.

A_T	6.75E-3m ²	c_f	3.5E-2m ³ /s
K	0.13E-2m ³ s ^{-1/2}	R, L	3.75E-1m
x_g	2E-3m	n_f	6
A_f	5.02E-5m ²	g	9.8 m/s ²
r	4E-3m	v_r	0.093m/s

2.3 Hydraulic Actuator

The hydraulic servo system considered to drive the stopper valve is regulated in an inner control loop and is described by

$$\frac{d}{v_d} = \frac{K_a A_p K_{eq0}}{a_1 s^3 + a_2 s^2 + a_3 s + a_4} \quad (4)$$

where $a_1 = (M_a V_t / 4\beta_e)$, $a_2 = (M_a K_{co} + B V_t / 4\beta_e)$, $a_3 = (B_p K_{co} + A_p^2)$ and $a_4 = K_d K_a A_p K_{eq0}$ with M_a , V_t , β_e , K_{co} , B_p , A_p , K_d , K_{eq0} and K_a as in Table 2. The block diagram of the hydraulic servo system is illustrated in Figure 2.

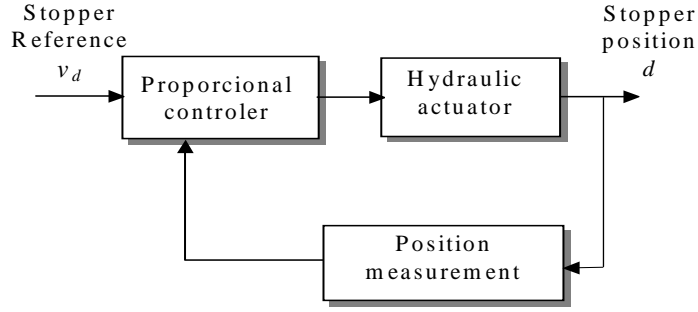


Fig. 2: Hydraulic servo actuator.

Table 2: Hydraulic parameters.

M_a	150Kg	V_t	7.9E-5m ³
β_e	7.8E8Pa	K_{co}	3.3E-12(m ³ /s)/V
A_p	10E-4m ²	K_d	40V/m
B_p	1200Ns/m	K_a	30
K_{eq0}	2E-5		

2.3 System Equations

In the state space form for $x_1 = h_1$, $x_2 = h_2$, $x_3 = d$, $x_4 = \dot{x}_3$, $x_5 = \ddot{x}_3$ we have the complete system equation

$$\dot{x} = f(x) + Bu$$

$$\text{where } f(x) = \begin{bmatrix} \frac{1}{A_r}(c_f x_3 - K\sqrt{x_1}) \\ \frac{1}{M(x_2)}(K\sqrt{x_1} - Q_{02}) \\ x_4 \\ x_5 \\ -\frac{a_2}{a_1}x_5 - \frac{a_3}{a_1}x_4 - \frac{a_4}{a_1}x_3 \end{bmatrix}, B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{b}{a_1} \\ a_1 \end{bmatrix}, u = v_d \text{ and } M(x_2) = [x_g + 2R - 2\sqrt{R^2 - x_2^2}]L.$$

3. NONLINEAR MOLTEN STEEL LEVEL CONTROL

The molten steel level between the twin rolls may be regulated using as control input the inflow Q_i or the casting speed v_r . However, the casting speed v_r is usually used to control the roll separation force due to the system constraints. Therefore, as

we introduced an intermediary tundish, here the molten steel level control is pursued by controlling the level of the intermediary tundish with an inner control loop for the stopper actuator using a servo-valve. The purpose of the inner control loop is to avoid abrupt changes in the valve position.

The inclusion of the intermediary tundish is very important to the quality of the final product, as it is detailed in Section 1.

However, due to its inclusion the molten steel level in the intermediary tundish needs to be monitored and considered in the controller to avoid possible overflow, guaranteeing a good working condition for the process. In this section we explore the use

of the Mamdani fuzzy control and the feedback linearization control to regulate the molten steel level. The fuzzy control approach has emerged as an alternative to control plants that exhibit complex non-linear behaviour.

3.1 Mamdani Fuzzy Control

The fuzzy logic systems used is formulated using the Mamdani's method, which has been successfully applied to a variety of industrial processes and consumer products [6]. The first fuzzy controller configuration considered is systematized in Figure 3. Defining the error e as $e := x_2 - x_{2d}$, in this configuration, the fuzzy controller is formed by three input fuzzy sets, the error e , the error derivative \dot{e} and the level in the intermediary tundish x_1 , and one output fuzzy set corresponding to the stopper actuator input voltage named v_d .

The fuzzy controller use the singleton fuzzifier, the center average defuzzifier, the product inference rule and a fuzzy rule base, which consists of a collection of fuzzy IF-THEN rules of the following form.

$$R(\ell): \quad \text{IF } e \text{ is } F_1^\ell \text{ and } \dot{e} \text{ is } F_2^\ell \text{ and } x_1 \text{ is } F_3^\ell$$

$$\text{THEN the stopper reference for } v_d \text{ is } G_4^\ell, \ell = 1, 2, \dots, r \quad (6)$$

where $r = 7$, the number of linguistic rules; F_1^ℓ, F_2^ℓ and F_3^ℓ are the input fuzzy sets and G_4^ℓ the output fuzzy set; $(e, \dot{e}) \in U_{in}$, $x_1 \in V_{in}$ and $v_d \in H_o$, with U_{in} , V_{in} and H_o input and output universes of discourse, respectively.

The rule bases are shown in Table 3 where the first marked cell can be interpreted as follows: IF the error e is Negative Small (NP) and the error derivative \dot{e} is Positive Small (PP) with the intermediary tundish height Zero THEN the stopper actuator input voltage v_d is Zero. All the membership functions are shown in Figure 4.

Let $w := [e \quad \dot{e} \quad x_1]$ and $v := v_d$. A fuzzy implication for w and v denoted $\mu_R(w, v)$ is a fuzzy set in the product space $U_{in} \times V_{in} \times H_o$, that is the fuzzy relation induced by the rules with a membership function and a membership grade. When no rule involves the association of the input linguistic terms, F_1^ℓ, F_2^ℓ and F_3^ℓ with the output G_4^ℓ , the fuzzy implication is simply assigned to zero. The fuzzy implication rule is given by the product-operation rule

$$\mu_R(F_1^\ell, F_2^\ell, F_3^\ell, G_4^\ell) = \mu_{F_1^\ell}(e) \mu_{F_2^\ell}(\dot{e}) \mu_{F_3^\ell}(x_1) \mu_{G_4^\ell}(v_d)$$

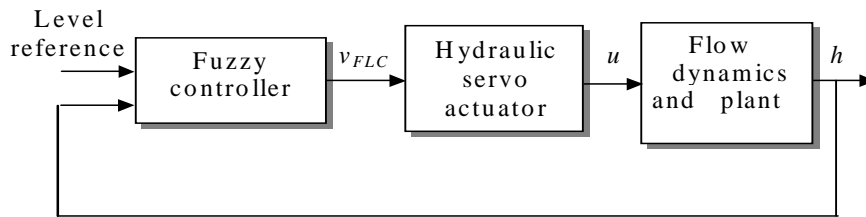


Figure 3. Schematic of the steel level control unit using the Mamdani fuzzy controller with $h := [x_1, x_2]^T$.

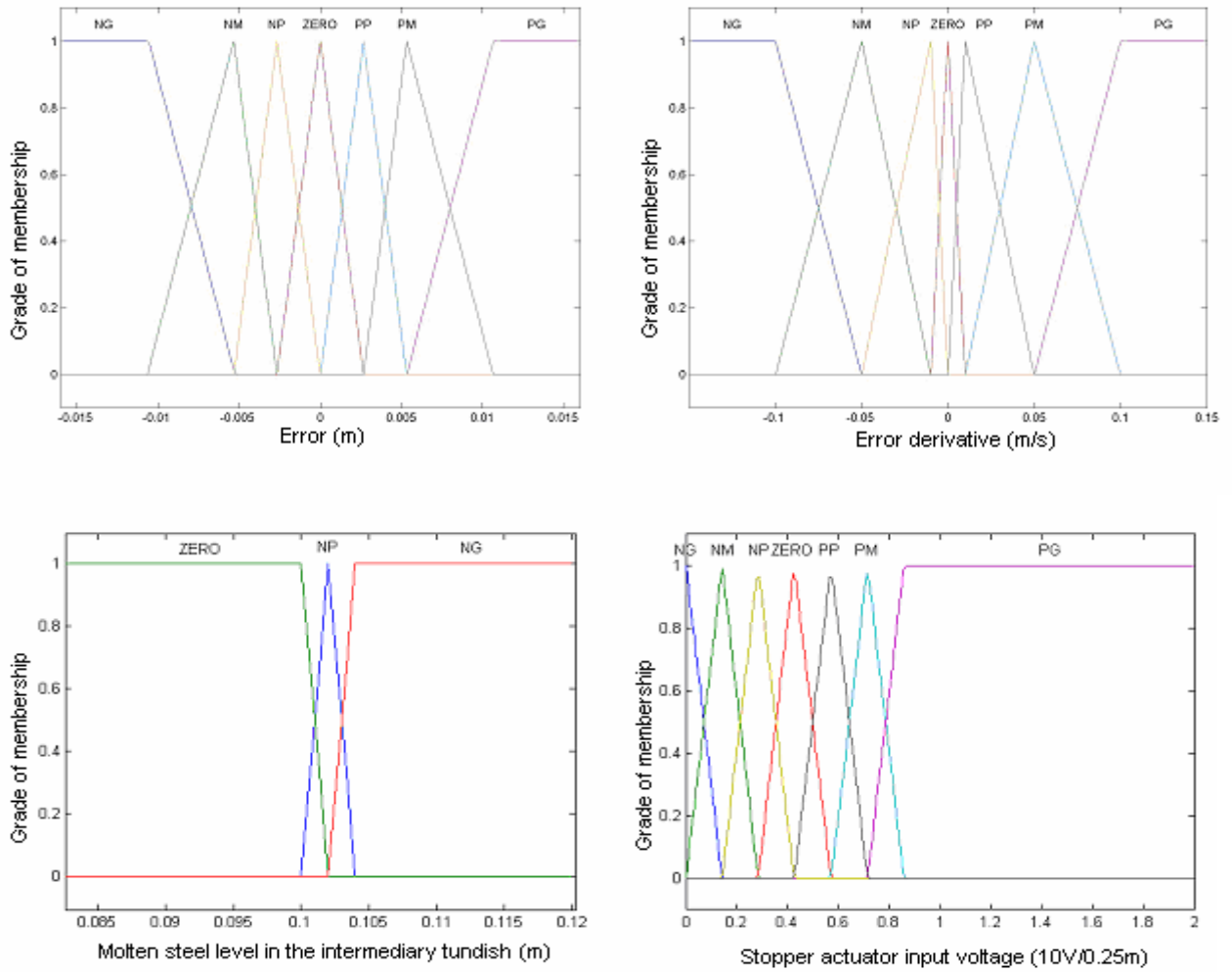


Figure 4: Membership functions.

3.1.1 Stability analysis

The stability of the Mamdani fuzzy controller can be analyzed using the Lyapunov's direct method by forming an input-output mapping for the feedback fuzzy system and considering the fuzzy base rules [7]. Figure 5 shows the complete non-linear system under fuzzy control. For the stability analysis it is considered the hydraulic servo actuator in series with the flow dynamics and plant. The linearized flow dynamics and plant about the operating point $(\bar{h}, \bar{\xi})$ is of the form

$$\begin{aligned} \dot{z} &= A_1 z + B_1 u \\ y_1 &= z \end{aligned}$$

where

$$A_1 = \begin{bmatrix} \frac{-K}{2A_r \sqrt{\bar{x}_1}} & 0 \\ \frac{K}{2M \sqrt{\bar{x}_1}} & 0 \end{bmatrix}, B_1 = \begin{bmatrix} \frac{c_f}{A_r} \\ 0 \end{bmatrix}$$

with $z := h - \bar{h}$ and $u := d - \bar{d}$. The hydraulic servo actuator dynamics is of the form

$$\begin{aligned} \dot{\xi} &= A_2 \xi + B_2 v_{FLC} \\ y_2 &= C_2 \xi \end{aligned}$$

with

$$A_2 = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ \frac{-a_2}{a_1} & \frac{-a_3}{a_1} & \frac{-a_4}{a_1} \end{bmatrix}, B_2 = \begin{bmatrix} 0 \\ 0 \\ \frac{b}{a_1} \end{bmatrix}, C_2 = [1 \ 0 \ 0] \text{ and } \xi := [x_3 x_4 x_5].$$

Table 3: Rule bases for the fuzzy controller.

N: negative, P: positive, M: medium, Z: zero; G: big and PP: positive small

		Error derivative						
		NG	NM	NP	Z	PP	PM	PG
Error	NG	NG	NG	NG	NG	NM	NP	Z
	NM	NG	NG	NG	NM	NP	Z	PP
	NP	NG	NG	NM	NP	Z	PP	PM
	Z	NG	NM	NP	Z	PP	PM	PG
	PP	NM	NP	Z	PP	PM	PG	PG
	PM	NP	Z	PP	PM	PG	PG	PG
	PG	Z	PP	PM	PG	PG	PG	PG
		Z	Z	Z	Z	Z	Z	Z

Height of the intermediary *tundish*

		Error derivative						
		NG	NM	NP	Z	PP	PM	PG
Error	NG	NG	NG	NG	NG	NM	NM	NP
	NM	NG	NG	NG	NM	NM	NP	Z
	NP	NG	NG	NM	NM	NP	Z	PP
	Z	NG	NM	NM	NP	Z	PP	PM
	PP	NM	NM	NP	Z	PP	PM	PM
	PM	NM	NP	Z	PP	PM	PM	PG
	PG	NP	Z	PP	PM	PM	PG	PG
		PP	PP	PP	PP	PP	PP	PP

Height of the intermediary *tundish*

		Error derivative						
		NG	NM	NP	Z	PP	PM	PG
Error	NG	NG	NG	NG	NG	NG	NG	NM
	NM	NG	NG	NG	NG	NG	NM	NM
	NP	NG	NG	NG	NG	NM	NM	NM
	Z	NG	NG	NG	NM	NM	NM	NM
	PP	NG	NG	NM	NM	NM	NM	NP
	PM	NG	NM	NM	NM	NM	NP	NP
	PG	NM	NM	NM	NM	NP	NP	NP
		PG	PG	PG	PG	PG	PG	PG

Height of the intermediary *tundish*

Theorem 1. The feedback system (5) with a control law constructed via the IF-THEN rules (6), rule base given in Table 3 and membership functions given in Fig. 4, is locally asymptotically stable.

Proof. Consider the Lyapunov function candidate for the complete linearized system

$$V(z) = \frac{1}{2} z^T P z$$

where P is a positive definite symmetric matrix. Since $y_1 = z$. The time derivative of V is given as

$$\dot{V}(z) = \frac{1}{2} z^T (A_1^T P + A_1 P) z + z^T P B_1 u .$$

The linearized flow dynamics and plant is a stable system in the sense of Lyapunov as it contains a pure integrator. For this system there exists a positive definite symmetric matrix P_1 and a positive semidefinite matrix Q_1 such that $A_1^T P_1 + A_1 P_1 = -Q_1$ [7-8]. The hydraulic actuator is regulated in an inner control loop with faster time response than the flow system and therefore its dynamic can be removed from the stability analysis.

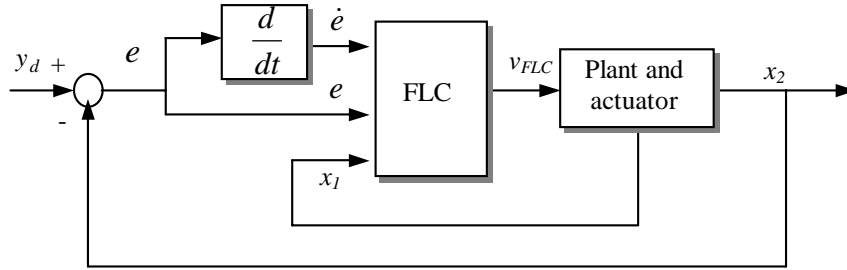


Figure 5: Cascade fuzzy control system structure.

The local stability of the feedback system is guaranteed if the fuzzy control law v_{FLC} is such that

$$\dot{V} = \frac{1}{2} z^T (A_1^T P_1 + A_1 P_1) z + y_1^T P_1 B_1 u \leq 0 . \quad (12)$$

Now, the linearized flow dynamics and plant yield

$$Q_1 = \begin{bmatrix} 8 & 0 \\ 0 & 0 \end{bmatrix}, A_1 = \begin{bmatrix} -0.3593 & 0 \\ 0.1848 & 0 \end{bmatrix}, P_1 = \begin{bmatrix} 13.7781 & 5.1433 \\ 5.1433 & 10 \end{bmatrix}, B_1 = \begin{bmatrix} 5.1852 \\ 0 \end{bmatrix} .$$

As u and v_{FLC} has the same sign in the vicinity of the operating point, $\dot{V}(z) \leq 0$ is assured if

$$(71.4397x_1 + 26.6682x_2)v_{FLC} < 0 .$$

The stability checking can be carried out considering the fuzzy rule base built for the control law. The possible control actions must be analyzed considering the change of variables to the operating point. The error is $e = y_d - x_2$. Note that the error e has the opposite sign of x_2 and that x_1 has the same sign of x_2 as the intermediary tundish output corresponds to the input of the mill drive. We consider now the fuzzy controller actions corresponding to the peripheral cases presented in Table 3. These actions can be represented by the rules R1, R2, R3, R4 given below

- R1: IF $e > 0$ and $\dot{e} > 0$ and $x_1 > 0$ THEN $v_{FLC} > 0$
- R2: IF $e > 0$ and $\dot{e} < 0$ and $x_1 > 0$ THEN $v_{FLC} > 0$
- R3: IF $e < 0$ and $\dot{e} > 0$ and $x_1 < 0$ THEN $v_{FLC} < 0$
- R4: IF $e < 0$ and $\dot{e} < 0$ and $x_1 < 0$ THEN $v_{FLC} < 0$.

Substituting the results of the rules R1, R2, R3 and R4 in (14) it is verified that $\dot{V} < 0$ is satisfied in the peripheral cases assuring a feedback system stable by an extension of La Salle invariance principle [9]. In addition, the system trajectory can not be stuck at a value other than the equilibrium due to the structure of the rule bases, which assures the asymptotically stability of the equilibrium. □

Fig. 6 illustrates the behavior of a \dot{V} for the process LCT-RD for a typical simulation case, considering the non-linear equations.

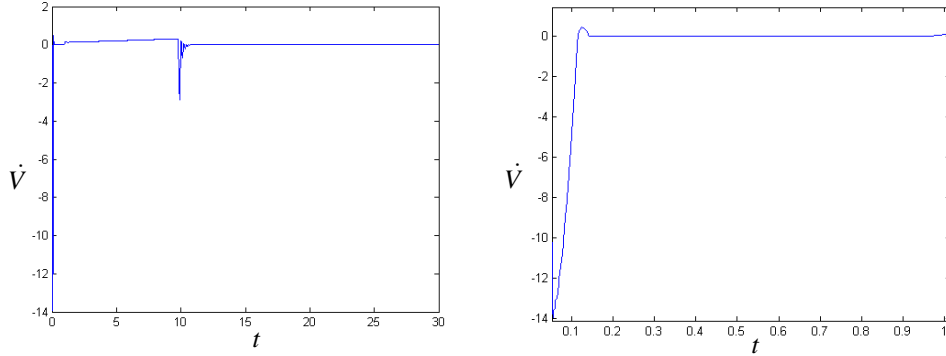


Figure 6: Derivative of the Lyapunov function. On the right, a zoom near the passage by zero is shown.

3.2 Feedback Linearization Control

In this section the method of feedback linearization with compensation for modeling errors is used to regulate the molten steel level at the desired value y_d . In the method of feedback linearization, the nonlinearities in a nonlinear system are canceled to yield a closed-loop linear system. The compensation for modeling errors is accomplished by including a fuzzy control law. In what follows we consider the feedback linearization method applied to the flow dynamics and plant. The flow dynamics and plant dynamic are obtained from (5) as

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} \frac{-K\sqrt{x_1}}{A_T} \\ \frac{[K\sqrt{x_1} - Q_{o2}]}{M(x_2)} \end{bmatrix} + \begin{bmatrix} 1 \\ A_T \\ 0 \end{bmatrix} u$$

Assuming in (14) that x_g , x_1 and x_2 are measured, a control law

$$Q_i = \alpha(h) + \beta(h) v \tag{15}$$

with $\alpha: \mathfrak{R}^2 \rightarrow \mathfrak{R}$, $\beta: \mathfrak{R}^2 \rightarrow \mathfrak{R}$, $h = [x_1 \ x_2]^T$ and v an equivalent control, can be found so that the nonlinear system dynamics is transformed into an equivalent linear dynamics of a simpler form as follows [8].

$$\begin{aligned} \dot{z}_1 &= z_2 \\ \dot{z}_2 &= v \end{aligned} \tag{16}$$

using $z(h) = [z_1 \ L_f z_1]^T$ and solving the following system for z_1

$$\begin{aligned} \nabla_{z_1} ad_f^0 g &= 0 \\ \nabla_{z_1} ad_f^1 g &\neq 0. \end{aligned} \tag{17}$$

where

$$\frac{\partial z_1}{\partial x} \dot{h} = L_f z_1 \text{ and } ad_f g = [f, g] = \nabla g f - \nabla f g, \text{ which is the Lie brackets.}$$

Solving (17) we obtain

$$z_1 = x_2 \text{ and } z_2 = \frac{[K\sqrt{x_1} - Q_{o2}]}{M(x_2)}.$$

Now, using

$$\frac{dz_2}{dt} = \frac{\partial z_2}{\partial x_1} \dot{x}_1 + \frac{\partial z_2}{\partial x_2} \dot{x}_2$$

we obtain

$$\dot{z}_2 = \frac{K}{2\sqrt{x_1}M(x_2)} \dot{x}_1 + \frac{-2x_2[K\sqrt{x_1} - Q_{o2}]}{\sqrt{R^2 - x_2^2}M(x_2)^2} \dot{x}_2$$

and

$$Q_i = \alpha(h) + \beta(h)v \tag{18}$$

$$\text{with } \alpha(x) = K\sqrt{x_1} + \frac{4x_2A_T\sqrt{x_1}[K\sqrt{x_1} - Q_{o2}]^2}{K\sqrt{R^2 - x_2^2}M(x_2)^2}, \beta(x) = \frac{2A_T\sqrt{x_1}M(x_2)}{K}.$$

Based on the equivalent linear system, a tracking controller for the level x_2 can be obtained. We define the error $e := z_1 - y_d$, with y_d the reference level. Then, the linear control can be given by $v = -K_1e - K_2z_2$. Figure 7 presents the feedback control system.

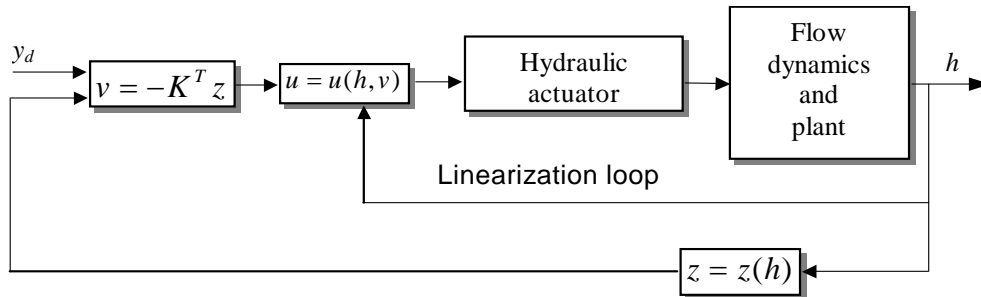


Figure 7: Feedback linearization control system.

To guarantee $e \rightarrow 0$ as $t \rightarrow \infty$ a control term called supervisory control u_s , is added to Q_i . The supervisory control is of the form $u_s := A \text{sgn}(e)$, with A a design parameter and sgn the sign function

$$\text{sgn}(e) = \begin{cases} +1 & \text{if } e > 0 \\ -1 & \text{if } e < 0. \end{cases}$$

The term supervisory control is inspired in the variable structure with sliding mode technique [7-8]. Moreover, in order to compensate modeling errors that inevitably occur in the strip-casting system, a fuzzy control term u_c is added to Q_i in (15). The fuzzy control term u_c is formed by two input fuzzy sets, the error e and the error derivative \dot{e} , and one output fuzzy set corresponding to an additional voltage for v_d , whereas the cascade fuzzy controller is formed by three input fuzzy sets, the error e , the error derivative \dot{e} and the molten steel level v_d in the intermediary tundish x_1 , and one output fuzzy set corresponding to the stopper actuator input voltage v_d . The fuzzy control term consists of a collection of fuzzy IF-THEN rules of the following form.

Fuzzy control term

$R(\ell)$: IF e is M_1^ℓ and \dot{e} is M_2^ℓ

THEN the additional stopper reference for v_d is K_3^ℓ $\ell = 1, 2, \dots, r$ (19)

where $r = 3$, the number of linguistic rules; M_1^ℓ, M_2^ℓ are the input fuzzy sets and K_3^ℓ the output fuzzy set; $(e, \dot{e}) \in U_{in}$ and $v_d \in H_o$, with U_{in} and H_o input and output universes of discourse, respectively. The control law thus becomes

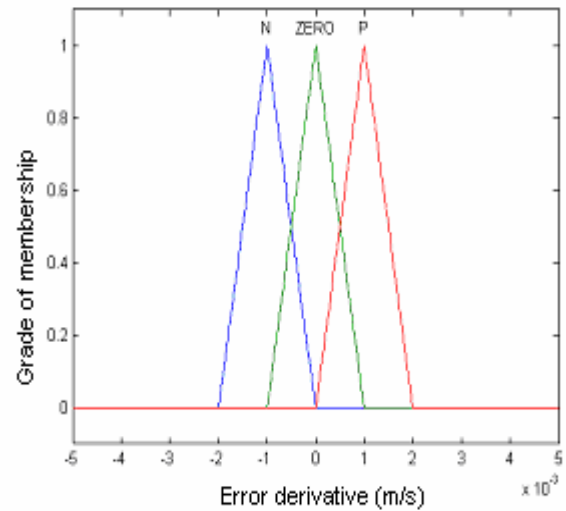
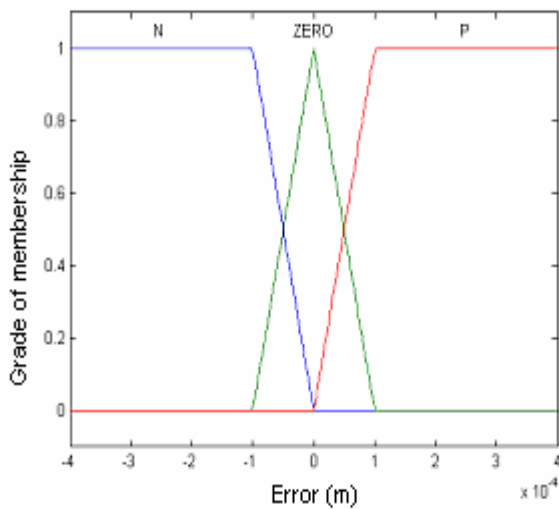
$$Q_i = \alpha(x) + \beta(x)[-K_1 e - K_2 z_2 + A \text{sgn}(e)].$$

The rule base, the membership functions and the molten steel level basic control configuration with the fuzzy control term are shown in Table 4, Figures 8 and 9, respectively.

The stability of the feedback control system can be verified in a similar manner as in Section 3.1 for suitable K_1, K_2 and A .

Table 4: Rule base for the selective fuzzy unit.

		Error derivative		
		N	Z	P
Error	N	P	P	Z
	Z	P	Z	N
	P	Z	N	N



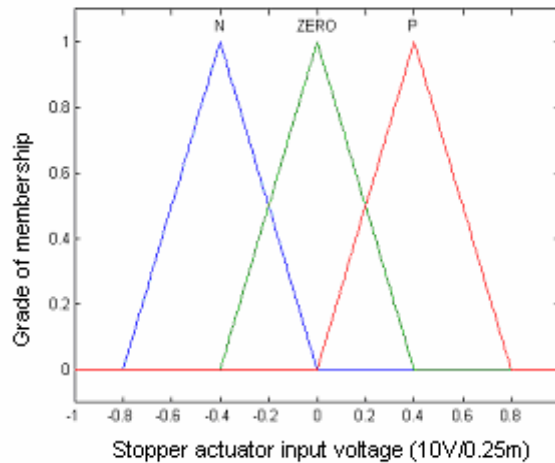


Figure 8: The membership functions for the selective fuzzy unit.

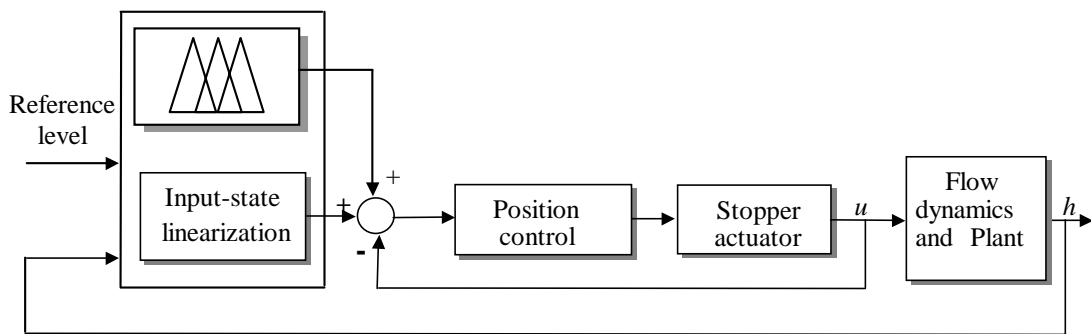


Figure 9. Schematic of the feedback linearization fuzzy control system.

4. SIMULATION RESULTS

All results were obtained considering the stopper actuator dynamics. The intermediary tundish height is $h_1 = 0.11$, the stopper valve position maximum is $d = 0.05$ [m]. The molten steel levels in normal operation are in the interval $h_2 \in [0.12 \quad 0.14]$ and the nominal inflow is $Q_{o2} = 3.07e-3$ [m^3/s] which is in accordance with the design of the intermediary tundish. The desired values of gap and level are set as $x_g = 0.002$ [m] and $h_{2d} = 0.13$ [m], respectively. In the design of the Mamdani fuzzy control law, we used seven linguistic rules ($r=7$) to the input fuzzy set error e and error derivative \dot{e} and three linguistic rules ($r=3$) to the input fuzzy set of the molten steel level in the intermediary tundish. The latter is needed to avoid possible over flow. For the output fuzzy set, the stopper actuator input voltage, we used seven linguistic rules ($r=7$). To verify the performance of the control strategies considered, Figures 10 and 11 show the process responses to a step reference with the desired molten steel level chosen as $h_{2d} = 0.13$ m. In Figure 10, a 10% outflow Q_{o2} disturbance is introduced after 50s. In Figure 11, a 10% roll gap x_g disturbance containing up to the third harmonic of the roll velocity is introduced (Lee. *et al*).

CONCLUSION

In this paper a non-linear control strategy for the molten steel level in a strip-caster plant installed at the IPT São Paulo is proposed. Different control methods are combined in order to achieve a high performance regulation. An important feature of the strategy is its flexibility to consider the control design constraints in the process and control variables. The simulation results show the superiority performance of the feedback linearization controller with a fuzzy control term for compensation of modeling errors as compared to conventional PID and stand alone cascade fuzzy controllers. The cascade fuzzy controller can be tuned to respond to modeling errors but at the cost of losing in adaptability to real operation conditions. The advantage of the Mamdani's fuzzy model is the simplicity of its control loop, which follows the same structure as the PID control. Since the aim of the process is to produce a solidified strip of constant thickness under a constant roll separation force, the main control unit of the strip-caster system must include the control of the separation force and this will be considered in future work.

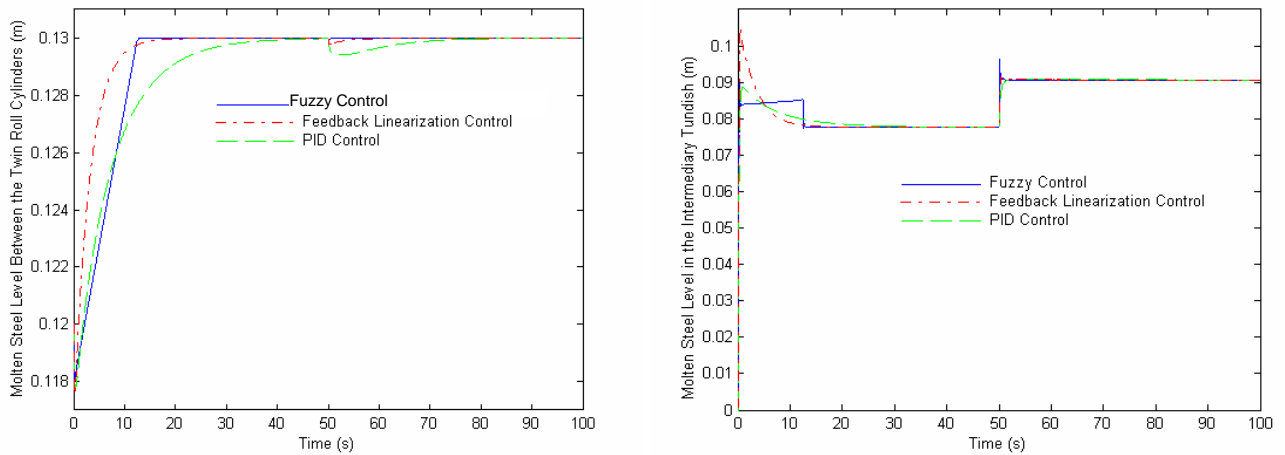


Figure 10: Step response results with outflow Q_{o2} disturbance.

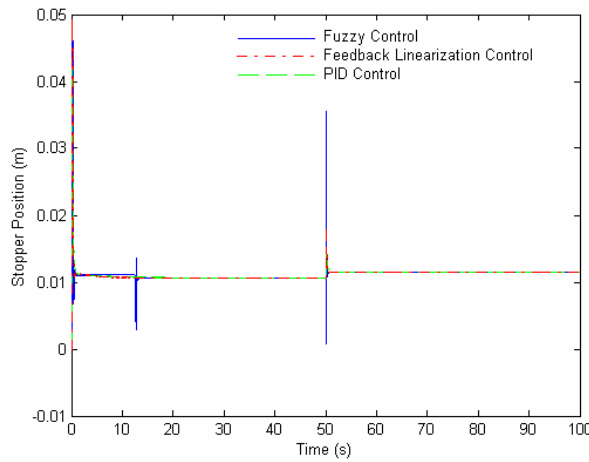


Figure 10: Step response results with outflow Q_{o2} disturbance (cont.).

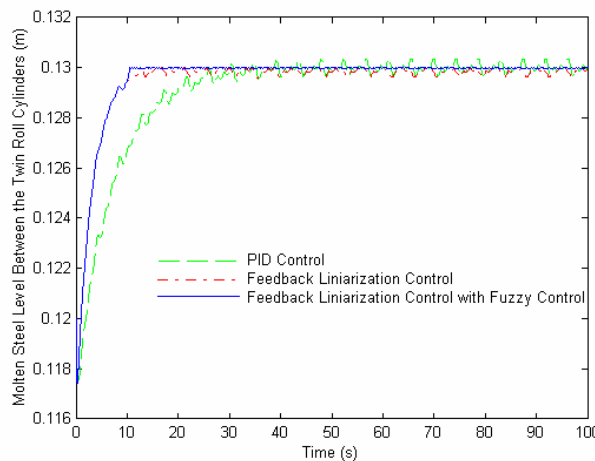


Figure 11: Step response results with harmonic disturbance in the roll gap.

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