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# Model Reference Adaptive Control System for Mould Level Measurement Control in Continuous Casting Shop of Steel Industry

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## ABSTRACT

Mould Level Measurement in any steel industry play vital role for smooth, reliable, accurate and better performance of the caster. The designed mould level controller automatically adapts any changes during the casting process. After treatment of steel in BOF, liquid steel is poured from the tundish into the casting mould through the submerged entry nozzle. Precaution is being taken for accurate and fast measurement of mould level. Accuracy of mould level is basic foundation of high quality steel and it also prevent the overflow of steel in the mould. Different type of mould level measurement i.e suspension type and head mounted sensor type is used in steel industry. In this paper, Model Reference Adaptive Control (MRAC) Mechanism for Mould Level Measurement system having external disturbances (noise) is applied and robust nature of MRAC is discussed via Matlab/Simulink. Robust MRAC gives better transient performance and stability of the plant and the results are compared for varying adaptation mechanisms due to variation in adaptation gain and result is compared for different value of adaption gain in presence of noise and without noise and its show that system is stable.

**Keywords**: Adaptive Control, MRAC (Model Reference Adaptive Controller ), Adaptation Gain, MIT rule, Mould Level, Noise, Robust, Disturbances.

## I. INTRODUCTION.

Mould level measurement control in any steel industry control the continuous casting process by maintaining the level of liquid steel in mould. Controlling of the level in mould is directly related to the quality and yield of the final product. Dynamic behavior of level of steel in mould effect the mould level control resulting unwanted surface and less accuracy in terms of measurement in cast slab. Controlling the level by manual operating the slide gate is dangerous and having safety hazard. Keeping the safety concern and increase productivity and readability, fully automation system is adopted, which is able to adapt any disturbances and abnormal situation during the casting. This robust system is widely used in steel industries across the world.

Traditional non-adaptive controllers are good for industrial applications; PID controllers are cheap and easy for implementation. Nonlinear process is difficult to control with fixed parameter controller. Adaptive controller is best tool to improve the control performance of parameter varying system. Adaptive controller is a technique of applying some system identification to obtain a model and hence to design a controller. Parameter of controller is adjusted to obtained desired output [1]. Model reference adaptive controller has been developed to control the nonlinear system. MRAC forcing the plant to follow the reference model irrespective of plant parameter variations. i.e decrease the error between reference model and plant to zero[3]. MRAC implemented in feedback loop to improve the performance of the system [2].

Robustness in Model reference adaptive Scheme is established for bounded disturbance and unmodeled dynamics. Adaptive controller without having robustness property may go unstable in the presence of bounded disturbance and unmodeled dynamics [4].

In this paper MRAC adaptive controller for mould level measurement system using MIT rule in the presence of order bounded disturbance and unmodeled dynamics has been discussed for different value of adaptation gain and accordingly performance analysis is discussed for MIT rule for second order system in the presence of bounded disturbance and unmodeled dynamics.

## II. MODEL REFERENCE ADAPTIVE CONTROL

Model reference adaptive controller is shown in Fig. 1. The basic principle of this adaptive controller is to build a reference model that specifies the desired output of the controller, and then the adaptation law adjusts the unknown parameters of the plant so that the tracking error converges to zero [1]

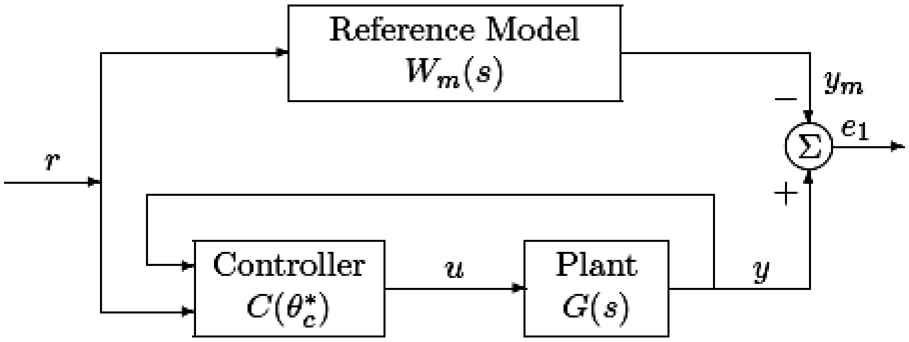


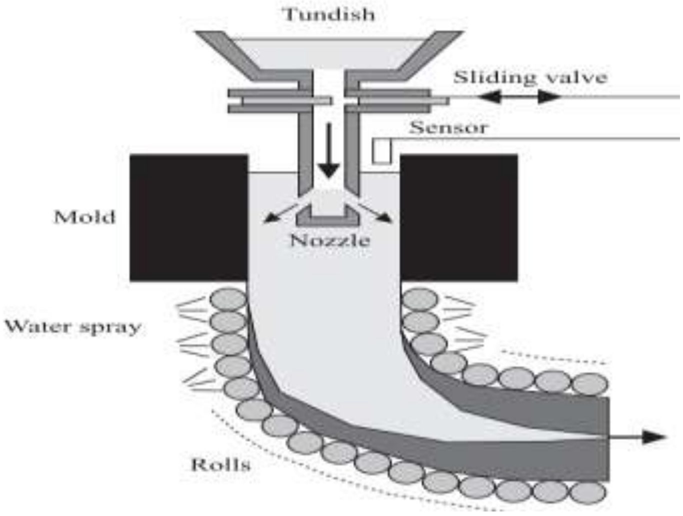
Fig. 1

## III. MOULD LEVEL MEASUREMENT CONTROL

Continuous casting is the process where molten metal is solidified into a "semifinished" billet, bloom, or slab for subsequent rolling in the finishing mills. After treatment in BOF, Molten steel discharge from a ladle in temporally stored in a tundish then poured through a immersion nozzle into a mould. Inside walls of mould are lined with water cooled copper plate. Once molten steel freezes by water cooled system, its form a solid shell and continuously withdraw from the mould at casting speed that matches the flow of incoming metal (Fig.-2)

It is steady state process. Liquid level in the mould is controlled by feedback controller to maintain the steady, reliable and trouble free operation [5], [6]

A sensor is either mounted or suspended in the mould are used to measure the level of liquid steel in the mould and give feedback signal to the controller to act and give signal to the slide gate to opening or close the slide nozzle [5], [6].



.

**Fig.-2**

If inflow of liquid steel in mould and outflow of casting speed is mismached causeing overflow of liquid steel and resulting slow the steady casting process and burn the mounted or suspended senors. It is also possiblities for clogging in continuous casting nozzles is the buildup of material in the flow passage between the tundish and mold. The consequences of clogging reduce the productivity. To avoid the clogging, the flow control device (e.g., slide gate) must be further opened. Mould level measuremnt is necessary for enhancing the productivity and improving the qulaity of caster semifinished steel product.

## IV. MATHEMATICAL MODELING FOR MODEL REFERENCE ADAPTIVE CONTROL FOR MOULD LEVEL MEASUREMENT CONTROL.

The basic principle of this adaptive mould level control system is to build a reference model of ideal plant that specifies with the desired output (liquid level in mould) of the controller, and then the adaptation law adjusts the causes of deviation of liquid steel level in mould so that the tracking error converges to zero. This means desired level is tracking the actual level of the liquid steel in mould.

Molten steel in the mould is poured through nozzle from tundish and level of molten steel is continuously monitored by the sensor which is either suspended in the mould or mounted on the top of mould. Any deviation from the desired level of liquid steel is fed back to controller to control the flow of molten steel by controlling the flap gate and nozzle to achieve the desire level.

Components of Model Reference Adaptive Control for mould level are as under:

i) **Reference Model:** It is use to give an ideal response to adaptive control system to a reference input. Reference model consist of mould, level sensor, actuator, slide gate, casting speed and withdrawal of liquid steel. In ideal case is time variant dynamic system and it is assumed that level of liquid steel in mould is a desired level.

ii) **Plant:** The plant comprises of mould, level sensor, actuator, slide gate, casting speed and withdrawal of liquid steel those liquid level is to be controlled is considered as time variant dynamic nature plant. Output of plant i.e level control should track the output of the reference model.

iii) **Adaptation Mechanism:** It is used to adjust the parameters in the control law. Adaptation law searches for the parameters such that the response of the plant should be same as the reference model. If the output of plant liquid level is not matching with the liquid level of reference plant then adaptation law can be applied to convergence of tracking error to zero by adjusting the movement of cylinder connected to the flapgate.

iv) **Controller:**. In model reference adaptive control adaptation mechanism adopt online parameter estimate technique such a way to control controller parameter so that controller gives controlled input to plant then output of plant track the model reference. Adaptation mechanism adapt the above reason and give the feedback to controller and controller control the movement of flap gate to control the liquid in mould and subsequent control the level so that output of plant liquid level track the reference plant liquid level

Consider the process consisting the plant transfer function [7],

$$G_p(s) = G_a(s)/s(1+ \tau_1 s)*G_n(s)*Sv*1/Ss*G_s(s)/(1+ \tau_2 s)$$

Where , Actuator transfer function = $G_a(s)/s(1+ \tau_1 s)$

Nozzle = $G_n(s)$
Withdrawal = Sv
Mould = 1/Ss
Level Sensor = $Gs(s)/(1+ \tau_1 s)$

Where $G_a$ is actuator gain, $G_n$ is nozzle gain, S is mould section, v is casting speed, $G_s$ is level sensor gain, $\tau_1$ is actuator time constant and $\tau_2$ is level time constant.

Based on the analysis and using model reduce order reduce technique, following transfer function for mould level measurement system is considered for study of performance analysis in presence of first order and second order bounded disturbance and unmodeled dynamics

$$G(s) = 9.275/(s^2 + 7.329+ 9.275)$$

## V. MIT RULE

There are different methods for designing such controller. While designing an MRAC using the MIT rule, the designer selects the reference model, the controller structure and the tuning gains for the adjustment mechanism. MRAC begins by defining the tracking error, e. This is simply the difference between the plant output and the reference model output:

system model e=y(p) −y(m) (1)

The cost function or loss function is defined as
F (θ) = $e^2$ / 2 (2)

The parameter θ is adjusted in such a way that the loss function is minimized. Therefore, it is reasonable to change the parameter in the direction of the negative gradient of F, i.e

$$J(\theta) = \frac{1}{2}e^2(\theta) \qquad (3)$$

$$\frac{d\theta}{dt} = -\gamma\frac{\delta J}{\delta\theta} = -\gamma e\frac{\delta e}{\delta\theta} \qquad (4)$$

- Change in $\gamma$ is proportional to negative gradient of J

$$J(\theta) = |e(\theta)|$$

$$\frac{d\theta}{dt} = -\gamma\frac{\delta e}{\delta\theta}sign(e) \qquad (5)$$

$$\text{where} \quad sign(e) = \begin{cases} 1, & e > 0 \\ 0, & e = 0 \\ -1, & e < 0 \end{cases}$$

From cost function and MIT rule, control law can be designed.

## VI. MATHEMATICAL MODELLING IN PRESENCE OF BOUNDED AND UNMODELED DYNAMICS.

Model Reference Adaptive Control Scheme is applied to a second order system using MIT rule has been discussed [13]. It is a well known fact that an under damped second order system is oscillatory in nature. If oscillations are not decaying in a limited time period, they may cause system instability. So, for stable operation, maximum overshoot must be as low as possible (ideally zero).

In this section mathematical modeling of model reference adaptive control (MRAC) scheme for MIT rule in presence of first order and second order noise has been discussed

Considering a Plant: $\ddot{y}_p = -a\dot{y}_p - by + bu$ (6)

Consider the first order disturbance is $\dot{y}_d = -y_d k + u_d k$

Where $y_p$ is the output of plant (second order under damped system) and u is the controller output or manipulated variable.

Similarly the reference model is described by:

$$\ddot{y}_m = -a_m\dot{y}_m - b_m y + b_m r \qquad (7)$$

Where $y_m$ is the output of reference model (second order critically damped system) and r is the reference input (unit step input).

Let the controller be described by the law:

$$u = \theta_1 r - \theta_2 y_p \qquad (8)$$

(9)

$$e = y_p - y_m = G_p G_d u - G_m r$$

$$y_p = G_p G_d u = \left(\frac{b}{s^2 + as + b}\right)\left(\frac{k}{s+k}\right)(\theta_1 r - \theta_2 y_p)$$

$$y_p = \frac{bk\theta_1}{(s^2 + as + b)(s+k) + bk\theta_2} r$$

Where $G_d$ = Noise or disturbances.

$$e = \frac{bk\theta_1}{(s^2 + as + b)(s+k) + bk\theta_2} r - G_m r$$

$$\frac{\partial e}{\partial \theta_1} = \frac{bk}{(s^2 + as + b)(s+k) + bk\theta_2} r$$

$$\frac{\partial e}{\partial \theta_2} = -\frac{b^2 k^2 \theta_1}{[(s^2 + as + b)(s+k) + bk\theta_2]^2} r$$

$$= -\frac{bk}{(s^2 + as + b)(s+k) + bk\theta_2} y_p$$

If reference model is close to plant, can approximate:

$$(s^2 + as + b)(s+k) + bk\theta_2 \approx s^2 + a_m s + b_m$$

$$bk \approx b$$

(10)

$$\frac{\partial e}{\partial \theta_1} = b / b_m \frac{b_m}{s^2 + a_m s + b_m} u_c$$

$$(11)\ \frac{\partial e}{\partial \theta_2} = -b / b_m \frac{b_m}{s^2 + a_m s + b_m} y_{plant}$$

Controller parameter are chosen as $\theta_1 = b_m$/b and $\theta_2 = (b - b_m)$/b

Using MIT

$$\frac{d\theta_1}{dt} \overset{(12)}{=} -\gamma \frac{\partial e}{\partial \theta_1} e = -\gamma\left(\frac{b_m}{s^2 + a_m s + b_m} u_c\right) e$$

$$\frac{d\theta_2}{dt} \overset{(13)}{=} -\gamma \frac{\partial e}{\partial \theta_2} e = \gamma\left(\frac{b_m}{s^2 + a_m s + b_m} y_{plant}\right) e$$

Where $\gamma = \gamma' \text{x}\, b / b_m$ = Adaption gain

Considering a =7.329, b = 9.275 and $a_m$ =7.329 , $b_m$ = 464.147

## VII. SIMULATION RESULTS FOR MIT RULE WITHOUT BOUNDED DISTURBANCE AND UNMODELED DYNAMICS.

To analyze the behavior of the adaptive control the designed model has been simulated in Matlab-Simulink. The simulated result for different value of adaptation gain for MIT rule is given below:

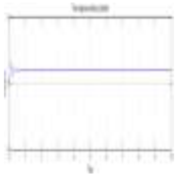


Fig.3

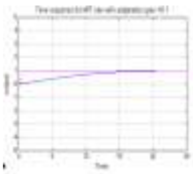


Fig.4

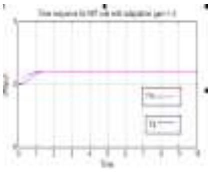


Fig.5

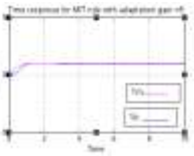


Fig.6

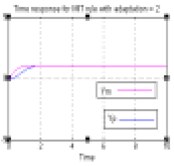


Fig.7

The time response characteristics for the plant and the reference model are studied. It is observed that the characteristic of the plant is oscillatory with overshoot and undershoot whereas the characteristic of the reference model having no oscillation. Dynamic error between these reduced to zero by using model reference adaptive control technique.

Results with different value of adaptation gain for MIT rule is summarized below:

| | Without any controller | With MRAC | | | |
|---|---|---|---|---|---|
| | | $\gamma$=0.1 | $\gamma$=2 | $\gamma$=4 | $\gamma$ =5 |
| Maximum Overshoot (%) | 57% | 0 | 0 | 0 | 0 |
| Undershoot (%) | 43% | 0 | 0 | 0 | 0 |
| Settling Time (nano second) | 1.63 | 24 | 2.3 | 2.25 | 2.15 |

Without controller the performance of the system is very poor and also having high value of undershoot and overshoot (fig.3 ). MIT rule reduces the overshoot and undershoot to zero and also improves the system performance by changing the adaptation gain. System performance is good and stable (fig. 4, fig. 5, fig. 6 & fig. 7) in chosen range (0.1< $\gamma$ <5).

## VIII. MIT RULE IN PRESENT OF BOUNDED DISTRUBANCE AND UNMODELED DYNAMICS:

Consider the first order disturbance:

$$G_d = \frac{1}{s+1}$$

Time response for different value of adaption gain for MIT rule in presence of first order disturbance is given below:

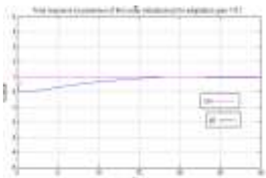


Fig. 8

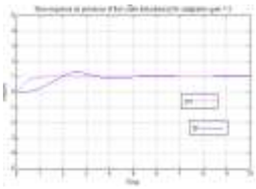


Fig.9

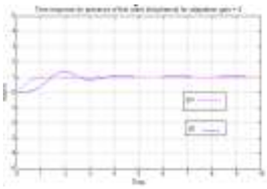


Fig.10

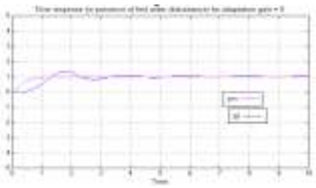


Fig.11

Simulation results with different value of adaptation gain for MIT rule in presence of first order bounded and unmodeled dynamics is summarized below:

| | Without any controller | In presence of first order bounded and unmodeled dynamics | | | |
|---|---|---|---|---|---|
| | | $\gamma$=0.1 | $\gamma$=2 | $\gamma$=4 | $\gamma$ =5 |
| Maximum Overshoot (%) | 57% | 0 | 24% | 25% | 30% |
| Undershoot (%) | 43% | 0 | 12% | 14% | 20% |
| Settling Time (second) | 1.63 | 29 | 7 | 6 | 3 |

In the presence of first order disturbance, if the adaptation gain increases the overshoot and undershoot increases, but the settling time decreases. This overshoot and undershoot are due to the first order bounded and unmodeled dynamics. It shows that even in the presence of first order bounded and unmodeled dynamics, system is stable.

Consider the second order disturbance:

$$G_d = \frac{20}{s^2 + 15s + 20}$$

Time response for different value of adaption gain for MIT rule in presence of first order disturbance is given below:

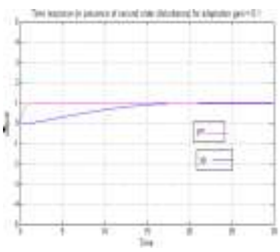


Fig.12

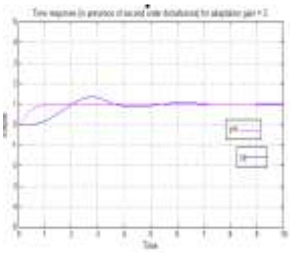


Fig.13

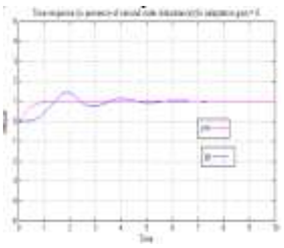


Fig.14

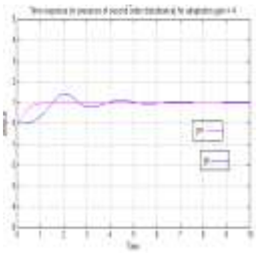


Fig.15

Simulation results with different value of adaptation gain for MIT rule in presence of second order bounded and unmodeled dynamics is summarized below:

| | Without any controller | In presence of second order bounded and unmodeled dynamics | | | |
|---|---|---|---|---|---|
| | | $\gamma$=0.1 | $\gamma$=2 | $\gamma$=4 | $\gamma$ =5 |
| Maximum Overshoot (%) | 57% | 0 | 32% | 37% | 42% |
| Undershoot (%) | 43% | 0 | 13% | 15% | 22% |
| Settling Time (nano second) | 1.63 | 30 | 9 | 7 | 4 |

In the presence of second order disturbance, if the adaptation gain increases the overshoot and undershoot increases, but the settling time decreases. This overshoot and undershoot are due to the second order bounded and unmodeled dynamics. It shows that even in the presence of second order bounded and unmodeled dynamics, system is stable.

## IX. CONCLUSION:

Model Reference Adaptive Control (MRAC) by using MIT rule in the presence of first order & second order bounded and unmodeled dynamics for control of liquid level of molten steel in the mould has been discussed. Time response in the presence of bounded and unmodeled dynamics using MIT rule has also been discussed. It can be concluded that even in the presence of bounded and unmodeled dynamics, system performance is stable for control of the liquid level of steel in the mould.

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