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Feedwater Level Control of Boiler Steam Drum using IMC and Lead - Lag IMC

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***Abstract*-This paper presents intelligent control approaches for regulating the level of steam drum. Drum level control systems are widely used in industrial process applications. The inverse response of the boiler drum cannot regulate the feed water level. Therefore advanced control strategies are necessary for the system to perform accurately and efficiently. This paper demonstrate the optimized performance of Internal Model Control(IMC) and Lead-Lag Internal Model Control(Lead-Lag IMC)with disturbance in boiler drum level process in terms of transient response characteristics.**

Index Terms-Boiler Drum, Internal Model Controller, Lead – Lag IMC, Single Element, Two Element, Three Element.

I. INTRODUCTION

Boileris a closed vessel in which steam is produced from water by the combustion of fuel. Boiler drum level control systems are extensively used in process industries for many purposes such as for generating power in steam engines or steam turbines, for sizing and bleaching in textile industries, for heating the buildings in cold weather and so on. In process industries, different kinds of boilers are used to fulfil the industrial process applications. The primary requirements of a boiler are to contain the water safely and the steam must be delivered in desired condition (as regard its pressure, temperature, quality and required rate.). For providing tight water level control of boiler steam drum, there are three types of control strategies are mainly used. Those three types of control strategies includes Single Element Control, Two Element Control and Three Element Control.

A.Single Element Control

Single Element Drum Level Control is the simplest and least effective method to regulate the water level. It is mainly used for boilers with modest change requirement and start-up operation. The process variable coming out from the drum level transmitter is compared to the set point and a deviation value is produced. This signal is fed into the controller and make corrective action.

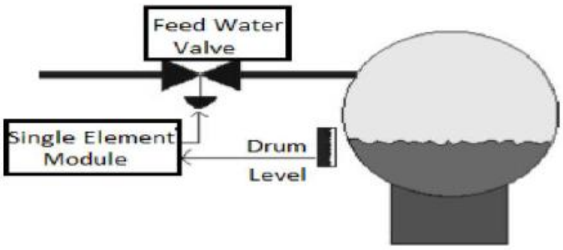

Fig 1: Single Element Control

B.Two Element Control

Two Element Drum Level Control includes steam flow as a feed forward element. Two element control system has two variables, drum level and steam flow to manipulate the feed water control valve. This strategy compensate the imbalance between feed water mass flow and steam mass flow out into the drum. It is adequate for load changes of moderate speed and magnitude. It has some drawbacks i.e. it can use on a single boiler with a single feed water pump using a constant feed water pressure, it cannot adjust for pressure or load disturbances in the feed water system and it cannot eliminate phasing interaction between various portions of the process.

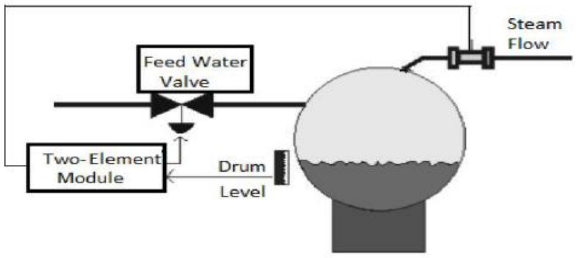

Fig 2: Two Element Control

C. Three Element Control

Three element control strategy is the commonly used method to control the drum water level. This method is ideally suited for a boiler plant, which consists of multiple boilers with multiple feed water pumps. By using cascade control mechanism, level element act as primary loop, flow element acts as the secondary loop and steam flow acts as the feed forward controller. This strategy attempts to compensate the changes or disturbance in steam flow and feed water flow.

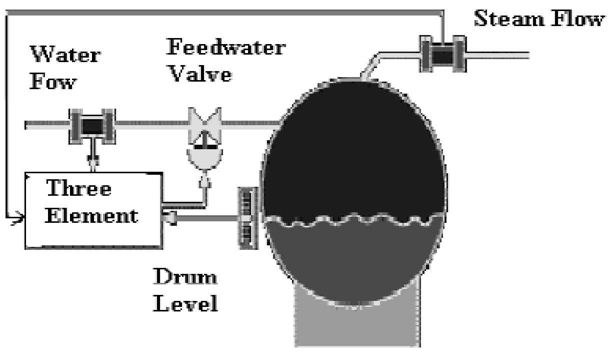

Fig 3: Three Element Control

The full scale mathematical model of a drum boiler for water level control is established by H. Kim and S.Choi [1], which includes the water level dynamics in the drum-riser-down comer loop.The mathematical model of Steam Drum is extracted from Juhua Wang and QingjinMeng, [2] which involves the state space dynamics of steam Drum and LQR is designed to make the boiler drum water level control. Controller design based on Immune principle for regulation of Drum water level is proposed by Yuan Guili and Liu Jizhen, [3]. Another application to the drum level control was proposed by Le Wei and Fang Fang[4] which was very helpful in formulating this work. Other application of drum level control by using Fuzzy controller and fuzzy self-adaptive PID controller[5][6] .The theory of Internal Model control (IMC) was proposed by Wayne Bequette et al,[7] in his book which was a key reference in this work. For drum level control, there are some influence factors as disturbances. The major disturbance like steam pressure is considered in this work for the regulation of water level.

The Paper has been organised as follows. Section II deals with the mathematical modelling of Boiler Steam Drum. Section III deals with the Theory of Internal Model controller and Lead-Lag IMC. Section IV deals with the Design of Internal Model Controller and Lead-Lag IMC. In Section V the Simulation results with disturbance are shown with some discussions on it. Section VI is the Conclusion part and Section VII deals with Future Works.

II. MATHEMATICAL MODELLING OF DRUM WATER LEVEL CONTROL SYSTEM

For the modelling of Drum water level, we should consider the important influence factors on water level control system. The main influence factors on drum water level control system are steam flow, feed water flow variations, steam pressure, boiler pressure and drum temperature.
The Drum material balance equation is

$$F(t) = Q_W(t) - Q_D(t)(1)$$

Where $Q_W(t)$is feed water flow and is $Q_D(t)$is steam flow of the steam Drum.F(t) is Drum water level variation. Level transmitters are used for measuring the variations in steam and feed water flow.
We get the physical expression of the transmitter as,

$$C\rho\frac{dH(t)}{dt} = \alpha\sqrt{\Delta p_w} - \beta\sqrt{\Delta p_D} \ (2)$$

α *and* $\beta$are the feed water and steam flow coefficients. C is the boiler sectional area, ρ is the water severe of boiler, H(t) is water level of boiler, Δp_w and Δp_D are the pressure difference of feed water and steam orifice flow respectively.
Taylor series expansion is used for linearizing the model. By using the Taylor series expansion of (2), after the derivation and simplification, we get a differential equation (3), which includes the dynamic characteristics of boiler drum water level under the effect of water supply flow and steam flow.

$$T_1T_2\frac{d^2h}{d^2t} + T_1\frac{dh}{dt} = \left(T_w\frac{du_w}{dt} + K_wU_w\right) - \left(T_D\frac{du_D}{dt} + K_DU_D\right) \ (3)$$

T_1 ,T_2 are water level transmitter coefficient and boiler sectional coefficient.T_w , K_w are the flow conversion coefficients of feed water flow transmitter. T_D , K_D are the flow conversion coefficients of steam flow transmitter.
The motion equation of regulation of drum water level under the effect of water supply flow can be expressed as:

$$T_1T_2\frac{d^2h}{d^2t} + T_1\frac{dh}{dt} = \left(T_w\frac{du_w}{dt} + K_wU_w\right)(4)$$

By taking Laplace transform on both sides of (4) and smaller T_w can be neglected.

$$G_w(s) = \frac{H(s)}{U_w(s)} = K_1\frac{1}{s(1+T_w s)} \ (5)$$

The motion equation of regulation of drum water level under the effect of steam flow can be expressed as:

$$T_1T_2\frac{d^2h}{d^2t} + T_1\frac{dh}{dt} = -\left(T_D\frac{du_D}{dt} + K_DU_D\right)(6)$$

Take Laplace transform on both sides of (6), we get

$$G_D(s) = \frac{H(s)}{U_D(s)} = \frac{K}{(1+T_w s)} - \frac{1}{TS}(7)$$

Steam flow and feed water flow variations are the important influence factors on boiler drum water level.

III. THEORY OF INTERNAL MODEL CONTROL AND LEAD-LAG IMC

A .INTERNAL MODEL CONTROL

The main advantage of Internal Model Control(IMC) is that it provides a transparent framework for control system design and tuning. The Internal Model Control theory relies on the Internal Model Principle which states that the control can be achieved only if the control system encapsulates, either implicitly or explicitly, some representation of the process to be controlled. The standard form of IMC is shown in fig 4 [7].

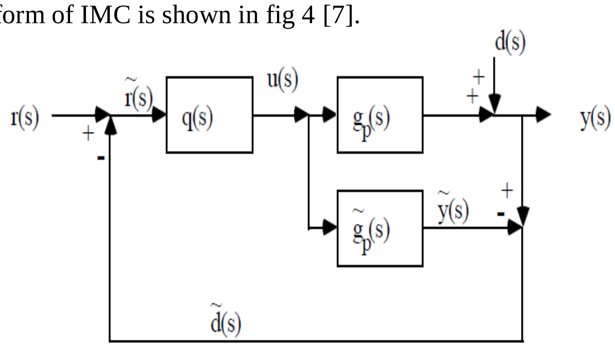

Fig 4: Internal Model Controller

From fig 4, the transfer function variables are given below: d(s) is disturbance,$\hat{d}(s)$is estimated disturbance,$g_p(s)$ is process,$\widehat{g_p}(s)$ is process model, q(s) is Internal Model Controller, r(s) is set point, $\hat{r}(s)$ is modified set point, u(s) is manipulated input, y(s) measured process output, $\hat{y}(s)$ is model output.

IMC is an advanced process control technique in which process model is used to compute the value of control variable. In IMC, process model is connected in parallel with the actual process. We can compare both the process and process model with the help of this.

From the figure, notice that the feedback signal can be:

$$\hat{d}(s) = (g_p(s) - \widehat{g_p}(s))\ u(s) + d(s) \quad (8)$$

The signal fed into the controller is

$$\hat{r}(s) = r(s) - \hat{d}(s) \quad (9)$$

$$\hat{r}(s) = r(s) - (g_p(s) - \widehat{g_p}(s))\ u(s) + d(s) \quad (10)$$

Now consider the limiting cases of IMC [7]:

a.Perfect Model, No Disturbances

If the model is perfect ($\widehat{g_p}(s) = g_p(s)$) and no disturbances (d(s) =0), then the feedback signal is zero.

The relationship between r(s) and y(s) becomes

$$y(s)=g_p(s)q(s)r(s)(11)$$

b. Perfect Model, Disturbance Effect

If the model is perfect ($\widehat{g_p}(s) = g_p(s)$) and there is a disturbance, then the feedback signal is

$$\hat{d}(s) = d(s)\ (12)$$

If unmeasured disturbances entering into a process, feedback is needed.

c. Model Uncertainty, No Disturbances

If there is no disturbances (d(s) =0) but there is a model uncertainty ($\widehat{g_p}(s) \neq g_p(s)$), then the feedback signal is

$$\hat{d}(s) = (g_p(s) - \widehat{g_p}(s))\ u(s)(13)$$

Because of model uncertainty, feedback is also needed in this case.

B .LEAD-LAG INTERNAL MODEL CONTROL

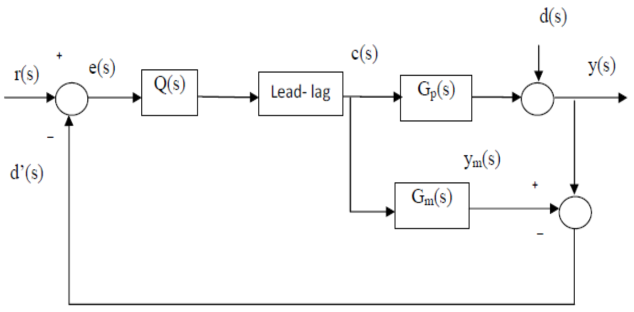

Fig 5: Lead-Lag Based IMC

Fig 5 shows the block diagram of Lead-Lag Internal Model Control (Lead-Lag IMC). Here, we can see that a Lead-Lag network is added to the Internal Model Control. Except the design of Lead-Lag network, the design procedure is same as that of Internal Model Control.

By using Lead-Lag network, the Lead network can stabilize the system, increase the speed of response and improve the transient response of the system. Lag network can decrease the steady state error and increase the accuracy.

IV. DESIGN OF IMC AND LEAD-LAG IMC WITH DISTURBANCES FOR THE DRUM WATER LEVEL CONTROL

For the design procedure of IMC, we use dynamic control law. Because dynamic controller can give faster response than static controller. This paper proposes a controller which can provide robustness to the system.

The controller design procedure has been generalized as follows:

A. INTERNAL MODEL CONTROL

STEP 1

Factorize the process model into 'good stuff' (invertible) and 'bad stuff' (non-invertible---RHP zeros and time delays) by all-pass factorization or simple factorization.

$$\widehat{g_p}(s) = \widehat{g_p}^{+}(s)\widehat{g_p}^{-}(s) \quad (14)$$

The resulting controller will be stable, if all-pass factorization is used.

STEP 2

Idealized IMC controller can be created by invert the good stuff portion of the process model.

$$\hat{q}(s) = \frac{1}{\widehat{g_p}^{-}(s)} \quad (15)$$

STEP 3

Add a filter f(s) to make the controller proper. If the order of the numerator and denominator is same, the controller is semi proper. If the order of denominator is higher than numerator, the controller is proper.

$$q(s) = \hat{q}(s)f(s) \quad (16)$$

$$\text{Where, } f(s) = \frac{1}{(1+\lambda s)^n} \quad (17)$$

$'\lambda'$ is the tuning parameter of Internal Model Control.For making the controller proper or semi proper, change the values of 'n' (1 2 3 …).

If it is desirable to track the set point changes, then

$$f(s) = \frac{n\lambda s+1}{(1+\lambda s)^n} \quad (18)$$

STEP 4

Adjust the filter tuning parameter $'\lambda'$to vary the speed of response of the system. The closed loop system is "fast", if the value of tuning parameter is small. The closed loop system is more "robust", if the value of tuning parameter is large.

B. LEAD-LAG IMC

The design procedure of Lead-Lag IMC is same as that of generalized IMC procedure except the design of Lead-Lag network.

The design of Lead-Lag IMC as follows:

Transfer function of Lead-Lag IMC is

$$T(s) = \frac{\alpha s+1}{\beta s+1} \quad (19)$$

Therefore controller function of Lead-Lag based IMC becomes

$$q(s) = \frac{f(s)}{\widehat{g_p}^{-}(s)}T(s) \quad (20)$$

$$q(s) = \frac{f(s)}{\widehat{g_p}^{-}(s)}\frac{\alpha s+1}{\beta s+1} \quad (21)$$

Where 'α' and 'β' are time constants and used as the tuning parameters of Lead-Lag based IMC. So Lead-Lag IMC has three tuning parameters such as α, β and$f(s)$.

V. SIMULATION RESULTS AND DISCUSSIONS

The Boiler Drum water level control system is modelled in this paper, and used with Internal Modelcontrol and Lead-Lag based IMC. IMC and Lead-Lag IMC is implemented with disturbance using MATLAB/SIMULINK environment.In both cases, steam pressure factor is considered as the disturbance. The presence of steam pressure may create the Shrink and Swell effects. Because of this, it indicates false water level in boiler steam Drum.

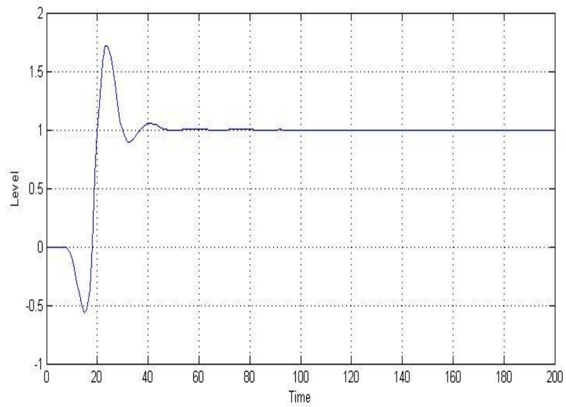

Fig.6:Regulation of Drum water level using IMC with Disturbance

Using the described controller design, feed water level control of boiler drum is implemented using SIMULINK. We get the output response shown in fig 6. From the response of Internal Model Control, it is found out that the settling time and overshoot is high. To improve the transient response of Internal Model Control, here we use the Lead-Lag network with IMC.

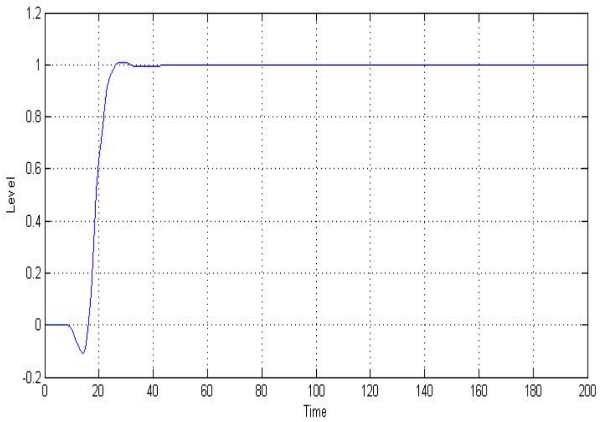

Fig.7: Regulation of Drum water level using Lead-Lag IMC with Disturbance

From fig 7, we can see that the transient response of feed water level control of boiler drum is improved using Lead-Lag network. Almost 90% of the overshoot is reduced and settling time also reduced when compared to IMC. The comparison results are shown in the below table.

Table I: Comparison Results of Control Parameters of Boiler Drum with Disturbance.

	IMC	Lead-Lag IMC
Settling Time	85 seconds	42 seconds
Overshoot (%)	41%	1%

VI. CONCLUSION

In this paper, Internal Model Control (IMC) and Lead-Lag IMC is designed for the regulation of feed water level of boiler steam drum. This work basically evaluate the performance of IMC and Lead-Lag IMC of drum level control system with disturbance. The simulation result shows the performance of proposed control system and the comparison between both the control strategies are studied. From Simulink response and time domain specifications, the performance of Lead-Lag IMC is more accurate and better than Internal Model Control.

VII. FUTURE SCOPE

Internal Model Control and Lead-Lag IMC are good approaches, but the main drawback of this method is that, it cannot eliminate undershoot and overshoot completely. So design a new Lead-Lag IMC-PID controller for more better and accurate results in feed water level control of Boiler steam Drum. Then make a comparative study of these different approaches.

REFERENCES

[1] H. Kim, S. Choi,"A Model on Water Level Dynamics in Natural Circulation Drum-type Boiler", *International Communications in Heat and Mass Transfer 32 (2005) 786–796.*

[2] Juhua Wang, QingjinMeng," Research on Optimal Control System of Boiler Drum Water Level Based on LQR", *International Conference on Transportation, Mechanical and Electrical Engineering (TMEE) December 16-18 2011*.

[3] Yuan Guili, Liu Jizhen, Wang Tianhong" The Controller Designfor the Boiler Drum Level System Based on Immune Principle", *Fourth International Conference on Intelligent Computation Technology and Automation*, 2011.

[4] Le Wei,Fang Fang," A Novel IMC Cascade Control Structure of Super-Heated Steam Temperature System for Super Critical Coal Fired Boilers", *Chinese Control and Decision Conference (CCDC) 2011*.

[5] ZHuo Wang, Qiang Wang, "Application of Fuzzy controller in Drum-Water level control", *IEEE International Conference on Mechatronic science,Electric Engineering and Computer*, August 2011, pp. 19-22.

[6] Liang Chen, Cuizhu Wang, Yang Yu, YaweiZhao,"The Research on Boiler Drum Water Level Control System based on Self-Adaptive Fuzzy PID", *Chinese Control and Decision Conference 2010*.

[7] Wayne Bequette,"Process Control Modelling Design and Simulation", *Pearson Education, 2003, 260-290*.

[8] Wang ZHuo, Wang SHichao, Jiang Yanyan"Simulation of Control of Water Level in Boiler Drum", *IEEE International Conference on Mechatronic science,Electric Engineering and Computer*, August 2012.

[9] K. GhousiyaBeegom, D. Mercy, "An Intelligent Model Based Level Control of Boiler Drum,"*International Journal of Emerging Technology and Advanced Engineering, vol3,issue 1, January 2013.*

[10] Om Prakash Verma and Gaurav manik,"Comparitive Analysis of Boiler Drum Level Using Advanced Classical Approaches", *International Journal for Engineering Science and Innovative Technology, Vol. 2, Issue 5, September 2013.*