Boiler Drum Level Control Using Internal Model Controller

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***Abstract*-The water level of boiler drum is one of the crucial control parameters for any process industry which reflects the control of mainly boiler load and feed water indirectly. If the level exceeds the limits, boiler water carryover into the superheater or the turbine may cause damage resulting in extensive maintenance costs. If the level is low, overheating of the water wall tubes may cause tube ruptures and serious accidents, resulting in expensive repairs, downtime, and injury or death to personnel.A rupture or crack most commonly occurs where the tubes connect to the drum. Damage may be a result of numerous or repeated low drum level conditions where the water level is below the tube entry into the drum. Boiler drum is one of the typical multi-input multi-output systems, and also shows high non-linearities, time varying response and a transportation lag. Conventionally, such system has been controlled using PID (proportional, integral, derivative) controller. Due to presence of nonlinearity (dead time) boiler drum performance can be affected when it is controlled by PID controller.Moreover PID controller produces larger settling time. To have an effective tracking of set point, an internal model based control (IMC) methodology can be implemented.The transfer function for drum level is obtained using mathematical modeling and transfer function for steam flow rate is obtained using system identification tool box.single element control is implemented using PID and IMC controllers.Three element control is implemented using cascade structure in which PID is used in primary and secondary loops.From the performance criteria it has been analysed and found that the IMC controller has better settling time, rise time, peak time and peak overshoot compared to conventional PID controller.**

I.INTRODUCTION

Boiler is defined as a closed vessel in which steam is produced from water by the combustion of fuel. Generally, in boilers steam is produced by the interaction of hot flue gases with water pipes which is coming out from the fuel mainly coal or coke. In boilers, chemical energy of stored fuel is converted into the heat energy and this heat energy is absorbed by the water which converts them into a steam. It is critical for the safe operation of the boiler and the steam turbine. Too low a level may overheat boiler tubes and damage them. Too high a level may interfere with separating moisture from steam and transfers moisture into the turbine, which reduces the boiler efficiency. Various controlling mechanisms are used to control the boiler system so that it works properlyShrink and swell must be considered in determining the control strategy of a boiler. During a rapid increase in load, a severe increase in level may occur. Shrink and swell is a result of pressure changes in the drum changing water density.During a rapid increase in load, a severe rise in level may occur because of an increase in volume of the bubbles.

The most significant cause of shrink and swell is rapid changes in drum pressure expanding or shrinking the steam bubbles due to load changes. When there is a decrease in demand, the drum pressure increases and the firing rate changes, thus reducing the volume of the bubbles (i.e., bubbles get smaller). Boiler drum is one of the typical multi-input multi-output systems, and also shows high non-linearities, time varying response and a transportation lag. Due to the non-linearity boiler drum level cannot be effectively controlled by the Proportional Integral Derivative (PID) controllers. Two types of boiler drum level control is being used at industry.They are single element and three element drum level control.

In single element control drum level is compared with a set value in level controller and the output is sent to the feed water control valve to regulate the feed water according to the deviation in level measurement and set value.In three-element control third element is steam flow. The steam flow signal is added to the output of the level controller as feed forward control to take care of sudden changes at drum level.

This work proposes the Internal Model Control design for both single and three element control.The basic idea of IMC is to use a model of the open loop process transfer function in such a way that the selection of the specified closed loop response yields a physically realisable controller. In order to design a controller the transfer function for drum level is obtained using mathematical modeling and transfer function for steam flow rate is obtained using system identification tool box.

In this project the single element control is implemented using PID and IMC controllers in MATLAB/SIMULINK environment.Since three element control has one manipultaed variable (inflow of boiler drum) and two measured output (steam, drum level) cascade structure is used in this work.cascade structure is implemented using both PID and IMC for three element.It is proved that IMC provides better performance compared to conventional PID controller in both single and three element control.

II.MATHEMATICAL MODELLING FOR SINGLE ELEMENT CONTROL

The mathematical model of the spherical tank is determined by considering two assumption levels as the control variable, inflow to the tank as the manipulated variable. This is achieved by controlling the input flow into the tank. The single spherical tank system is shown.

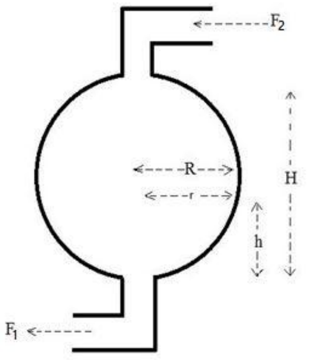


Fig 2.1 spherical tank

The system analyse has done by writing a transient mass balance around the tank, Rate of accumulation of mass in the tank = Mass flow in – Mass flow out .The mass balance is rewritten by in terms of variables used in system analysis

$$\frac{dv}{dt} = F_1 - F_2$$

$$V = \frac{4}{3}\pi r^3$$

The ratio of R/H which is equal to the ratio of r/h $\frac{r}{h} = \frac{R}{H}$.

By replacing the r term in equation then obtain,

$$V = \frac{4}{3}\pi \frac{R^3 h^3}{H^3}$$

Hence the Volume of spherical tank is differentiating with respect to variation in time, to obtain the rate of accumulation of mass inside the tank

$$\frac{dV}{dt} = 4\pi \frac{R^3}{H^3} h^3 \frac{dh}{dt}$$

from the equation considering that,

The volume of spherical tank varies with respect to the height of the liquid present inside the tank,

$$A\frac{dh}{dt} = F_1 - F_2$$

MODELING FOR SINGLE TANK

To obtain a transfer function for Tank,$H_1(s)/F_1(s)$, by writing a transient mass balance around Tank,

$$A_1 \frac{dh_1}{dt} = F_1 - F_2$$

$$A_1 \frac{dh_1}{dt} = F_1 - F_2$$

In steady state the inlet flow rate of spherical tank which is equal to the outlet flow from the tank, in practical condition

$F_{1s} = F_{2s}$, then $h_{1s} = 0$

The outlet flow rate of spherical tank is given by Torricelli’s law it states that the speed of outflow of a fluid through a edged hole at the bottom of a tank filled to the depth is same as the speed that a body (inside case a drop of water) would acquire in falling freely from height h.

Therefore, as per the size and shape of the valve the outflow is given by

$$F = C_V \sqrt{2gh}$$

According to Torricelli’s law Outlet Flow rate of spherical tank is

$$F_2 = C_V \sqrt{2gh}$$

Then the above equation is rewritten by,

Let considering from the equation

$$\alpha = \left[\frac{H_1^3}{4\pi R_1^3}\right]$$

From the equation equating

$$\alpha C_V \sqrt{2g} = \beta$$

Then the equation is rewritten by

$$\frac{dh_1}{dt} = \alpha h_1^{-2} F_1 - \beta h_1^{-3/2}$$

There are two non- linear functions in the equation (3.14), which are

h_1^{-2} and $h_1^{-3/2}$

Taylor's series expansion, it is a representation of a function as an infinite sum of terms that calculated from the values of the function derivative at a single point.

To linearize the system equation apply the Taylor series as follow for the term h_1^{-2}

$$f(h_{1s}^{-2}) = -2h_{1s}^{-3} F_{1s} \left(h_1 - h_{1s}\right) + h_{1s}^{-2} \left(F_1 - F_{1s}\right).$$

By solving the above equation and neglecting higher order terms

Then obtaining,

$$f(h_1, F_1) = h_{1s}^{-2} F_{1s} - 2h_{1s}^{-3} F\left(h_1 - h_{1s}\right) + h_{1s}^{-2}\left(F_1 - F_{1s}\right)$$

To linearize the system equation apply the Taylor series as follow for the term $h_1^{-3/2}$

$$f(h_{1s}^{-3/2}) = h_{1s}^{-3/2} - \frac{3}{2} h_{1s}^{-5/2} (h_1 - h_{1s})$$

At steady state condition in the spherical tank is,

$$\alpha F_{1s} = \beta h_{1s}^{-1/2}$$

Let considering, from the equation

$H_1 = h_1 - h_{1s}$ and $F = F_1 - F_{1s}$

Therefore, the equation is rewritten

$$\frac{dH_1}{dt} = h_{1s}^{-2} F_1 - \frac{\beta}{2} h_{1s}^{-5/2} H_1$$

Taking Laplace transform for equation

$$\frac{H_1(s)}{F_1(s)} = \frac{2\frac{\alpha}{\beta} h_{1s}^{1/2}}{\frac{2}{\beta} h_{1s}^{5/2} + 1}$$

By substituting $\frac{\alpha}{\beta} = \frac{F_2}{h_{1s}^{1/2}}$ and

$$\beta = \frac{8\pi R^3 h_{1s}^{1/2}}{C_V H^3 \sqrt{2g}}$$

$$\frac{H_1(s)}{F_1(s)} = \frac{K}{\tau s + 1}$$

By substituting L=4sec, the Equation becomes,

$$\frac{H_1(s)}{F_1(s)} = \frac{Ke^{-4s}}{\tau s + 1}$$

In a steady state, at a height of 10cm, transfer function obtained as,

$$\frac{H_1(s)}{F_1(s)} = \frac{0.02828e^{-4s}}{35.53s + 1}$$

III. IMC BASIC STRUCTURE

Internal model control is model based controller structure .The IMC structure which makes use of a process model to infer the effect of immeasurable disturbance on the process output and then counteracts that effect.Using the IMC design procedure, controller complexity depends exclusively on two factors.They are complexity of the model and the performance requirements. Furthermore, the proposed procedure provides valuable insight regarding controller tuning effects on both performance and robustness

3.1 IMC DESIGN FOR SINGLE ELEMENT CONTROL

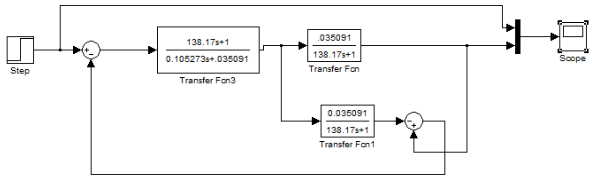


Fig 3.1 simulink model for single element control

3.2 IMC DESIGN FOR THREE ELEMENT CONTROL

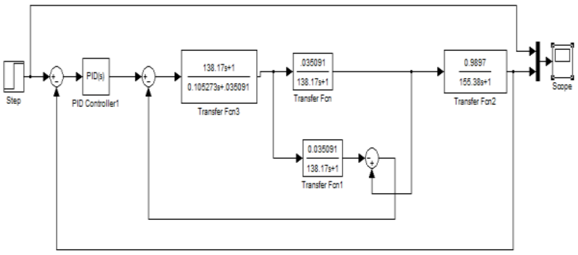


Fig 3.2simulink model for three element control

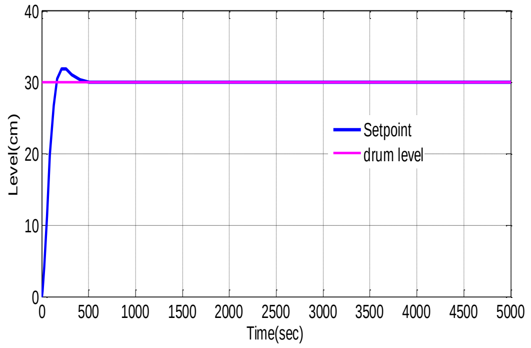
IV.RESULTS AND DISCUSSION

SINGLE ELEMENT CONTROL

The single element drum level is compared with a set value in level controller and the output is sent to the feed water control valve to regulate the feed water according to the deviation in level measured and set value.

4.1 PID CONTROLLER

In single element control drum level is maintained by controlling inflow rate of drum.The response of PID controller for single element is shown in Fig 4.



4.1 Response of PID controller for single element control

4.2 IMC CONTROLLER

The advantage of IMC over PI is better disturbance rejection capability, due to its good tracking capability, low overshoot and settling time. Response of IMC controller for single element control is shown in Fig 4.2.

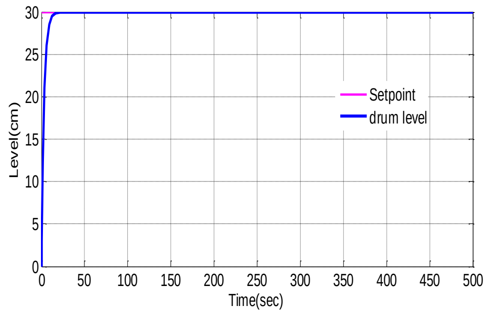


Fig 4.2 Response of IMC controller for single element control

4.3 COMPARISON OF RESULTS

To Compare the Controller action various parameters such as rise time, peak time, peak overshoot and settling time are taken in simulated response.Integral absolute error (IAE) allows larger deviation of error than integral square error(ISE).So it is considered as performance criteria in this work.The response obtained for PID controller and IMC controller is compared.Comparison is shown in Table 4.3.

Table 4.3 Comparison of PI, IMC controller for single element control

PARAMETERS	PID CONTROLLER	IMC CONTROLLER
Settling time(sec)	**500**	**30**
Rise time(sec)	**250**	**10**
Peak time(sec)	**300**	**0**
Peak Overshoot (%)	**6.6**	**0**
IAE	**4000**	**2521**

From the Table 4.3 it is clear that IMC controller produces the better performances in simulation compared to PID controller. IAE also reduced in IMC controller.

4.4 THREE ELEMENT CONTROL

In three-element control third element is steam flow. The steam flow signal is added to the output of the level controller as feed forward to take care of sudden steam flow changes.

PID CONTROLLER

Three element control requires the measurement of drum level, steam flow rate, feed water flow rate.In three element control the drum level is maintained by measuring steam. The response of PID controller for three element control is shown in Fig 4.4

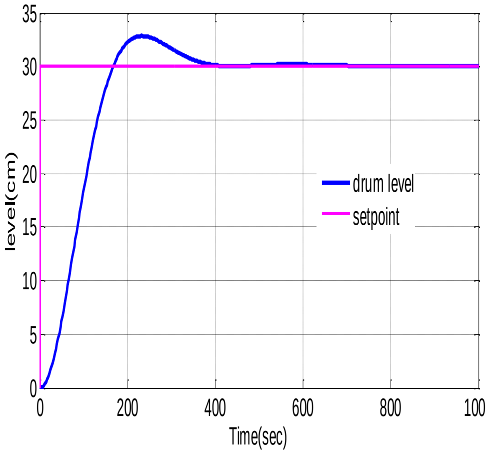


Fig 4.4 Response of PID for three element control

4.5 IMC CONTROLLER

The response of IMC controller is shown in Fig 7.3.

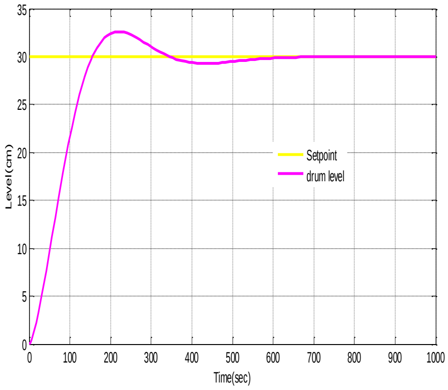


Fig 4.5 Response of IMC three element control

4.6 COMPARISON OF RESULTS FOR THREE ELEMENT CONTROL

To Compare the Controller action various parameters such as rise time, peak time, peak overshoot and settling time are taken from simulated response. Integral Absolute Error (IAE) is considered as performance criteria.The response obtained for PID controller and IMC controller is compared.Comparison is shown in Table 4.6.

Table 4.6 Comparison of PID and IMC controller for three element control

PARAMETERS	PID CONTROLLER	IMC CONTROLLER
Settling time(sec)	**700**	**600**
Rise time(sec)	**136**	**130**
Peak time(sec)	**224.6**	**224.6**
Peak Overshoot (%)	**8.9**	**8.6**
IAE	**2980**	**2639**

From the Table 4.6 it is observed that IMC controller produces the better performances in simulation compared to PID controller. IAE also reduced in IMC controller.

V. CONCLUSION AND FUTURE SCOPE

The crucial control parameters of boiler drum were considered and the corresponding process transfer function was obtained using mathematical modeling.The PID and IMC controller was designed and the response of PID and IMC controllers for both single element and three element boiler drum level control was simulated.the performance of both the controllers was justified using integral absolute error performance criteria. From the performance criteria it has been analysed that the IMC controller has better settling time,rise time,peak time,and peak overshoot compared to conventional PID controller.

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