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# Implementing IMC Based PID Controller for Temperature Control Loop

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## ABSTRACT

*This work mainly focuses on the implementation of industry grade temperature transmitter in the loop and designing the controller for it. The temperature transmitter is highly modular and robust thermometer having several applications in industries. Because of its common communication protocols makes it a ready to use with enhanced measurement accuracy and reliability as compared to conventional wired sensors. Now a day temperature control systems are widely used in industries to manage manufacturing processes or operations. Some examples are plastic extrusion and injection modeling machines, thermo-forming machines, packaging, food processing, storage, blood banks, healthcare industries etc. In these entire system, controller plays an important role to control and monitor the temperature. Here in this poster temperature loop with temperature transmitter, controller, communication protocol, control configuration are presented.*

***Keywords:—****PID controller, Tuning methods, IMC, MATLAB.*

## I. INTRODUCTION

Temperature control is a complex procedure so integration of various software and hardware are used such as a traditional PLC can be integrated with a fuzzy logic controller to obtain stability and robustness and also with any embedded circuitry which involves microcontroller based temperature controller [1, 2]. PID controller is widely used controllers in industries in which each parameter compensate for disturbances such as P gives output proportional to error, I eliminates steady state error, & D reacts to set point change [3, 4]. Any control loop requires a system identification procedure for simulation and experimental purpose which is obtained by open loop responses [5, 6]. The mathematical modeling of these loops is executed by a IMC-based PID controller methodology by MATLAB simulation [7, 8, 9].

This work shows the improvement in temperature control loop by compensating for disturbance which is not achievable by traditional loop control. This paper is organized as–Section 2 represents methodology, section 3 represents major components, section 4 represents controller design method, section 5 designing of IMC-based PID controller, section 6 represents steps for IMC, section 7 gives result and section 8 represents conclusion.

## II. METHODOLOGY

The process is to get hot water as outlet from the cold water which is flowing through the setup. The cold water is passed through the rotameter which will help to control the flow rate of the water. Water is then collected in a tank which has a transmitter (tr-24) mounted on it. It will measure the temperature (PV) of the water in the tank and will send the signal to the controller. Now the controller will check if the process variable (PV) is equal to set point (SP). If this condition is not satisfied, the heating device shall be started via a solid-state relay. Once the temperature has reached the desired point the hot water is given as outlet.

## III. MAJOR COMPONENTS

***TR-24 transmitter:*** This is a RTD type transmitter which takes temperature as input from tank and feed it to controller.

***Controller:*** A PID controller has been placed in this system. Simple reasons choosing this over ON-OFF, P, PI, and PD is PID uses feedback control to evaluate error taking set point into consideration. PID is most accurate and stable in all these controllers. The fundamental difficulty with PID control is that it is a feedback system, with constant parameters, and no direct knowledge of the process, and thus overall performance is reactive and a compromise – while PID control is the best controller with no model of the process, better performance can be obtained by incorporating a model of the process.

***Heater:*** An immersion heater of 2Kw is used in loop in order to raise temperature inside tank. Heater is indirectly controlled by controller.

***Rotameter:*** A rotameter consists of a tapered tube, typically made of glass with a 'float' (a shaped weight, made either of anodized aluminum or a ceramic), inside that is pushed up by the drag force of the flow and pulled down by gravity. The drag force for a given fluid and float cross section is a function of flow speed squared only. A higher volumetric flow rate through a given area increases flow speed and drag force, so the float will be pushed upwards.

***Solid State Relay:*** A solid-state relay (SSR) is an electronic switching device that switches ON or OFF when an external voltage (AC or DC) is applied across its control terminals. It serves the same function as an electromechanical relay but has no moving parts and therefore results in a longer operational lifetime. SSR consist of a sensor which responds to an appropriate input (control signal), a solid-state electronic switching device which switches power to the load circuitry, and a coupling mechanism to enable the control signal to activate this switch without mechanical parts.

## IV. CONTROLLER DESIGN METHOD

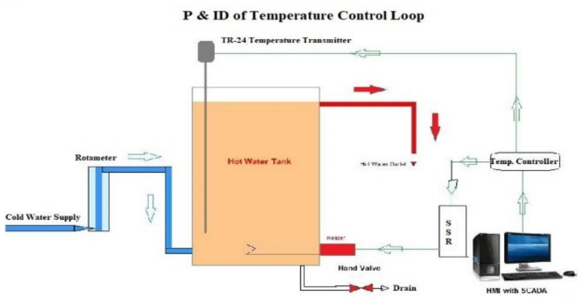

*Figure 1: Process Flow Diagram*

Selection of controller was purely based on accuracy and stability provided to the system. ON-OFF controller work with relatively large response time. Proportional controller overcomes limitations of On-Off controller. It is achieved by modulating output of controlling device. And result is smoother than proportional controller. But in our case, we are controlling different entities at the same time so PID is workably best among controllers we have discussed.PID controller uses feedback control system by which it compares both set point and true value of system with each other and minimize it according to conditions. P from PID improve rise time, I term reduces steady state error, and D term reduces overshoot value. PID controller is also called as composite controller because it's composition.

The transfer function of PID controller is:

$$G_{\downarrow}c\,(s) = K_{\downarrow}c\,(1 + 1/(T_{\downarrow}I\,s) + T_{\downarrow}D = K_{\downarrow}p + K_{\downarrow}I/s + K_{\downarrow}D\,s$$

Where,

$K_p$ is the proportional gain

$T_I$ is the integral time

$T_D$ is the derivative time

To design and tune PID controller we should follow following steps:

- Obtain dynamic model system.
- Specify desired close loop performance.
- Adoption of controller strategy to get better performance.
- Validate the performance and modify accordingly.

## V. DESIGNING OF PID USING IMC

IMC is a translucent method and commonly used method for designing and tunning of various controllers. IMC tunning method allow good set point tracking and if not then one of the best methods for dealing with disturbances. Some processes are unstable, in such cases rather than set point tracking, Disturbance rejection matters. Like PID controllers, IMC must be tuned for changes in process gain or time constant. This paper proposes the design of IMC-PID controller, with an improved IMC filter to provide effective disturbance rejection and robust operation. In this paper we are designing IMC based PID model having a good record of set point tracking and adding an IMC filter that will helps us to reject disturbances in order to make controller more accurate and robust. Robustness comes in a system where mismatched is minimal. Most of the time the frequency mismatch is really high, so in actual model-based process to attenuate add a low pass filter into the system.

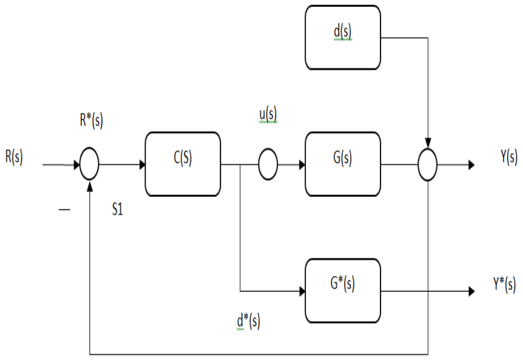

*Figure 2: Block Diagram of IMC*

The schematic representation gives us an overview about IMC process which contains following parameters.

***R(s) = Input signal***

***R*(s) = Feedback signal***

***C(s) = Controller***

***u(s) = Manipulated variable***

***d(s) = Process disturbances***

***d*(s) = Model disturbances***

***G(s) = Actual process***

***G*(s) = Model based process***

***Y(s) = Actual process output***

***Y*(s) = Expected output in model***

From the figure of IMC strategy disturbances affecting system. The manipulated input u(s) is introduced to both process and model. The process output is y (s) is compared with model output Y*(s) and comparison output result into model disturbances which is d*(s). d*(s) is signal sent to controller. If process and process model is same then d*(s). The error signal R*(s) incorporates the model mismatch and the disturbances and helps to achieve the set -point by comparing these three parameters. It sends as control signal to the controller.

## VI. STEPS FOR INTERNAL MODEL CONTROL

### *Step 1: Factorization*

Factorizing transfer function into invertible portion and non-invertible portion. The factor containing zeros or time delay transforms into poles in the invert of process model while designing the controller. So the non-invertible portion after factorization must be removed. The equation is given as:

$$Gp(s) = G_p{}^{+}(s) G^{-}{}_{p}(s)$$

Where,

$G_p{}^{+}(s)$ is a non-invertible portion

$G^{-}{}_{p}(s)$ is a invertible portion

### *Step 2: Ideal IMC Controller Identification*

The ideal internal model controller is the inverse of the invertible portion of the process model. Represented as:

$$Q_c(s) = inv[\, G_p{}^{-}(s) \,]$$

### *Step 3: Addition Of Filter*

In order to improve the robustness of the system the effect of model mismatch should be minimized. Since the mismatch between models occur and high frequencies end of the system, a low pass filter ***f(s)*** is used in conjunction to attenuate the effects of model mismatched. The filter transfer function ***f(s)*** is to make the controller stable, causal and proper. The controller with filter is given by:

$$q(s) = \frac{G_p(s)^{-1}}{(\lambda s + 1)^n}$$

Where ***n*** is the order of the filter and $\lambda$ is the filter time constant.

The order of the filter is chosen such that $G_{imc}(s)$ is proper to prevent excessive differential control action.

$$G_{imc}(s) = \frac{q(s)}{1 - q(s)\widetilde{G_p}(s)}$$

## VII. RESULT AND DISCUSSION

The process model for this loop is identified by considering time delay as 26 sec

$$G(s) = \frac{6e^{-26s}}{1 + 156s}$$

As per 1st order Pade Approximation,

$$e^{-26s} = \frac{-13s + 1}{13s + 1}$$

Hence,

$$G_{imc}(s) = \frac{6(-13s + 1)}{(156s + 1)(13s + 1)}$$

The general form of non-minimum phase with delay after Pade approximation is,

$$\tilde{G}(s) = \frac{k(-\beta s + 1)}{(\tau_1 s + 1)(\tau_2 s + 1)}$$

By using IAE optimal factorization,

$$\tilde{G}_{(+)} = -\beta s + 1$$

$$\tilde{G}_{(-)} = \frac{k}{(\tau_1 s + 1)(\tau_2 s + 1)}$$

$$\tilde{Q} = \frac{(\tau_1 s + 1)(\tau_2 s + 1)}{k}$$

By introducing 1st order filter to make controller proper we get,

$$Q(s) = \frac{(\tau_1 s + 1)(\tau_2 s + 1)}{k(\lambda s + 1)}$$

A basic feedback controller equation is given by,

$$C(s) = k_c\left(1 + \frac{1}{\tau_i\, s} + \tau_d s\right)$$

PID parameter after solving the basic controller equation are,

$$k_c = \frac{\tau_1 + \tau_2}{k(\beta + \lambda)}$$

Where,

$$\tau_i = \tau_1 + \tau_2$$

$$\tau_d = \frac{\tau_1 \tau_2}{\tau_1 + \tau_2}$$

By comparing equations we get,

k = 4, $\beta$ = 13, $\tau_1$ = 156, $\tau_2$ = 13

Since,

$$\lambda = 0.8 * \theta$$

Consider, $\lambda = 2$

$$k_i = \frac{k_c}{\tau_i}, k_d = k_c \tau_d$$

There $\lambda = 2$ fore, $k_c = 0.39$ , $k_i = 0.03$ , $k_d = 2.21$

Performance and Robustness:

**Table 1 : Comparison Table**

| | With PID | Without PID |
|---|---|---|
| Rise time | 106 seconds | 215 seconds |
| Settling time | 478 seconds | 879 seconds |
| Overshoot | 6.59% | 0.833% |
| Peak | 1.07 | 1.01 |
| Gain Margin | 14.7 dB @0.06 rad/s | 3.7 dB @0.0809 rad/s |
| Phase Margin | 64.5 deg @ 0.0114 rad/s | 90 deg @0.0329 rad/s |

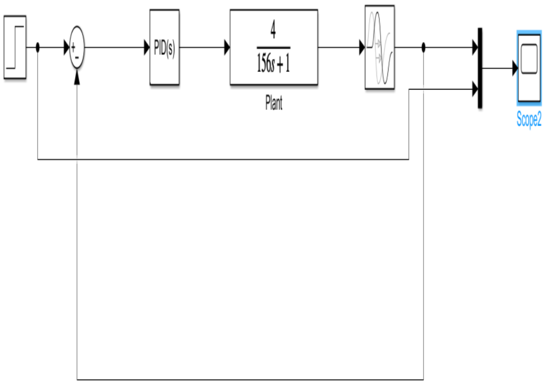

*Figure 3 : Plant model simulation on MATLAB*

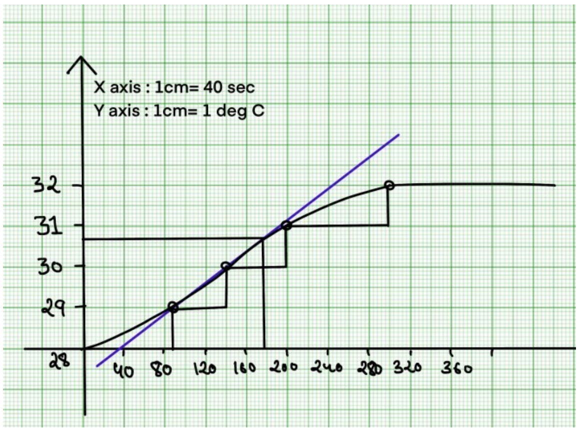

*Figure 4: Open loop response*

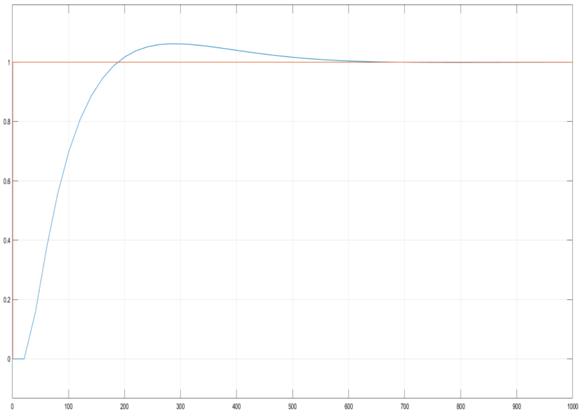

*Figure 5: Response of temperature loop with tuning*

## VIII. CONCLUSION

The above experimental work on temperature control loop shows that the effectiveness of IMC tuned PID controller that provides better time response characteristics i.e. optimum settling time and reduced overshoot as compared to other tuning methods. The results have proven that IMC-PID control setting is more effective way in disturbance rejection and to enhance the stability of system.

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