Designing IMC based Controller for Process Loops

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Abstract - *In this work process loops under consideration are Liquid Flow Control (LFC) Loop and Level Control (LC) Loop. Both loops are controlled by controller designed by using Internal Model Control (IMC) principle. In LFC and LC loops industry grade electromagnetic flow and level transmitters are used. The electromagnetic meters are essential in measuring the displacement or bulk movement of liquids in an application. In level control loop there are important variations of the liquid storage process the tank exit line may contain a valve that provides significant resistance to flow. An important consequence of this configuration is that the exit flow rate is then completely independent of liquid level over a wide range of conditions. In this situation, the tank operates basically as a flow integrator. These flow-meters do not obstruct flow, so they can be applied to clean, sanitary, dirty, corrosive and abrasive liquids. Process model is obtained to predict the behaviour of a process. Models can be used to simulate expected process behavior with a proposed control system. IMC PID controller is designed and its parameters are selected based on knowledge of process, experience and insight. The model can be used in a computer simulation to evaluate alternative control strategies and to determine preliminary values of the controller settings.*

***Key Words*: IMC, Electromagnetic Flow-meter, PID, Level measurement**

1. INTRODUCTION

This project belongs to process control loops.[1] [2] The process loops under consideration are Liquid Flow Control (LFC) Loop and Level Control (LC) Loop. Designing and development of this control loop is main integral part of this project. [3] In Flow and Level control loops industry grade transmitters (Proline Promag 50P & Prosonic FMU40) are used [5] [6]. Process model is obtained by writing a set of equations that allows us to predict the behaviour of a process [7]. Models play a very important role in control-system design. Models can be used to simulate expected process behaviour with a proposed control system. [8]. One of the most commonly used controllers in the industries at present are Proportional-Integral-Derivative (PID). [9]. The choice of PID is due to its linear dynamics, simpler gain tuning and simple to implement in process. The traditional way of tuning the gain parameter using Ziegler-Nichols method results in large overshoot for servo Problems. [10]. In practical applications or an actual process in industries PID controller algorithm is simple and robust to handle the model inaccuracies and hence using IMC-PID tuning method a clear compromise between closed loop performance and robustness to model inaccuracies is achieved with a single tuning parameter. In IMC-PID controller IMC filter is design for better set-point tracking and disturbance rejection [11]. As the IMC approach is based on pole zero cancellation. Which comprise IMC design principles result in good set point responses.

The rest of the paper is organized as follows: Section II describes the process modelling and identification of the system, Section III discusses the tuning of PID and Internal Model Control (IMC). The results and simulation are given in Section IV while the concluding remarks are summarized in Section V.

2. METHODOLOGY

2.1 FLOW CONTROL LOOP

The flow loop shown in Figure 1, consists of a Flow Transmitter Promag P50 which is based on Electromagnetic induction technology. This technology has a number of advantages for liquid flow measurement. In this technology the sensors are generally inserted in line into the pipes' diameter. Therefore, these sensors are designed such a manner that they do not disturb or restrict the flow of the medium under measurement. In this case the sensors are not directly dipped in the liquid or there are no moving parts and there are no wear and tear concerns.

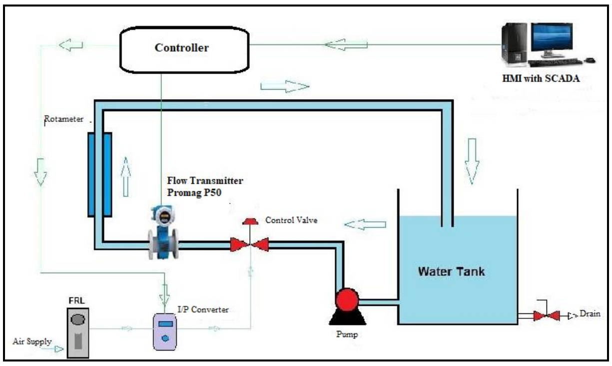

Fig 1: Piping and Instrumentation Diagram of Flow Loop

2.1 LEVEL CONTROL LOOP

The Figure 2 shows a Piping and Instrumentation Diagram of Level Loop. This loop mainly having an Ultrasonic Level Transmitter Prosonic FMU40. The Prosonic level transmitter is a compact measuring device for continuous, non-contact level measurement. As far as a maintenance is concern and these type of sensors do not make physical contact with the process material are mostly preferred in industries. Ultrasonic type sensors can be located outside the tank as shown in Figure 2,

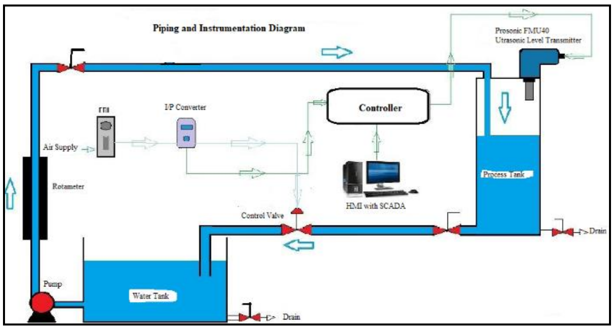

Fig 2: Piping and Instrumentation Diagram of Level Control Loop

2.2 TRANSMITTERS

In this work industry grade transmitters are used for flow and level measurement and transmitting the signal to the controller. The advantage of using these transmitters are flowmeter in LFC does not obstruct flow, so it can be applied to clean, sanitary, dirty, corrosive and abrasive liquids. In LC Loop an Ultrasonic Prosonic MFMU40 is used. The sensor of the Prosonic M transmits ultrasonic pulses in the direction of the product surface. There, they are reflected back and received by the sensor. The Prosonic M measures the time between pulse transmission and reception. The instrument uses the time and the velocity of sound to calculate the distance between the sensor membrane and the fluid surface. [4]

Table 1: Specifications of Proline Promag 50P Flow Transmitter

Parameters	**Values**
Measuring range	0…9'600 m3/h
Max. process pressure	PN10...40 Cl 150...300 JIS 10...20K AS 2129 Table E AS 4087 PN16
Medium temperature range	-40...+180°C (-40...+356°F)
Ambient temperature range	-20...+60°C -40...+60°C (optional)
Degree of protection	IP 67 (NEMA 4x) IP 68 (Nema 6P)
Max. measurement error	±0.5% ±0.2% (optional)
Nominal diameter range	DN 15...600 1/2"...24"

Benefits: Measurement with a high degree of accuracy for a wide range of process conditions. The uniform Proline transmitter concept comprises:

- Modular device and operating concept resulting in a higher degree of efficiency
- Software options for batching, electrode cleaning and for measuring pulsating flow
- High degree of reliability and measuring stability
- Uniform operating concept

The Prosonic FMU40 is an ultrasonic type of level transmitter. The Ultrasonic level sensors work by the "time of flight" principle using the speed of sound. The sensor sends pulses toward the surface and receives echoes pulses back. Basically, the transmitter divides the time between the pulse and its echo by two, and that is the distance to the surface of the material.

Table 2: Specifications of Ultrasonic Prosonic M FMU40 Level Transmitter

Parameters	**Values**
Maximum measuring distance	Liquids 5m (16.4ft) Solids 2m (6.56ft)
Blocking distance	0.25m (0.8ft) for both Liquids and Solids
Temperature	-40 to +80°C (-40 to +176°F)
Pressure	+0.7 to +3bar (+10 to +44 psi)
Accuracy	+/- 2 mm or +/- 0.2 % of set measuring range
Supply / Communication	2/4-wire (HART), PROFIBUS PA,

	FOUNDATION Fieldbus
Process connection	G / NPT 1 1/2"

Benefits:

- Reliable non-contact measurement
- Quick and simple commissioning via menu-guided on-site operation with four-line plain text display, 7 languages selectable
- Envelope curves on the on-site display for simple diagnosis
- Hermetically sealed and potted sensor
- Chemically resistant sensor out of PVDF
- Calibration without filling or discharging
- Integrated temperature sensor for automatic correction of the temperature dependent sound velocity

3. SYSTEM IDENTIFICATION

The determination of the dynamic behaviour of a process by experiment is called process identification. Open-loop identification is widely used in the industry. In open loop step testing, a step change in input is applied to the process which will produce a corresponding response. It is called process reaction curve. In the chemical industry, for many processes the process reaction curve is an S-shaped curve Figure 3. [10]

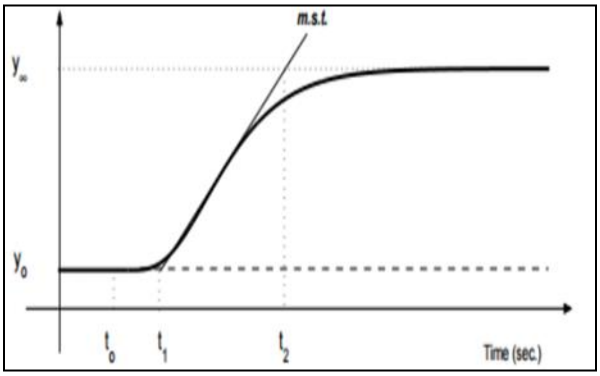

Fig 3: Plant Step Response

A useful empirical tuning formula was proposed by Ziegler and Nichols [10]. The tuning formula is obtained when the plant model is given by a first-order transfer function model with a pure time-delay. In real-time process control systems, a large variety of plants can be modelled approximately. If the system model cannot be physically derived, experiments can be made to extract the parameters for the approximate model. Many industrial processes show step responses with pure a periodic behaviour according to Figure 3. This S-shape curve is characteristic of many high-order systems and such plant transfer functions may be approximated by the mathematical model can be expressed as

$$G(s)=\frac{K}{(Ts+1)}\, e^{-Ls} \qquad (1)$$

This contains a 1st order delay element and a dead time.

Where, K = process gain.

T = process time constant,

L = dead time of the process

3.1 INTERNAL MODEL CONTROL (IMC) ALGORITHM

Step 1: Select the plant and consider the transfer function of the plant $G_p(s)$.

Step 2: Chose the process model $\tilde{G}_p(s)$.

Step 3: Factorize the process model into minimum phase and nonminimum phase components. $G_p(s) = G_p^+(s)G_p^-(s)$. This step ensures that $q(s)$ is stable and causal. However, $G_p^-(s)$ contains all Non-minimum Phase Elements (Noninvertible) in the plant model

i.e. all right half plane (RHP) zeros and time delays. The factor $G_p^+(s)$ is Minimum Phase and invertible.

Step 4: The controller $q(s)$ is chosen as inverse of minimum phase component. $q(s) = G_p(s)^{-1}$. If the process model contains only components which cannot be factorized but is does show stability with no right half poles (RHP) on the s-plane then the model is considered invertible.

Step 5: If the controller $q(s)$ is improper, then q(s) is normally augmented with the optimal controller to attenuate the effects of process model mismatching and remove the higher frequency part of the noise in the system in order to meet robust specifications. The robust compensator (filter) plays a pivotal role in the system as it combats plant uncertainties in the system design so that the designed control system can achieve the design objectives of robust stability and robust performance. The filter transfer function $f(s)$ is to make the controller stable, causal and proper. The controller with filter is given by

$$q(s)=\frac{G_p(s)^{-1}}{(\lambda s+1)^n} \qquad (2)$$

Where n is the order of the filter and λ 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. The filter parameter in the design can be chosen as a rule of thumb; hence the filter parameter values are often dictated by modelling errors, as already stated that in the design, it remains only tuneable parameter. The final form for the closed loop transfer functions characterizing the system is

$$\varepsilon(s) = 1 - q(s)\, f(s)\, \tilde{G}_p(s) \qquad (3)$$

$$\eta(s) = q(s)\, f(s)\, \tilde{G}_p(s) \qquad (4)$$

Filter time constant shall be selected so as to obtain good closed loop performance and disturbance rejection.

Step 6: Internal model control parameter

$$G_{imc} = \frac{q(s)}{1 - q(s)\, \tilde{G}_p(s)} \qquad (5)$$

Increasing λ increases the closed loop time constant and slows the speed of the response; decreasing λ does the opposite. Usually, the choice of the filter parameter depends on the allowable noise amplification by the controller and on modelling errors. Filter time constant λ avoids the excessive noise amplification and accommodate the modelling errors. To avoid excessive frequency gain of the controller is not more than 20 times its low frequency gain. For controllers that are ratios of polynomials, this criterion can be expressed as

$$\left|\frac{q(\infty)}{q(0)}\right| \leq 20 \qquad (6)$$

Higher the value of λ, higher is the robustness of the control system

4. RESULT AND DISCUSSION

For flow loop, the model identified by considering the time delay due to flow is about 2 sec and time constant as per recommended to flow transmitter is considered as 100msec. The gain is considered as 1 where input and output flows are equal.

$$G(s) = \frac{e^{-2s}}{0.1s+1} \qquad (7)$$

As per 1st order Pade approximation,

$$e^{-2s} = \frac{-s+1}{s+1}$$

Therefore, $G(s) = \dfrac{-s+1}{(0.1s+1)(s+1)}$ (8)

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

$$\tilde{G}(s) = \frac{k \times (-\beta s+1)}{(\tau_1 s+1)(\tau_2 s+1)} \qquad (9)$$

Where $\tau_1, \tau_2, \beta > 0$

Reference input and disturbance are step input with amplitude 1 for input and variable for disturbance respectively.

By using IAE optimal factorization of step input

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

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

$$\tilde{Q} = \frac{(\tau_1 s+1)(\tau_2 s+1)}{k} \qquad (10)$$

Now introducing the 1st order filter to make $q(s)$ controller as a proper transfer function

$$f(s) = \frac{1}{\lambda s+1} \qquad (11)$$

$$\therefore\ Q(s) = \frac{(\tau_1 s+1)(\tau_2 s+1)}{k(\lambda s+1)} \qquad (12)$$

Now classical feedback controller equation is -

$$C(s) = k_c\left(1 + \frac{1}{\tau_i s} + \tau_d s\right) \qquad (13)$$

Now solving for classical feedback controller yield the PID parameters as -

$$k_c = \frac{\tau_1 + \tau_2}{k(\beta + \lambda)} \qquad (14)$$

Where ,

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

Comparing Equations 8 and 9, we get -

$k = 1,\ \tau_1 = 0.1, \tau_2 = 1, \beta = 1,$

According to Rivera et. al. [11] $\lambda > 0.8*\theta$

$\lambda = 1.6$

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

Output of the PID parameters,

$K_c = 0.4231$, $K_i = 0.3846$, $K_d = 0.0385$,

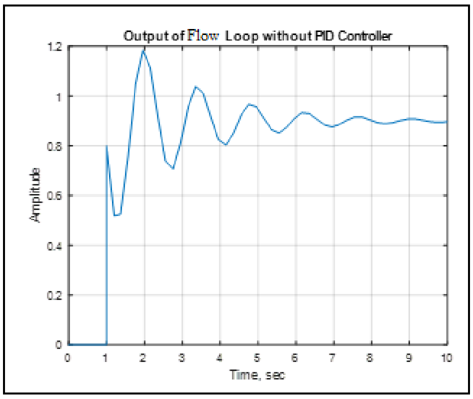

Fig 4: Output of Flow Loop without Controller shows unstable response

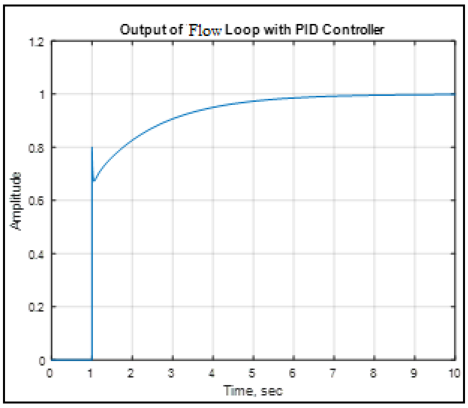

Fig 5: Output of PID Controlled Flow Loop shows stable response with disturbance

For level loop, the model is identified by considering the delay of 5 sec and time constant 100msec.

$$G(s) = \frac{1216e^{-5s}}{304s+1} \quad (15)$$

As per 1st order pade approximation,

$$e^{-5s} = \frac{-0.2s+1}{2.5s+1} = \frac{-s+0.4}{s+0.4}$$

$$G(s) = \frac{1216(-s+0.4)}{(304s+1)(s+0.4)} \quad (16)$$

Now comparing Equations (16) and equation (9) we get

$$k_c = \frac{\tau_1+\tau_2}{k(\beta+\lambda)} \quad (17)$$

Where,

$$\tau_i = \tau_1 + \tau_2 \text{ , } \tau_d = \frac{\tau_1\tau_2}{\tau_1+\tau_2}$$

Therefore, We get; $k = 1$, $\tau_1 = 0.1$, $\tau_2 = 1$, $\beta = 1$,

According to Rivera et. al. [11] $\lambda > 0.8*\theta$
Therefore, $\lambda = 4$

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

Output of the PID parameters,

$K_c = 0.0388$, $K_i = 1.2652 \times 10^{-4}$, $K_d = 0.0962$

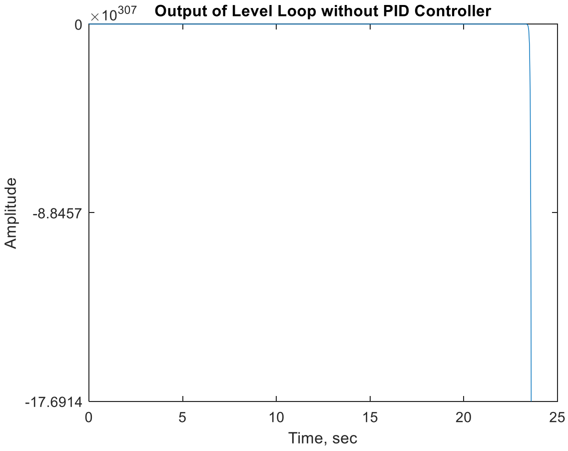

Fig 6: Output of Level Loop without Controller shows unstable response

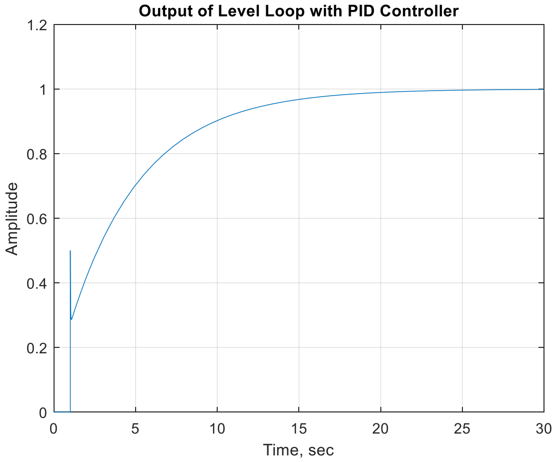

Fig 7: Output of PID Controlled Level Loop shows stable response with disturbance

5. CONCLUSION

The control of flow and liquid level in tanks is one of the basic problems in the process industries. To overcome this, IMC PID controller is simulated and implemented. From the simulation results given in Section 4, it has been observed that, for variation in amplitude of the disturbances does not affect the stability. Because of IMC structures that have claimed improvements in control quality over PID for simple systems where a properly tuned PID controller would show a good result. The IMC design procedure is generally applicable regardless of the system involved. In practical systems occurrences no nonlinearities, constraints, or multivariate interactions are very rare. In all other situations, the PID controller must be "patched up" with anti-reset windup, dead-time etc. while the IMC technique allows a unified treatment of all cases. Therefore, the IMC PID controller is used to obtain a more accurate, faster response which will acquire more precise control on level and flow in the system.

6. REFERENCES

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