IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 9, Issue 3, March 2021

DOI 10.17148/IJIREEICE.2021.9308

Determination of Suitable Controller for Flow Process Between PID and PLC

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Abstract: Liquid flow rate is a measure of velocity of a liquid which is flowing through a pipe or a closed cross-section. This paper aims to compare, analyze and determine the suitable control method for liquid flow process. There are several ways to control and stabilize flow process, in that we compare two control methods (PID controller and PLC) which has vital role in industrial applications. A Proportional–Integral–Derivative controller is a control loop mechanism employing feedback that is widely used in industrial control systems. Programmable Logic Controller (or PLC) is a ruggedized computer used for industrial automation. This controller can automate a specific process, machine function, or even an entire production line. This paper aims to conclude best controller for a real-time liquid flow process.

Keywords: PID, Cohen-Coon, Ziegler-Nichols, PLC, Flow Control, Process Control, DeltaPLC, MATLAB

I. INTRODUCTION

Liquid flow rate is a measure of velocity of a liquid which is flowing through a pipe or a closed cross-section. Generally, there are 2 types of flow rates volumetric flow rate and mass flow rate. Volumetric flow rate is a measure of the 3-dimensional space that the liquid occupies as it flows through the instrument under the measured pressure and temperature conditions. Volumetric flow rate can also be called actual flow rate. On the other hand, Mass flow rate is a measure of the mass of a liquid passes per unit time. Flow control is essential in many industrial applications such as chemical reactors, heat exchangers and distillation columns. This paper aims to design a liquid volumetric flow monitoring and control of liquids (petrol, diesel, kerosene etc.) pipeline system to offer accurate flow through the channel. There are several controllers available in industries out of which we employed two control methods.

- PID controller
- PLC controller

A Proportional–Integral–Derivative controller is a control loop mechanism employing feedback that is widely used in industrial control systems and a variety of other applications requiring continuously modulated control. A PID controller continuously calculates an error value e(t) as the difference between a desired set-point (SP) and a measured process variable (PV) and applies a correction based on proportional, integral, and derivative terms (denoted P, I, and D respectively). In practical terms it automatically applies an accurate and responsive correction to a control function.

A Programmable Logic Controller (or PLC) is a ruggedized computer used for industrial automation. This controller can automate a specific process, machine function, or even an entire production line. The PLC receives information from connected sensors or input devices, processes the data, and triggers outputs based on pre-programmed parameters. Depending on the inputs and outputs, a PLC can monitor and record run-time data such as input pressure for pneumatic control valve, flow rate, level etc. It automatically starts and stop processes. Programmable Logic Controllers are a flexible and robust control solution, adaptable to almost any application. The experimental system consists of pneumatic valve actuator (final control element), orifice flow meter (sensor), differential pressure transmitter (to measure the flow rate using pressure head), PLC, rotameter (regulation) and human machine interface (PC as HMI). The mathematical model for the designed system is derived based on open loop response of the system. Orifice flow meter and DP transmitter measures the flow rate then controller compares the sensed value with the set-point and produces corresponding control signal then actuator acts with respect to the control signal. Thus the stability and steady state with desired flow rate is reached.

II. LITERATURE REVIEW

[1] The flow is maintained constantly by implementing control valves depends on the different flow rate of the transmitting pipe and these parameters are monitored and controlled using HMI screen. In order to fulfil the above requirement, there is a continuing need for research on improved forms of control. Hence plc (programmable logical controller) is used to automatically regulate the flow of the petroleum product by controlling the percentage of opening of the control valves.

[2] The theoretical concepts are validated utilizing numerical simulations and analysis, which proves the effectiveness of the PID controller in the control of flow rates in pipelines. [3] The ordinary orifice transducer widely used in process industries for flow rate measurement produces a differential pressure which is generally measured by a DP cell and thus may suffer from various problems like leakage of process fluid, corrosion of diaphragm materials, etc. [4] Expert PID control algorithm to form a closed loop control system, so as to realize the control of the flow rate. The debugging results show that the control system is stable and can achieve the control of the flow quickly and accurately. [5] The PID controller constants will automatically self-tuning using fuzzy logic and the generated control signal will be limited using anti-windup. Self-tuning of PID constants is designed using the fuzzy logic Mamdani method with the inputs are error value and its change. [6] PI and PID control schemes are accepted in various types of control applications. Pc based position control schemes have wide applications in process plant. In recent years, it is more common to integrate control actions into PLC systems. The analog I/O of a PLC can be used to achieve PID control. [7] A comparative study of performance of PID controller and the state feedback gain controller is done by implementing both the controller on the flow loop. It is observed that the state feedback controller has less rise time and no peak overshoot as compared to PID controller.

III. EXPERIMENTAL SETUP

PLC based flow process is designed to understand the elements of a flow process and its control. It consists of a pipeline fitted with orifice as flow device and a differential pressure transmitter calibrated to measure flow. One end of the pipeline is connected with a pump and rotameter. The flow of the pipeline is controlled by a control valve which operates on a 3 to 15 psi pressure signal. A current to pressure (I/P) converter is used to convert the output of the controller (4-20mA) to the signal pressure. The process parameter is controlled by a digital indicating controller. These units along with necessary piping are fitted on the support frame. The setup is designed for tabletop placement and access. The setup is designed for tabletop placement and access. The setup can be controlled using ladder logic program using WPLSoft. The controller is connected to computer through USB for monitoring and controlling the process. User friendly software will be supplied along with the hardware to perform different set of experiments.

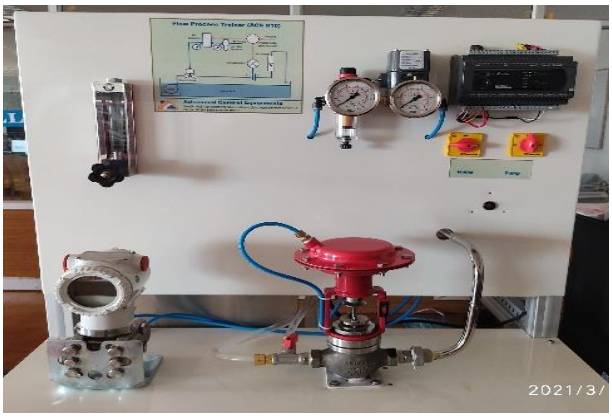

Fig 1: Experimental setup for flow monitoring and control system

IV. P&I DIAGRAM FOR THE EXPERIMENTAL SETUP

As shown in fig 2, the experimental setup was visualised using P&I Diagram using their own standard blocks corresponding to the components used in the setup. Each of the three parts of the lab scale setup contains a pressure transmitter (PT), a pressure gauge (PG), and a gate valve (GV). At the conclusion of the two sections, an equal percentage opening of the control valve (CV) is implemented. The flow transmitter (FT) has been installed along the pipeline after control valve. The pressure indicator, flow indicating controller (FIC), and flow controlling controller (FCC) are all part of the controller section. The level of control valve opening is determined by a PLC-mounted Flow controlling controller (FCC), and this FCC is not available to the operator for system operation.

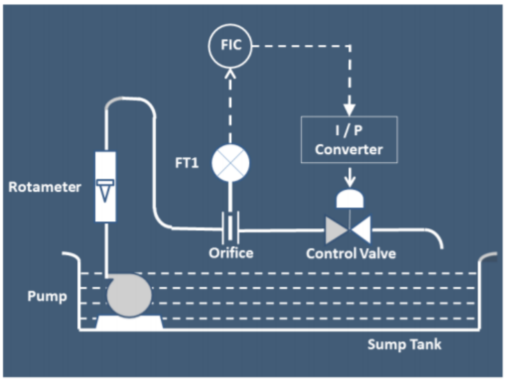

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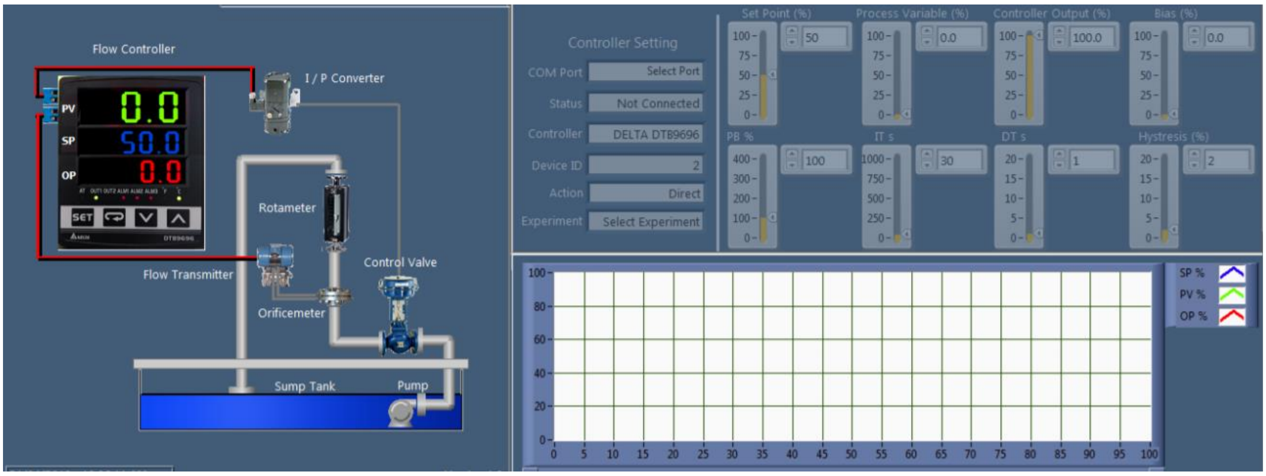
Fig 2: P & I diagram of the flow system

V. INTERFACING THE REAL TIME SYSTEM WITH HMI

Using LabVIEW, a Human Machine Interface (HMI) screen was created to view the performance of PLC-based controllers. Fig. 3 depicts the HMI screen used to maintain the pressure and flow rate of liquid through transmission lines. The screen depicts the patterns obtained by the pressure and flow signals, as well as their parameter values. The flow range is set here, the pressure for the same flow result is then controlled, and the control valve is actuated accordingly. The introduced PLC-based controller regulates and controls the level of control valve opening based on the pressure and flow signal data to maintain a constant flow rate at the destination. The numerical display of the pressure readings read by the pressure transmitter can be found on the control panel of the HMI screen. It also shows the flow rate measured by the flow sensor, the percentage of valve opening, the parameters to control the process and set point scale.



PV 0.0
SP 50.0
OP 0.0

COM Port: Select Port
Status: Not Connected
Controller: DELTA DTB9696
Device ID: 2
Action: Direct
Experiment: Select Experiment

Set Point (%): 50
Process Variable (%): 0.0
Controller Output (%): 100.0
Bias (%): 0.0
PB %: 100
IT s: 30
DT s: 1
Hystresis (%): 2

Fig 3: HMI for monitoring and control of flow process.

VI. EXPERIMENTAL ANALYSIS

Fig. 4 shows a flow diagram for a controller design for a system that transports liquid through a pipeline, in which a PLC-based controller regulates the level of opening control valves based on pressure signal monitoring to achieve the desired constant flow rate. To make the decision, the optimised pressure signal is fed to the PLC controller from the pressure signal received for the control valve opening levels.

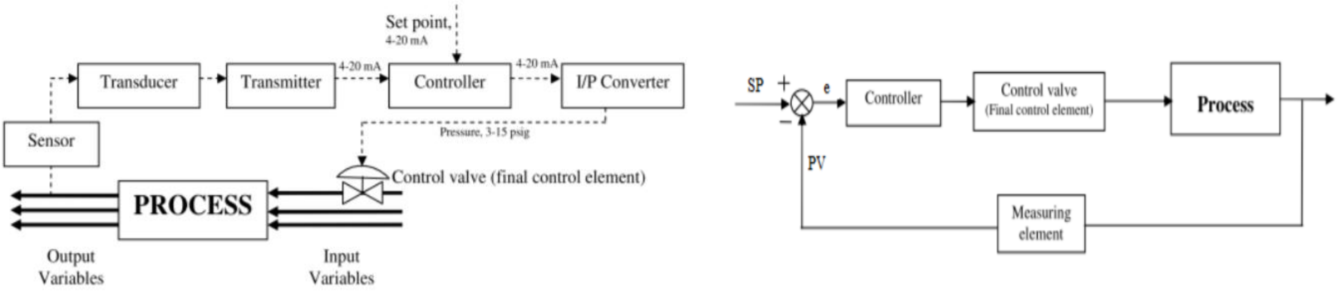


Fig. 4 Block diagram of controller design for the experimental setup

VII. OPEN LOOP RESPONSE

Open-loop system, also referred to as non-feedback system, is a type of continuous control system in which the output has no influence or effect on the control action of the input signal. In other words, in an open-loop control system the output is neither measured nor “fed back” for comparison with the input. Therefore, an open-loop system is expected to faithfully follow its input command or set point regardless of the final result. Also, an open-loop system has no knowledge of the output condition so cannot self-correct any errors it could make when the pre-set value drifts, even if this results in large deviations from the pre-set value.

From the lab scale experimental system, the experiment is conducted to find the influence of the pressure on the flow rate of liquid through transmission lines. For the model development, in the open loop scheme, a transient response curve is recorded by regulating the pressure in order to obtain the corresponding flow of the liquid. The curve describes the influence of pressure on the flow rate and level of complexity in terms of nonlinearity. The flow is varied by using the control valve opening based on the obtained three pressure signals from the pressure sensor.

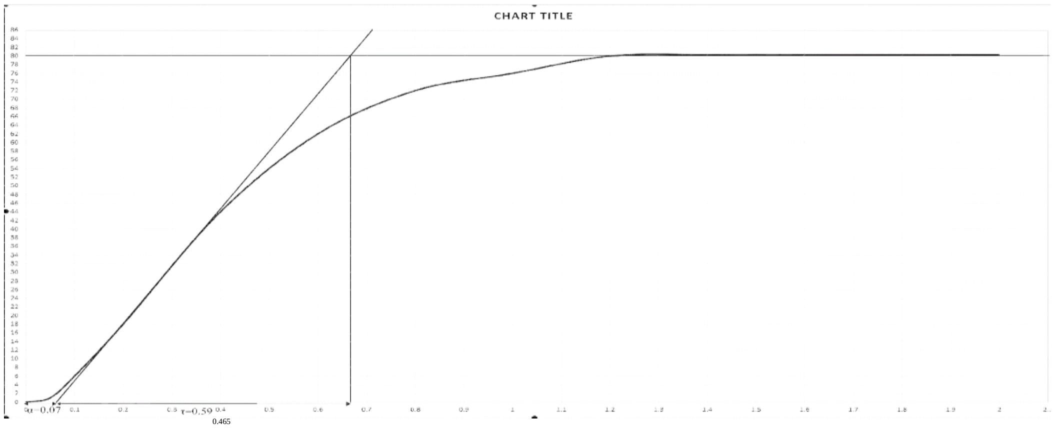


Fig. 5 Process Reaction Curve obtained from the flow process (Open Loop)

Transfer Function:

$$G(s) = \frac{K\, e^{-t_d s}}{\tau s + 1}$$

K= 80 is the final value of the system (at steady state)

$$G(s) = \frac{80\, e^{-0.05s}}{0.465s + 1}$$

$\boldsymbol{\tau}$ =**0.465** sec, which is time taken to reach 63.2% of the final value(**K**)

$\boldsymbol{t_d}$ = **0.05** sec, which is a dead time

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VIII. TUNING OF THE PID CONTROLLER

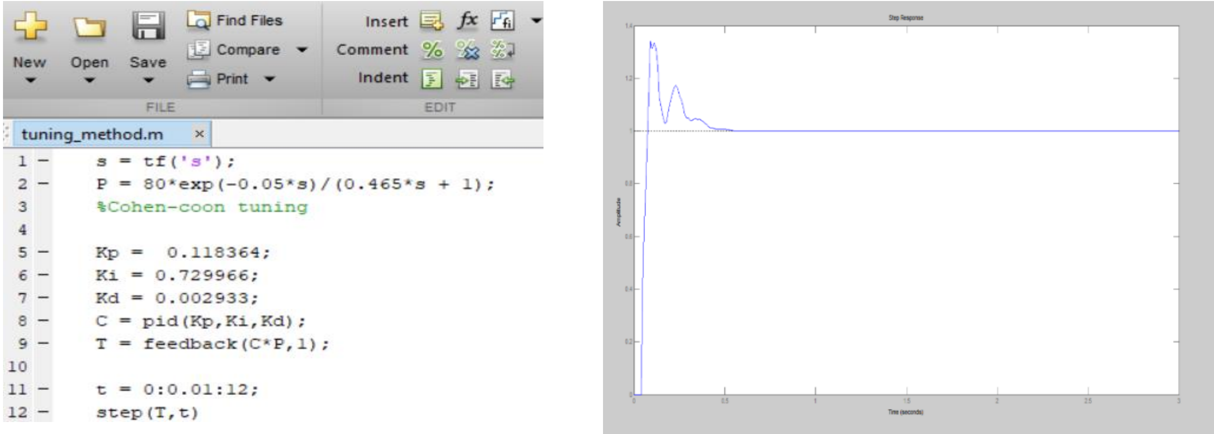
The three-mode controller (PID) is the most common feedback controller used in industrial control. The method of determination of the optimum mode gains, depending on the nature and complexity of the process is known as loop tuning. The three parameters should be selected to meet a set of defined goals. These goals typically require a plant response with minimum steady state error, insensitivity to load disturbances and an acceptable transient response to set point changes and disturbances. In practice the choice of proportional band, integral time and derivative time is a compromise between the set point tracking and disturbances. If a mathematical model of the process is known, selecting the controller parameters is relatively simple. A widely used set of rules for tuning a PID controller are proposed by Cohen-Coon and Ziegler-Nichols

A. *Cohen-Coon Tuning:*

The Cohen-Coon method is classified as an 'offline' method for tuning, meaning that a step change can be introduced to the input once it is at steady-state. Then the output can be measured based on the time constant and the time delay and this response can be used to evaluate the initial control parameters. For the Cohen-Coon method, there are a set of pre-determined settings to get minimum offset and standard decay ratio of 1/4(QDR). A 1/4(QDR) decay ratio refers to a response that has decreasing oscillations in such a manner that the second oscillation will have 1/4 the amplitude of the first oscillation.

PID Parameters	**Formula**	**For, k=80, α=0.07, τ=0.465**
K_p Proportional gain	$\frac{1}{K}\frac{\tau}{\alpha}\left[\frac{4}{3}+\frac{1}{4}\left(\frac{\alpha}{\tau}\right)\right]$	0.118364
τ_i Integral Time	$\alpha\left[\frac{32+6\left(\frac{\alpha}{\tau}\right)}{13+8\left(\frac{\alpha}{\tau}\right)}\right]$	0.162150
τ_d Derivative Time	$\alpha\left[\frac{4}{11+2\left(\frac{\alpha}{\tau}\right)}\right]$	0.024776
K_i Integral Gain	$\frac{K_p}{\tau_i}$	0.729966
K_d Derivative Gain	$K_p\tau_d$	0.002933

Table 1 PID Parameters obtained from Cohen-coon tuning



```
s = tf('s');
P = 80*exp(-0.05*s)/(0.465*s + 1);
%Cohen-coon tuning

Kp =  0.118364;
Ki = 0.729966;
Kd = 0.002933;
C = pid(Kp,Ki,Kd);
T = feedback(C*P,1);

t = 0:0.01:12;
step(T,t)
```

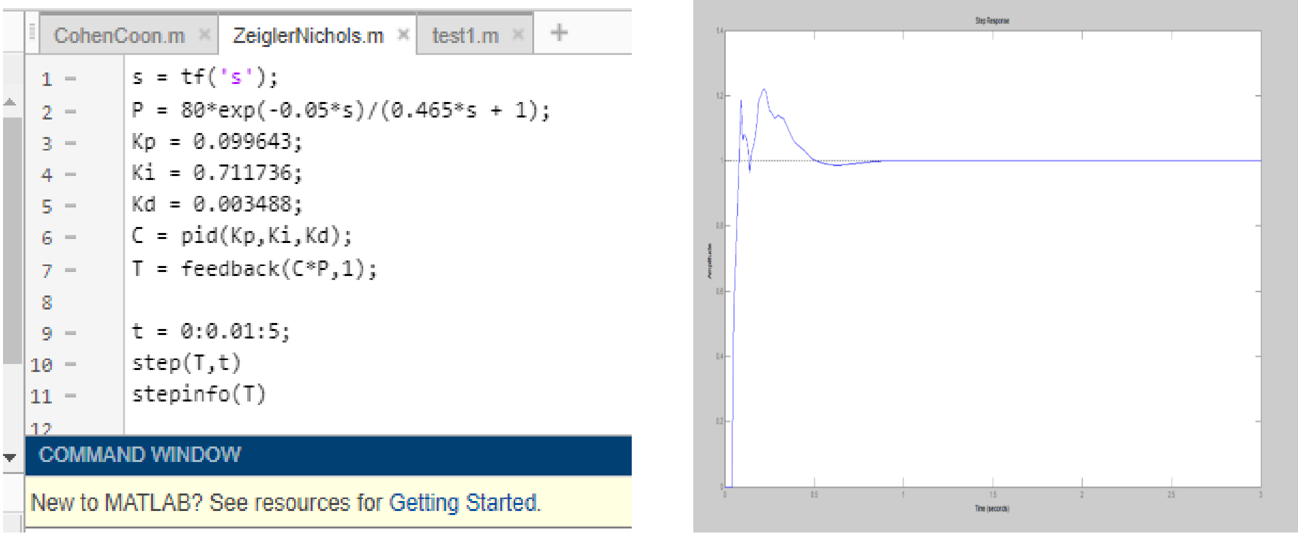
Fig. 6 Implementation of PID gain values and corresponding response graph obtained

B. *Ziegler-Nichols First Method:*

This approach is still widely used to fine-tune controllers with proportional, integral, and derivative actions. Because it tests the open-loop response of the process to a change in the control variable output, the Ziegler-Nichols open-loop method is also known as a process reaction method. This fundamental test necessitates the recording of the system's response, preferably using a plotter or computer. Once certain process response values have been identified, they can be plugged into the Ziegler-Nichols equation for the gains of a controller with P, PI, or PID actions, using specific multiplier constants.

PID Parameters	**Formula**	**For $K = 80; \alpha = 0.07; \tau = 0.465$**
K_p Proportional Gain	$\frac{1.2}{K}\frac{\tau}{\alpha}$	0.099643
τ_i Integral Time	2α	0.14
τ_d Derivative Time	0.5α	0.035
K_i Integral Gain	$\frac{K_p}{\tau_i}$	0.711736
K_d Derivative Gain	$K_p\tau_d$	0.003488

Table 2 PID Parameters obtained from Ziegler-Nichols First Method



```
s = tf('s');
P = 80*exp(-0.05*s)/(0.465*s + 1);
Kp = 0.099643;
Ki = 0.711736;
Kd = 0.003488;
C = pid(Kp,Ki,Kd);
T = feedback(C*P,1);

t = 0:0.01:5;
step(T,t)
stepinfo(T)
```

COMMAND WINDOW

New to MATLAB? See resources for Getting Started.

Fig. 7 Implementation of the PID gain values and corresponding graphs response obtained

C. *Auto-Tuning PID controller using MATLAB:*

"Autotuning" or "self-tuning" PID controllers are designed to simplify matters by choosing their own tuning parameters based on some sort of automated analysis of the controlled process's behaviour. For this experiment the autotuned values are determined from the MATLAB software with an inbuilt function “pidTuner()” which gives tuned PID gain values which when implemented makes the system to stabilize on its own.

Proportional Gain(K_p) = 0.080064	Integral Gain(K_i) = 0.11122	Derivative Gain(K_d) =0.00060031

Table 3 PID Parameters obtained from MATLAB Auto-Tuning

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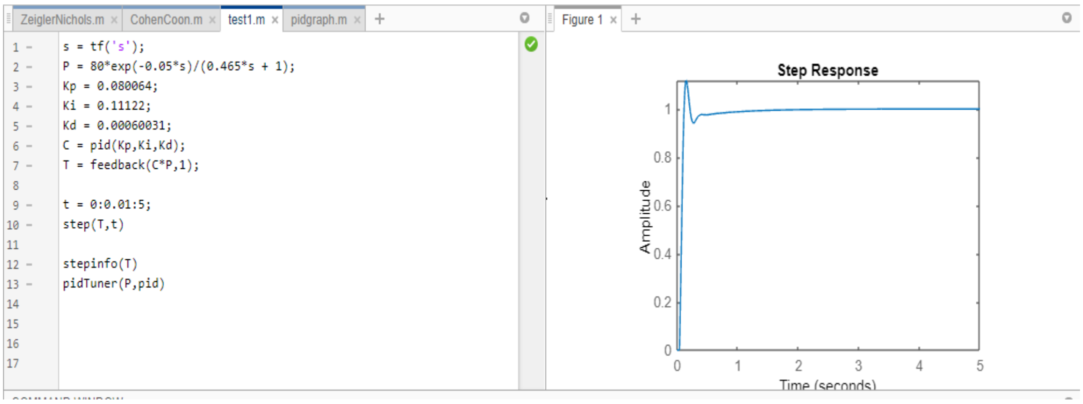

```
s = tf('s');
P = 80*exp(-0.05*s)/(0.465*s + 1);
Kp = 0.080064;
Ki = 0.11122;
Kd = 0.00060031;
C = pid(Kp,Ki,Kd);
T = feedback(C*P,1);

t = 0:0.01:5;
step(T,t)

stepinfo(T)
pidTuner(P,pid)
```

Fig. 8 Response obtained from implementing the Autotuned PID gain values

IX. IMPLEMENTATION

The Tuned PID values are implemented in two modes of operation for the same flow process, The PID values are implemented in two different modes of operation, one is implemented in a system only with a PID controller and the other in PLC (PID) controller

A. *PID controller implementation:*

The flow control system is first designed with a PID controller and the autotuned values obtained are entered as K_p, K_i and K_d respectively thus the PID controller responds to the error signal and produces a control signal which makes the system to stabilize, this stability is achieved only when the control parameters are accurate. Thus, resulting is low rise time, Low peak overshoot, High stability and quick response time. Thus the system response obtained is given in Fig. 10

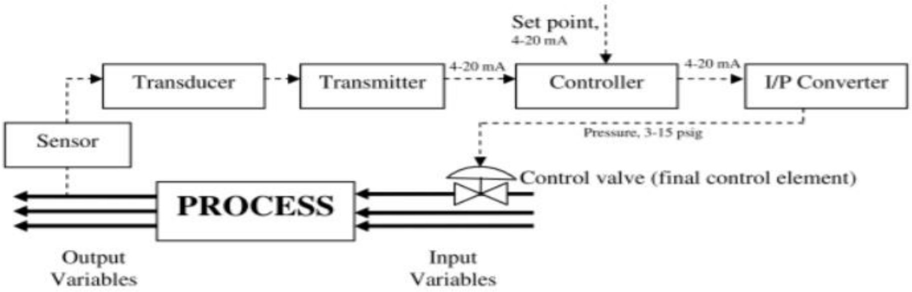

Fig. 9 Flow system implemented with PID controller

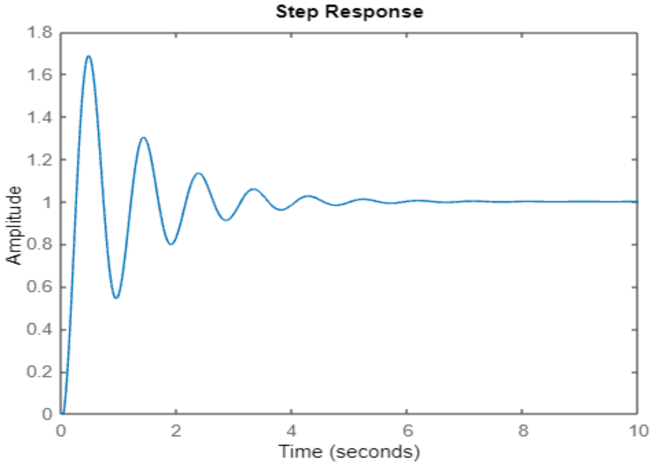

Fig. 10 Response of system using PID controller

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

Vol. 9, Issue 3, March 2021

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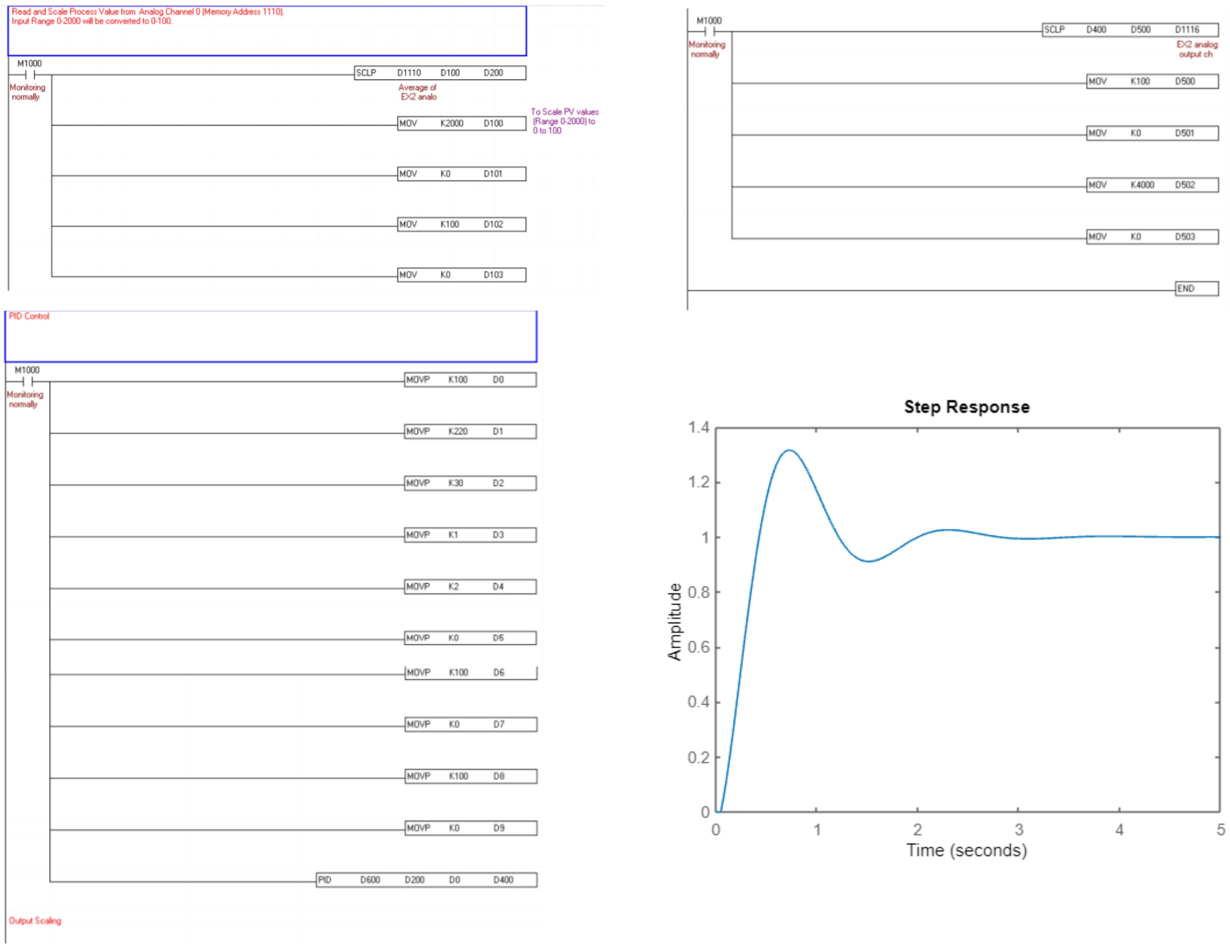
B. *PLC (PID) controller implementation:*

A PLC logic is created for the flow control process using ladder logic programming in the WPLSoft software, The PLC logic consists of input block, output block and a PID block where the input sensed signals are manipulated and the flow is controlled, The flow control process involves following procedures, The sensor first senses the current flow rate through the pipe, Then the obtained value is scaled from 0 to 100%, Then the scaled value is implemented to the PID controller and according to the tuned PID gain values a control signal is produced, The output of the PID control is unscaled from 0 to 100% to 0 to 4000 unit value, then the value is written as output. The PLC (PID) gives the best response because the system responds spontaneous due to fast switching actions which results in greater accuracy in the system response



```
Read and Scale Process Value from  Analog Channel 0 (Memory Address 1110).
Input Range 0-2000 will be converted to 0-100.

M1000
Monitoring normally
SCLP  D1110  D100  D200    Average of EX2 analo
MOV   K2000  D100          To Scale PV values (Range 0-2000) to 0 to 100
MOV   K0     D101
MOV   K100   D102
MOV   K0     D103

PID Control

M1000
Monitoring normally
MOVP  K100   D0
MOVP  K220   D1
MOVP  K30    D2
MOVP  K1     D3
MOVP  K2     D4
MOVP  K0     D5
MOVP  K100   D6
MOVP  K0     D7
MOVP  K100   D8
MOVP  K0     D9
PID   D600   D200  D0  D400

Output Scaling

M1000
Monitoring normally
SCLP  D400   D500  D1116   EX2 analog output ch
MOV   K100   D500
MOV   K0     D501
MOV   K4000  D502
MOV   K0     D503
END
```

Fig. 11 Flow system interfaced with Delta PLC and the Response graph

X. RESULTS AND COMPARISION

There are so many methods available to tune PID controller that results suitable gain values. Among them Cohen-Coon method and Ziegler-Nichols First method are popular ones. Here, we have tuned the PID controller using Cohen-Coon and Ziegler-Nichols methods and also, we have used MATLAB to simulate the most exact PID gain values. Here is the comparison of responses of all the 3 set PID gain values.

Methods-- Time Domain Parameters	Cohen-Coon method	Ziegler-Nichols First method	Auto-tuned PID values
Rise Time	0.0197 sec	0.0180 sec	0.0663 sec
Settling Time	0.4051 sec	0.4567 sec	0.8186 sec
Minimum Settling Time	0.9258 sec	0.7849 sec	0.9356 sec

Maximum Settling Time	1.5700 sec	1.4992 sec	1.0511 sec
Overshoot	56.99 %	49.9249 %	5.1132 %
Undershoot	0 %	0 %	0 %
Peak	1.5700	1.4992	1.0511
Peak Time	0.1000 sec	0.1000 sec	0.1620 sec

Table 4 Comparison of Time Domain Parameters of different tuning methods

From the comparison table we can know that MATLAB auto-tuned gain values results best response less rise time, settling time and overshoot which results in stable system. Between manual methods of tuning (between Cohen-Coon and Ziegler-Nichols) Ziegler-Nichols First methods gives best response as it has less rise time, settling time and overshoot which results in stable system.

The best PID gain values obtained from MATLAB simulation is implemented in the real-time system with 2 different controllers namely conventional PID controller and Programmable Logic Controller (with PID block). The time domain specifications of its responses are compared in the below table.

Methods— Time Domain Parameters	With Typical PID Controller	With PLC-PID Controller
Rise Time	0.1617 sec	0.2882 sec
Settling Time	4.3931 sec	2.4711 sec
Minimum Settling Time	0.5434 sec	0.9106 sec
Maximum Settling Time	1.6859 sec	1.3150 sec
Overshoot	68.5923 %	31.5016 %
Undershoot	0 %	0 %
Peak	1.6859	1.3150
Peak Time	0.4967 sec	0.7270 sec

Table 5 Comparison of Time Domain Parameters of different controller responses

From the comparison table we can infer that process with PLC response has the better time domain specifications compared to PID controller response.

XI. CONCLUSION

Flow process is normally a quick process hence choosing a proper control strategy is quite tough job. Here we have proposed advanced control strategy that is Programmable Logic Controller and compared it with conventional PID controller which proves PLC is the best controller as it has improved time domain parameters. As far as the future scope for developments with this paper are concerned, very advanced control strategies like fuzzy and adaptive fuzzy control schemes can be implemented along with or without existing control methods, the performance of the system can be improved more.

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BIOGRAPHY

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