Controller optimization for a single tank liquid level system

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***Abstract*— The prime motto of process control is to uphold a process at the preferred operating states safely and proficiently and also meeting out the environmental and product quality standards. The term "process" denotes an arrangement or a facility that needs to be regulated. It could be a chemical process like digesters, CSTR, thermal mixers, reactors, liquid level controlled feed water tanks etc., Kkeeping track of certain system throughput variables, such as heating rate, pressure gradient, and tank level, etc., is crucial if the plant is to be automated. Depending on the application selected, it is possible for the controlled technique to be incremental or sustained.. In this study, a typical first order tank is taken into account. A controller's design is extremely complex because it calls for nonlinear variations in the parameters. Process control techniques like feedback, feed forward, ratio control are frequently used. The level of the tank is kept close to the set point value using a conventional PID controller. The transfer function model is gleaned from the fundamental concepts.. The tuning methodology adopted are Ziegler –Nichols tuning and Genetic algorithm based method. Time domain quality factors like peak response, rise time, and settling time are determined and compared. It is proven that GA tuned controller optimises the settling of the level of the fluid in the tank**

Keywords: Ziegler-Nichols tuning, Single tank,PID controllers, Genetic algorithm

I. Introduction

Controlling liquid levels in industrial processes is absolutely vital for processes like pulp and paper production, crude oil purification, distillation columns, and petroleum and refineries[15]. In these processes, numerous such tanks will be used as processing units and connected in tandem. For a single tank process, the system's effectiveness is contrasted to various tuning methods using a mathematical model that is based on the basic principles of flow. Any process control system's core component is process control software. There are some businesses out there that offer basic, pre-built process control platforms, though they are typically customized based on your plant, industrial processes, and particular needs. The findings demonstrate that the Ziegler-Nichols approximation method works effectively for transforming higher order system models into first order plus time delay form. Process control, which uses specialised, frequently custom-built industrial control systems, principally integrates the fields of industrial engineering and control engineering [14]. These systems control the flow, output, and other similar aspects of a continuous production process based on feedback from sensors, data monitoring systems, and other sources. Applications in industry that control liquids, gases, dry solids, and slurry composites are referred to as process control implementations. Since no other advanced control schemes can match the ease, conciseness, practicability offered by this controller, PID controllers are still widely used in 90% of industries. A PID controller adjusted at a distinct operating point won't produce an appropriate response when the process operating range is exceeded.

Gain scheduling-based solution is very similar to the exact inverse-engineering extended by disturbance reconstruction and compensation. Both options ensure behavior that can asymptotically approach the ideal. Huba addresses the practical applications of these new structures [3]

In [4], a feedback law is envisioned that, under various flow conditions in the water tank, greatly enhances the responsiveness of the model output to the predicted parameter values. The uncertain input issue is resolved analytically. This problem's solution is used to forecast the attribute of importance with the minimal amount of variation feasible. Theoretical solutions are compared to experimental results from real-world situations.

To stabilise the level in the lower tank, the flow rate into the top of the tank is altered. An IBM AT with a universal analogue input/output board governs the process.[5]

Simple tuning rules for evaluating the gains of PI-PD controllers focused on the centroid of the stability region to address the limitations of the centroid of the convex stability boundary locus approach.. A robustness analysis was also carried out to assess the efficacy of the proposed tuning rules. In order to assess the effectiveness and feasibility of the proposed approach, several simulation examples and a real-time application were considered..[6]

In this essay, several well-known control strategies for managing a third-order process are compared. The controller used in various control schemes is a PID controller that has been tuned using Ziegler Nichols (ZN) and relay auto-tuning (RA) techniques. Some of the performance indicators used in the comparative evaluation are rise time (tr), settling time (ts), maximum overshoot (Mp), steady-state error (ess), integral of absolute error (IAE), integral of square error (ISE), integral of time square error (ITSE), and integral of time absolute error. The RA method outperforms other control schemes, according to simulation results. The ZN method, on the other hand, shows to be superior in the cascade plus feed-forward control scheme.[7]

This paper suggests a generalized tuning methodology which stands for proportional-integral-derivative. The approach is comparable to the Ziegler-Nichols forced oscillation method . To achieve this generalisation, a relay with customizable phase (RAP) is employed in a relay feedback trial, and expressions based on the findings of this

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investigation are implemented to tune the system. Results from experiments in a liquid processing plant using commercially available industrial equipment show how well the methodology performs and how its practical applications can be fully automated. [8]

It's been evidenced in this presented design that an improvement can be achieved by applying the GA method of optimising a plant. The envisaged GA optimised plant's performance was contrasted to that of a conventionally tuned plant, and the GA tuned (proportional, integral, and differential) PID controller outshone the classically designed PID controller..[9-10]

The transfer function model is derived in the next section. Part II explains open loop system and Part III about closed loop system design using the aforesaid methods.

II. SINGLE TANK PROCESS

The single tank process is shown in Fig.1. A single tank having a area of 'A' m^2 with the inflow and outflow of 'Q(t)' and 'F(t)' respectively

Where,

Q(t) - Water input discharge rate in tank f(t) – Water Outlet flow rate in tank R – Flow Resistance of tank

A - Area of tank

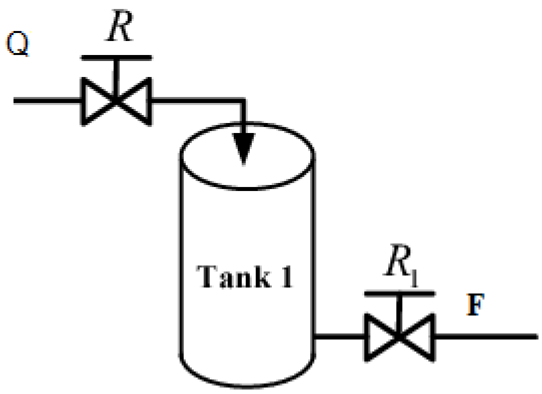


Fig 1:Single tank process

In order to determine the transfer function of given single tank process,

Transfer function = H(s)/Q(s) (1)

The first order model is generated by utilising the mass balance calculation to tank as

Inflow rate - Outflow rate = rate of accumulation of mass

$$A\frac{dh}{dt} = q(t) - f(t) \tag{2}$$

Steady state equation of (1) is given by

$$Q_s(t) - F_s(t) = 0 \tag{3}$$

Substituting $f(t) = \dfrac{h(t)}{R}$ (4)

Substituting equation 3 in 1 and 2 and thus obtaining equation 4

In equation 1 :

$$A\frac{dh_1}{dt} = q(t) - \frac{h(t)}{R} \tag{5}$$

$$q_s(t) - \frac{h_s(t)}{R} = 0 \tag{6}$$

Subtracting equation (5) and (6)

$$\mathrm{q}(\mathrm{t}) - \mathrm{q_s}(\mathrm{t}) - \left[\frac{\mathrm{h}(\mathrm{t}) - \mathrm{h_s}(\mathrm{t})}{\mathrm{R}}\right] = \boldsymbol{A}\frac{\boldsymbol{dh}(\boldsymbol{t})}{\boldsymbol{dt}} \tag{7}$$

$$q(t) - \frac{h(t)}{R} = A\frac{dh(t)}{dt} \tag{8}$$

Applying Laplace transform to the above Equation

$$Q(s) - \frac{H(s)}{R} = AsH(s) \tag{9}$$

$$Q(s) = AsH(s) + \frac{H(s)}{R} \tag{10}$$

$$Q(s) = H(s)\left[As + \frac{1}{R}\right] \tag{11}$$

$$Q(s) = H(s)\left[\frac{ARs+1}{R}\right] \tag{12}$$

$$\frac{H(s)}{Q(s)} = \frac{R}{1+ARs} \tag{13}$$

For our process let us consider time constant is 100 seconds.

$\tau = \boldsymbol{AR} = \mathbf{100}$

Given length of a tank is 30cm ,diameter is 10cm Area of a cylinder $=\boldsymbol{2\pi rh} + \boldsymbol{\pi r} * \boldsymbol{r}$ (14)

Since 1m=100 cm

Then the radius of the cylinder is 0.05 m and length is 0.3 m

A=$\mathbf{2} * \boldsymbol{\pi} * \mathbf{0.05} * \mathbf{0.3} + (\boldsymbol{\pi} * \mathbf{0.05^2})$ (15)

A=0.1021019$\boldsymbol{m^2}$

$\tau = \boldsymbol{A} * \boldsymbol{R} = \mathbf{0.1021019} * \boldsymbol{R} \rightarrow \mathbf{100}$ (16)

R=979.413 ohm$\cong$ $\mathbf{980}\boldsymbol{ohm}$

Transfer function for the first order system with τ= 100s is,

$$\frac{H(s)}{Q(s)} = \frac{980}{1+100s} \tag{17}$$

III. OPEN LOOP RESPONSE OF A SINGLE TANK

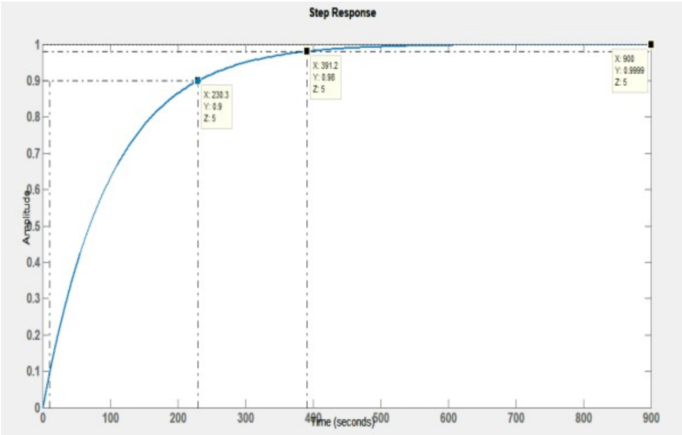


Fig 2: Applying a step input to Open loop system

The above figure[2] shows that by giving a step input to the plant transfer function and the result is obtained in scope using Matlab- Simulink.(Open loop response of a system).The output system by applying a step input is shown in the below graph by considering a unit step signal as an input to system, where r(t)=u(t).

A.MATLAB PROGRAM

1.Determine the continuous transfer function 'sys'.

2.Decide the Numerator coefficients.

3.Decide the Denominator coefficients.

4.Apply the step response to the transfer function.

5.Using Bode plot ,determine the Gain margin, phase margin , peak response ,settling time

B.BLOCK DIAGRAM **:**

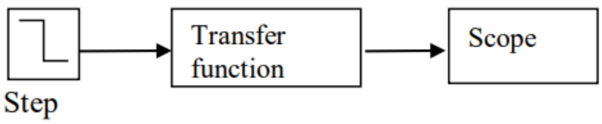


Fig 3: Block Diagram Of A Open Loop System

Single tank transfer function [fig 3]without the initialization of controllers .Thus from the above program the obtained gain margin is 7.8. Thus by using a PI controller the settling time can be reduced and steady state can be obtained in a less time .

IV.CLOSED LOOP OF A SINGLE TANK:

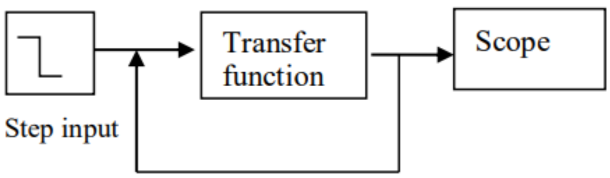


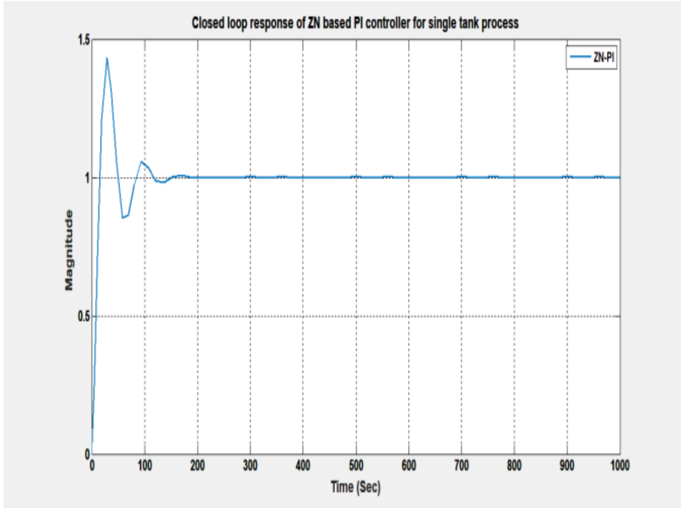
Fig 4:Closed loop transfer function

The above Block diagram[4] shows a close loop transfer with different types of controller and thus obtaining its plot and characteristics.

A. Design of a PID controller

Fig 5: Closed loop response of PI controller

Figure 5 shows the close loop response of the above derived



transfer function with PI controller for a single tank process.

B . *ZIEGLER-NICHOLS:*

PID tuning is the process of expressing the controller parameters as functions of the parameters Kp, Kd, and Ki by using the Ziegler-Nichols tuning method which is used as the starting point for tuning procedures in the manufacturing and process industries. Typically, it overshoots and produces an aggressive gain. If reducing overshoot is a goal, more tuning is required.

The Ziegler-Nichols method is commonly used for fine-tuning P,PI,PID controllers. In this method, the integral and differential gains are initially set to zero, and the proportional gain is then increased until the system becomes unstable..

Table 1: ZN controller tuning table

Type of the controller	Parameters for Step input			Parameters for Sinusoidal input		
	K_p	T_i	T_d	K_p	T_i	T_d
P	1/a	-	-	0.5Kc	-	-
PI	0.9/a	3L	-	0.4Kc	0.8Tc	-
PID	1.2/a	2L	L/2	0.6Kc	0.5Tc	0.12Tc

Fig 6: Tangent drawn to obtain gain Margin

$K_P=K_U/1.7==8/1.7=4.7$ (18)

$K_I=P_U/2==0.8$ (19)

$K_D=P_U/8==0.2$ (20)

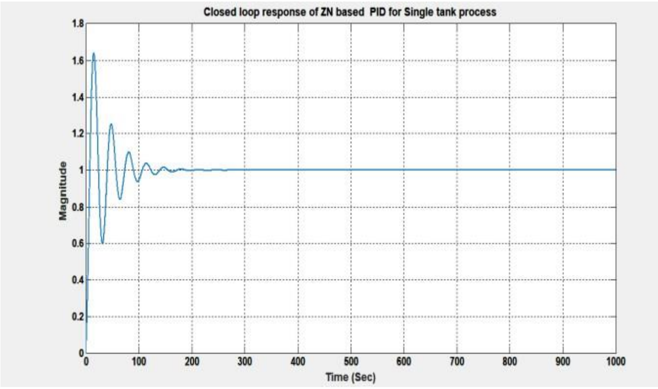


Fig 7: Closed loop response of PID controller

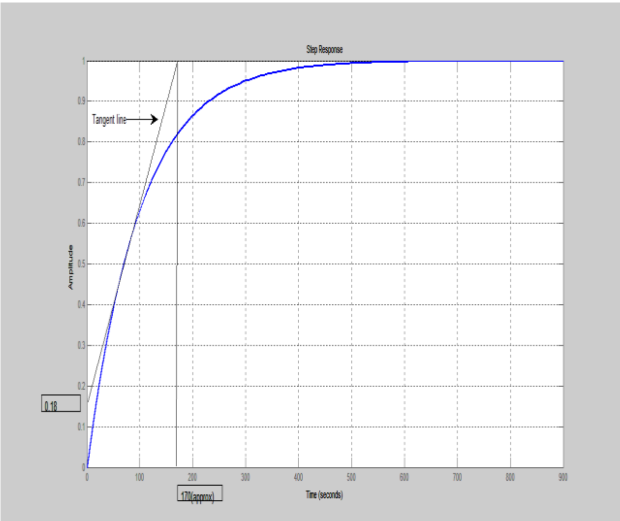
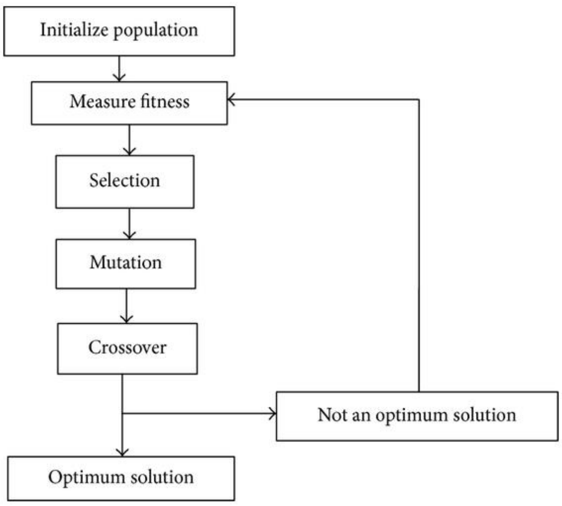


Fig 8:After ZN tuning ,the graph obtained

B.GENETIC ALGORITHM

The Genetic Algorithm (GA) is a search-based efficient algorithm based on the notions of hereditary and natural selection. It is commonly used to solve complex problems by locating the best or near-optimal solutions. It is frequently used in optimization problems, as well as in research and machine learning applications.



V.COMPARISON OF PI CONTROLLER:

Tuning of a PI controller and comparison with various optimization algorithms.

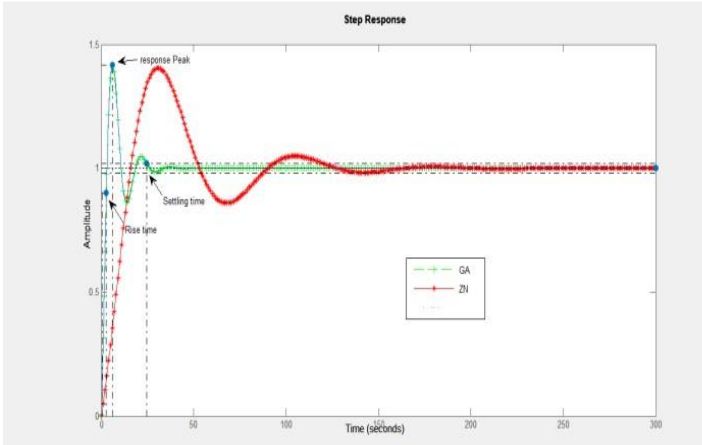


Fig 9:Comparison of various tuning method for PI

Table 2: Closed loop performance of PI controller

Tuning methods	Proportional-Integral controller		
	Rt(Rise time)	St(Settling time)	Peak overshoot
Ziegler-Nichols:	23s	129s	37s
Genetic Algorithm:	57s	90s	No peak overshoot

From the above table it could be concluded that GA tuned Proportional-integral-derivative controller has no peak overshoot which can be used for better efficiency in control plants.

VI. CONCLUSION:

In this paper, a brand-new level-controlling optimisation method for first-order processes is put forth. The transfer function model of a first order tank process was derived. To determine the approximate range of parameters to feed into GA, conventional tuning algorithms were used. Then, with the aid of a genetic algorithm, the PI controller is tuned in order to optimize the process' performance. The first order process that has been GA tuned is shown to behave well, with less settling time and no overshoot.

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