Relay Feedback based PID Controller for Nonlinear Process

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Abstract**—** This work is about designing a relay feedback based PID controller for a conical tank level process. The level control becomes quite typical due to the nonlinear shape of tank. Many process industries use conical tanks because of its shape contributes to better drainage of solid mixtures, slurries and viscous liquids. So control of conical tank presents a challenging problem due to its non-linearity and constantly changing cross-section.

Keywords**—**PID controller, Relay feedback, Conical Tank, Closed loop response

Nomenclatures:

h- Relay magnitude	W_u- Ultimate frequency of procees variable
a- Peak amplitude of process variable	D- Time delay
K_u- Ultimate gain of procees variable	T- Time constant
P_u- Ultimate period of procees variable	K_p-Steady state gain which is taken as 0.925
MPC – Model Predictive Control	DMC – Dynamic Matrix Control

I. Introduction

A conventional PID controller is used to control the conical tank level system based upon tuning rules. A single run of the relay feedback experiments carried out to characterize the dynamics including the type of damping behavior, the ultimate gain, and ultimate frequency. From the knowledge of ultimate gain and ultimate frequency, we can obtain the tuning parameters by using ZN-Continuous Cycle method.

The real time implementation of conical tank level process using relay feedback for various set points gave satisfactory plots. The respective process model for each & every plot has been identified. The PID controller parameters have been found by using relay testing and the PID controller has been designed for various set points.

The implementation of designed PID controller for the conical tank level system gave satisfactory and desired responses. The designed PID controller's response is able to provide tracking of the given set point whenever a positive or negative load was applied. MATLAB/SIMULINK software was used for simulation and real time implementation of conical tank level control system.

This paper is organized as Section-2 with literature review, Section-3 with Control Methodology, Section-4 with Result analysis and Section-5 with conclusion and future works.

1.1 Problem description

A basic problem in process industries is control of liquid level in non-linear process tank. A level that is too high may upset reaction equilibrium, cause damage to equipment, or result in spillage of valuable or hazardous material. If the level is too low, it may have bad consequences for the sequential operations. Hence, control of liquid level is an important and common task in process industries. [1]

Conical tanks are extensively used in process industries, petrochemical industries, food process industries and wastewater treatment industries. Control of conical tank is a challenging problem because of its non-linearity and constantly changing in area of cross section. Hence for these reasons the conical tank process is taken here. [2]

About 95% of process control loops are of PID or PI type. PID control is often combined with other technologies to build the complex automation systems that are used in many industries. Chemical and petrochemical control strategies are often organized in a hierarchy of functions, with scheduling and optimization functions running on top of the hierarchy, multivariable predictive controllers in the middle and PID controllers at the lower level, directly sending control signals to actuators. Tuning a controller implies setting its adjustable parameters to appropriate values that provide good control performance. Auto-tuning can be seen as a combination of a

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procedure for characterizing process dynamics with a method for calculating controller parameters. **[3]**

1.2 Objectives:

1. To study the nonlinear behavior of conical tank level process.
2. To identify the process model using relay feedback test.
3. To provide PID controller tuning using relay feedback test.
4. To evaluate the performance of designed controller.

II. Literature Review

T. Pushpaveni *et al* in their more generalized research identified the conical tank system as a non-linear system. They implemented model of conical tank system with the help of first principle differential equation. They used MATLAB ODE45 solver/Simulink to solve the differential equation. The results were validated by using the transfer function model and ODE response. The conventional PID controller was implemented to track the multi set point changes in level of the conical tank process by using different tuning rules. The relay feedback test was conducted to the process to identify the tuning parameters of PID structure. The MPC Controller was also implemented to track the servo response and regulatory response. The performance indexes of different tuning rules were also obtained. The simulation results proved that the MPC control method is an easy-tuning and more effective way to enhance stability of time domain performance of the conical tank system. **[5]**

Geetha M. and Jovitha Jerome *et al* in their research paper observed that the shapes of relay feedback responses are useful in extracting additional information about process dynamics. From a methodical analysis of the shape information, different processes can be broadly classified into three major categories. Different tuning rules were employed to find appropriate PID controller settings. The results showed that their proposed method resulted in improved auto tuning in a straight forward manner. Thus, shape information is useful in inferring the correct model structure of the process and also in selecting the appropriate control strategy to offer improved performance. The advantage of this method is that by using single relay feedback test all the parameters can be identified. The results showed that the proposed method gives improved tuning parameter estimates and hence an improved closed loop response.**[3]**

Majid Jamal Abdulraham AL-Kharoosi *et al* worked on the conical tank level process. They identified the conical tank system after interfacing the conical tank system setup with PC, designed PID and Robust controller for conical tank system and finally both controller results were compared. Several steps were described to identify conical tank system and to it's important parameters: time constant (T), time delay (D) and gain of the system. Designing PID and Robust controller was also described in this paper. For PID controller Ziegler Nicholas method was chosen to get PID elements. Robust controller was designed by Co-prime Factorization method. They found the closed loop response of conical tank system for different regions. They concluded that the PID controller was giving good performance within the given regions. On the other hand, robust controller have good responses in all regions.**[2]**

III. Control Methodology

3.1 Introduction

This section emphasizes on the experimental setup of the conical tank level process and the assumptions made while implementing the process. The relay properties have also been discussed in this section. The relay testing model equations and PID algorithm which is going to be used for result analysis is also presented in this section.

3.2 Experimental Setup

Fig.1 Experimental Setup of Conical Tank Level Process

Fig.1 shows the nonlinear system consist of a conical tank, a water reservoir, an electrical pump, a rotameter, a differential pressure transmitter, an electro pneumatic converter (I/P converter), an interfacing DAQ and a Personal Computer (PC). The differential pressure transmitter output is interfaced with Computer using DAQ in the RS-232 port of the PC. Fig.1. shows the real time setup of conical tank system.

One valve is to control the flow out which should be constant during the process so the tank does not get full with maximum flow in (340lph) and does not be empty with the lowest flow in (180lph). The flow in can be controlled by the valve or by the pump motor, in this process is controlled by the pump motor. The voltage of this pump is the input of the conical tank system and the water height in the conical tank is the output of this process. **[2]**

3.3 Assumptions:

- It is a 'medium process'. The sampling time is taken as 0.01s.
- A lower operating region in conical tank has been chosen to identify the level process.
- The actuator (pump) has limited physical operating range [0,100]. So a saturation block with lower limit 0 and upper limit 100 is added after relay device.
- The level in the conical tank is converted into its equivalent percentage so that it is made easy to convert D/A, A/D and standard unit conversion.

3.4 Relay Properties:

- Error is given as the input to the relay.
- Switching ON and OFF time of the relay can be varied.
- Output ON and OFF amplitude can also be varied.

3.5 Relay testing model equations:

By using Astrom –Hagglund relay feedback test the model equations (1,2) can be found .The Astrom and Hagglund relay feedback test is based on the observation that, when the output lags behind the input by π radians, the closed-loop system can oscillate with a period of *P*u. A relay of magnitude *h* is inserted in the feedback loop. Initially, the input *u*(*t*) is increased by *h*. Once the output *y*(*t*) starts increasing after a time delay (*D*), the relay switches to the opposite direction, *u*(*t*)-*h*. Because there is a phase lag of $-\pi$, a limit cycle of amplitude '*a*' is generated.

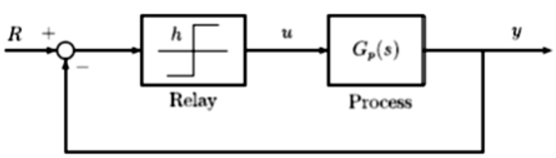

Fig.2 Block diagram for relay feedback test

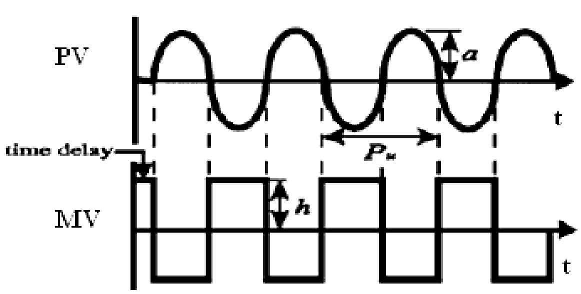

Fig.3 Output response for relay feedback test

The period of the limit cycle is the ultimate period, *P*u. The approximate ultimate gain, *K*u, and the ultimate frequency *W*u, are given by

$$K_u = \frac{4h}{\pi a} \quad (1)$$

$$\omega_u = \frac{2\pi}{Pu} \quad (2)$$

The Time constant and Time delay can be found by using the following equations:

$$T = \sqrt{\frac{(KpKu)^2 - 1}{\omega_u}} \quad (3)$$

$$D = \frac{P_u}{4} \quad (4)$$

The transfer function or model can be found by using the equation

$$G(s) = \frac{K * e^{-Ds}}{Ts+1} \quad (5)$$

3.6 PID algorithm:

The PID controller equation is given by:

$$U(t) = K_p * e(t) + K_i * \int e(t) d(t) + K_d \frac{de(t)}{dt} \quad (6)$$

The PID parameters can be found by using Z-N tuning method :

Proportional gain is given by:

$$K_p = 0.60 * K_u \quad (7)$$

Integral gain is given by: $K_i = \frac{2 * K_p}{Pu}$ (8)

Derivative Gain is given by: $K_d = \frac{K_p * P_u}{8}$ (9)

The basic experimental setup, the relay testing model equations (1-5) and PID algorithm (7-9) were discussed in this section. Now the real time experimentation by using the simulation block diagram model will be discussed in the next section.

IV. Result Analysis

4.1 Introduction

This research paper discusses the real time implementation of conical tank level process using relay feedback for various set points, identifying the process model using the plots obtained and shown in Fig.8. The Simulink model for the implementation of the PID controller is also shown in Fig.4 and Fig.7.

4.2 Experimentation and Plots:

The system is in a closed output feedback loop. Inside the loop just before the plant a relay with saturation block is added. The conical tank level system is made on. Using the Simulink model, the responses are obtained and plotted (Shown in Fig.5 and Fig.6)

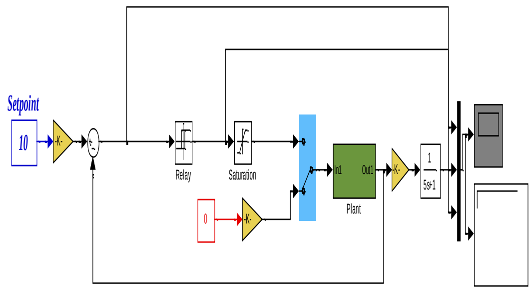

Fig.4 Simulation Block Diagram of relay testing

TABLE.I
RELAY SETTINGS FOR GIVEN SETPOINT 15

TRIAL NO	SWITCH ON POINT	SWITCH OFF POINT	OUTPUT WHEN ON	OUTPUT WHEN OFF
1	1	-1	50	-50

For Fig5. we keep the Output ON and OFF points constant at [50,-50] and keep on increasing the Switch ON and OFF points from [1,-1] to [20,-20] we get the following Plots:

Results:

From the set of observations with fixed set point it is observed that with Switch ON and OFF points at[10,-10] and Output ON and OFF points at [70,-70] we get proper sustained oscillations. It is also observed that with Switch ON and OFF points at [1,-1] and Output ON and OFF values at [50,-50] we get the minimum error.

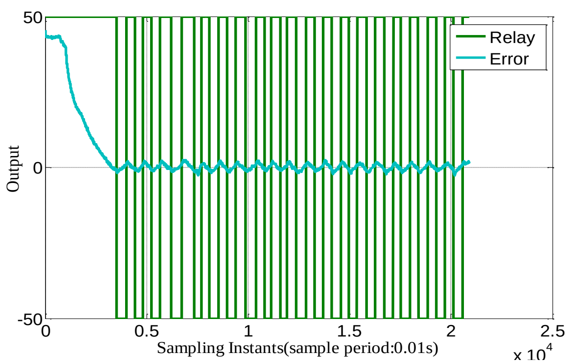

Fig.5 Input output of the relay with Switch ON/OFF points[1,-1] (Trial 1)

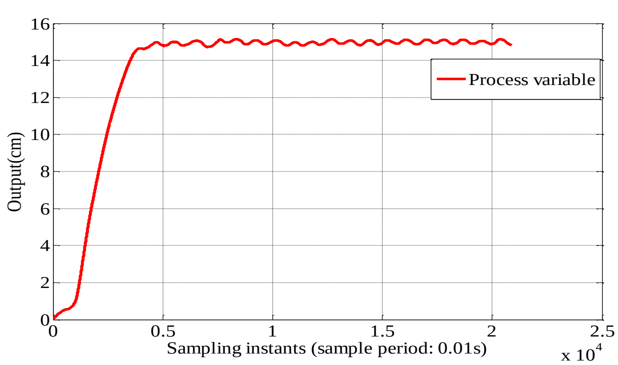

Fig.6 Closed loop response of conical tank process using relay with Switch ON/OFF points[1,-1] (Trial1)

4.3 System Identification:

TABLE III
PARAMETERS USED FOR PROCESS MODEL IDENTIFICATION FOR GIVEN SETPOINT 15

TRIAL NO	h	a (cm)	Ku	Pu	Wu (Hz)	D (s)	T (s)	MODEL
2	50	1.035	61.54	29.06	0.216	7.265	263.37	$\frac{0.925\, e^{-7.26s}}{263.37s+1}$

4.4 PID Controller Design :

Equations used for finding the PID parameters:

Enter the value of ultimate gain:

Ku= (Using given formula in equ.1), Enter the value of ultimate period:Pu= (Using given formula in equ.2) Proportional Gain Kp=0.60*Ku, Integral Gain, Ki=(2*Kp)/Pu, Derivative Gain Kd=(Kp*Pu)/8

TABLE VI
PID PARAMETERS FOR GIVEN SETPOINT 15

TRIAL NO	K_p	K_d	K_i
2	36.924	134.126	2.541

4.5 PID Controller Implementation

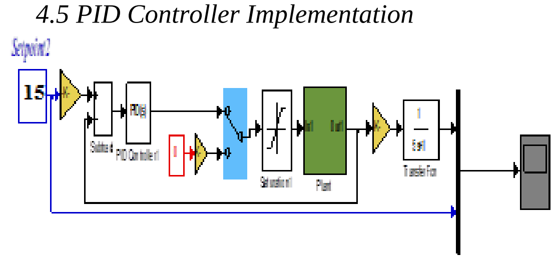

Fig.7 Block diagram for PID controller implementation for a given setpoint

From Table-6 for given setpoint 15, the values of K_p=36.924 K_d=134.126 and K_i=1.541 are chosen and following response is obtained as shown in Fig.8. using the simulink model shown in Fig.7.

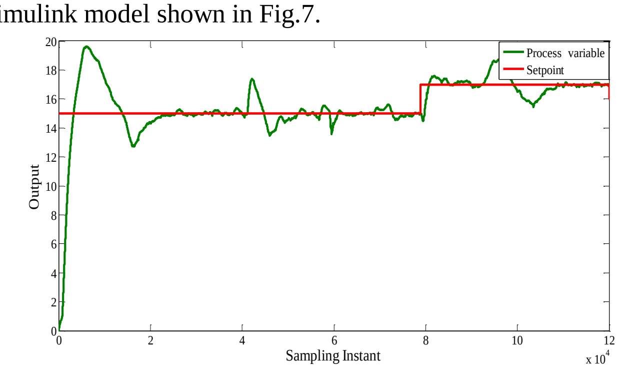

Fig. 8 PID controller response for given setpoint 15

Inference

It can be observed that the real time implementation of conical tank level process using relay feedback for various set points gave satisfactory plots. The respective process model for each region have been found. The PID controller parameters have been found by using equations (1,2,7,8,9). Also the implementation of designed PID controller gave satisfactory and desired response for the servo and regulatory mode.

V. Conclusion And Future Scope

5.1 Conclusion:

- The switching happens faster when the error range is small.
- If the error is higher than the relay signal width is also higher.
- Increase in Set point and Switch ON and OFF points increases error.
- Error is reduced by increasing the Output ON-OFF point
- The real time implementation of conical tank level process using relay feedback for various set points gave satisfactory plots
- The implementation of designed PID controller gave satisfactory and desired response.
- The PID controller's response tracks the given set point and showed disturbances whenever a positive or negative load was applied as shown in Fig.8 around $4e^{+4}$ and $9e^{+4}$ samples

5.2 Future scope :

In this paper the relay feedback based PID controller has been designed and implemented. The real time implementation of various other controllers like MPC ,DMC ,Robust controllers can be done using relay feedback in the future and results can be compared with respect to various performance indices.

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