Optimal FOPDT Modeling Of Liquid Level Control System Using Genetic Algorithm

Tushar Patel[1] Professor V.P.Patel[2]
[2]Head of department(I.C)
[1,2] Department of Instrumentation & Control Engineering
[1,2] L.D. College of Engineering , Ahmedabad

Abstract— PID controllers are commonly used in process loops. Most of industrial process loops are controlled by PID controllers due to its easy understanding, simple structure and robustness to the process parameter variations. PID controllers are commonly used in feedback control loops where industries processes are mostly open loop stable or unstable. Most of the PID controller parameters are tuned using trial and error method. Proper selection of feedback construction and controller parameter tuning helps to improve the performance of the close loop system. Poor PID controller parameter tuning can lead to wear and tear associated with excessive manipulating action, poor control response and even poor quality products. In this work, we used Liquid level system which is located in Process Control lab, I.C department at L.D.C.E Ahmadabad. Take real time reading for closing the control valve at different position like 30%, 40%, 50% and 60%.and find out first order plus dead time (FOPDT) model for this different readings. After finding the FOPDT model for this different readings we used Genetic Algorithm (G.A) method to optimize the solution and find out the best value of first order plus dead time (FOPDT) like process gain (K), Process time constant (T_p) and Delay time (t_d).

Key words: PID controller, Real time Liquid level system, Genetic Algorithm.

I. INTRODUCTION

PID controllers are still widely used in process industrial applications despite of advancement in modern control technology. Most of the process control loops are controlled by PID controller due to their simple construction which is easy to be understood by the engineers who work on it. This is not only due to the simple construction which is conceptually easy to understand and, which makes manual tuning possible, but also to the fact that the algorithm provides adequate performance in the vast majority of applications. It is widely used in process industries because of its simple structure and robustness to the modelling parameter variation.

According to a survey conducted by Japan electric measuring instruments manufacturers association in 1989, 90 percent of the control loops in industries are of PID type and small portion of the control loops works well [12]. Also survey indicates 30 percent of the controller is operated in manual mode and 20 percent of the loops use factory tuning [13]. It means that PID controller is widely used but having poorly tuned parameters. Poor tuning of parameters can lead to mechanical wear associated with excessive manipulating action, poor close loop response and even poor quality products.

In Fig. 1.1 block diagram of the conventional closed loop system with PID controller is shown. In Fig. 1.1, three controller parameters Proportional gain (K_p), Derivative gain (K_d) and Integral gain (K_i) are required to tuned such that the controller meets desired performance specification. The Fig. 1.1 shows Error as E, Manipulating action as P and Controlled output as C.

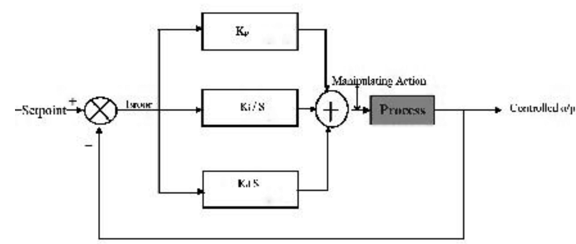

Fig. 1.1 Closed Loop Systems with PID Controller

In the second section, description of Liquid level system with its instruments. In the third section, FOPDT model identification for Liquid Level System. Fourth section, describe the Genetic algorithm based process model identification. and Fifth section describe the Conclusion of this present work.

II. DESCRIPTION OF THE LIQUID LEVEL SYSTEM

The Liquid level system shown in Fig. 2.1 is located at process control lab in Instrument and Control Engineering (A.I), L.D College of Engineering (LDCE) Ahmedabad.

It has process tank in acrylic type with 0-100% graduated scale and 30c.m heights. A level transmitter made by switzer, electronic type with two wire and range 0-250 mm (25 cm), 4-20mA output. A pneumatic control valve with air to close action, linear characteristic and input range 315 psig. A rotameter 10-100 litter per hours. In this Level system I/P convertor and it’s input range 4-20mA and output range 3-15 psig. A pressure gauge with range 0-2.5 Kg/cm2. A control module AX403 made by Yokogawa controller.

Fig. 2.1 Liquid Level System

The P & I diagram of liquid level system [17] is shown in Fig. 2.2

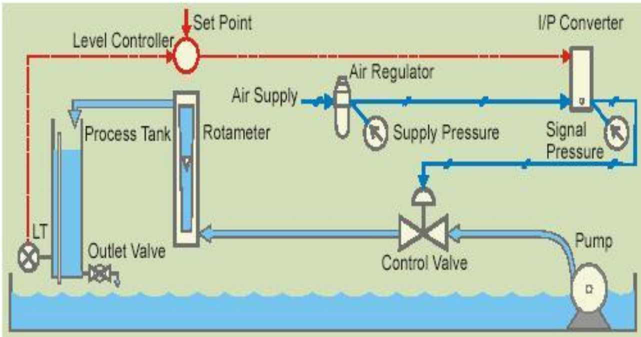

Fig. 2.2. Process diagram of Liquid Level System

Level control trainer is designed for teaching the basic level control principles. The process setup consists of supply water tank fitted with pump for water circulation. The level transmitter is fitted on transparent process tank senses level in the tank and transmits the signals to interfacing unit/control module. The output of interfacing unit/control module is connected to I/P converter. A pneumatic control valve adjusts the water flow in to the tank to control the level. The process parameter (Level) is controlled through computer or μp controller by manipulating control valve.

In this trainer, PID control action is adjusted through software by computer as well as by digital indicating controller. The computer is connected to controller through communication port in supervisory mode

III. FOPDT MODEL IDENTIFICATION FOR LIQUID LEVEL SYSTEM

Now, for find out the FOPDT (First Order Plus Dead Time) model for liquid level system, we take reading from the system. And this reading are describe in the Table 3.1. For taking this reading we, first adjusted control valve at 50% (50% open and 50 close).

Time	P.V	O/P	Time	P.V	O/P	Time	P.V	O/P	Time	P.V	O/P	Time	P.V	O/P
15:18:32	6.5	50	15:20:4	36.3	50	15:21:36	47.1	50	15:23:9	51.7	50	15:24:41	53	50
15:18:34	7	50	15:20:7	36.8	50	15:21:39	47.2	50	15:23:12	51.7	50	15:24:44	53	50
15:18:37	8.4	50	15:20:9	37.2	50	15:21:42	47.4	50	15:23:14	51.8	50	15:24:47	53	50
15:18:40	9.9	50	15:20:12	37.7	50	15:21:45	47.6	50	15:23:17	51.8	50	15:24:49	53	50
15:18:43	11.3	50	15:20:15	38.2	50	15:21:47	47.7	50	15:23:20	51.8	50	15:24:52	53	50
15:18:45	12.7	50	15:20:18	38.6	50	15:21:50	47.9	50	15:23:22	51.9	50	15:24:55	53.1	50
15:18:48	14.1	50	15:20:20	39	50	15:21:53	48.1	50	15:23:25	52	50	15:24:58	53	50
15:18:51	15.3	50	15:20:23	39.5	50	15:21:56	48.3	50	15:23:28	52.1	50	15:25:0	53.1	50
15:18:53	16.7	50	15:20:26	40	50	15:21:58	48.4	50	15:23:31	52.2	50	15:25:3	53.1	50
15:18:56	17.8	50	15:20:28	40.4	50	15:22:1	48.6	50	15:23:33	52.2	50	15:25:6	53.1	50
15:18:59	18.8	50	15:20:31	40.9	50	15:22:4	48.7	50	15:23:36	52.3	50	15:25:8	53.1	50
15:19:2	19.8	50	15:20:34	41.2	50	15:22:6	48.8	50	15:23:39	52.3	50	15:25:11	53.1	50
15:19:4	20.7	50	15:20:37	41.6	50	15:22:9	49	50	15:23:41	52.4	50	15:25:14	53.1	50
15:19:7	21.7	50	15:20:39	41.9	50	15:22:12	49.2	50	15:23:44	52.4	50	15:25:17	53.1	50
15:19:10	22.7	50	15:20:42	42.3	50	15:22:15	49.4	50	15:23:47	52.5	50	15:25:19	53.1	50
15:19:12	23.6	50	15:20:45	42.6	50	15:22:17	49.5	50	15:23:50	52.5	50	15:25:22	53.1	50
15:19:15	24.5	50	15:20:47	43	50	15:22:20	49.6	50	15:23:52	52.5	50	15:25:25	53.1	50
15:19:18	25.3	50	15:20:50	43.2	50	15:22:23	49.8	50	15:23:55	52.6	50	15:25:27	53.1	50
15:19:20	26.2	50	15:20:53	43.5	50	15:22:25	49.9	50	15:23:58	52.7	50	15:25:30	53.1	50
15:19:23	27	50	15:20:56	43.8	50	15:22:28	50.1	50	15:24:0	52.7	50	15:25:33	53.2	50
15:19:26	27.8	50	15:20:58	44	50	15:22:31	50.1	50	15:24:3	52.8	50	15:25:36	53.2	50
15:19:29	28.6	50	15:21:1	44.3	50	15:22:34	50.3	50	15:24:6	52.8	50	15:25:38	53.2	50
15:19:31	29.3	50	15:21:4	44.6	50	15:22:36	50.4	50	15:24:9	52.8	50	15:25:41	53.2	50
15:19:34	29.9	50	15:21:7	44.8	50	15:22:39	50.6	50	15:24:11	52.8	50	15:25:44	53.2	50
15:19:37	30.4	50	15:21:9	45	50	15:22:42	50.7	50	15:24:14	52.8	50	15:25:46	53.2	50
15:19:39	31.1	50	15:21:12	45.1	50	15:22:44	50.7	50	15:24:17	52.9	50	15:25:49	53.3	50
15:19:42	31.8	50	15:21:15	45.4	50	15:22:47	50.9	50	15:24:19	52.9	50	15:25:52	53.2	50
15:19:45	32.4	50	15:21:17	45.6	50	15:22:50	50.9	50	15:24:22	52.9	50	15:25:55	53.3	50
15:19:48	33	50	15:21:20	45.8	50	15:22:53	51	50	15:24:25	52.9	50	15:25:57	53.3	50
15:19:50	33.5	50	15:21:23	46.1	50	15:22:55	51.1	50	15:24:28	52.9	50	15:26:0	53.3	50
15:19:53	34.1	50	15:21:26	46.3	50	15:22:58	51.2	50	15:24:30	52.9	50	15:26:3	53.4	50
15:19:56	34.7	50	15:21:28	46.4	50	15:23:1	51.4	50	15:24:33	52.9	50	15:26:5	53.4	50
15:19:58	35.2	50	15:21:31	46.6	50	15:23:3	51.4	50	15:24:36	52.9	50	15:26:8	53.3	50
15:20:1	35.7	50	15:21:34	46.9	50	15:23:6	51.5	50	15:24:39	52.9	50	15:26:11	53.4	50

Table 3.1.Open loop reading

In the Table 3.1 change in input is 50% and corresponding change in output is,

output = 53.4 – 6.5 = 46.9

So, output = 46.9 -----------(3.1)

The open loop system gain is defined by,

$$K = \frac{\text{Change in output}}{\text{Change in input}}$$

$$K = \frac{46.9}{50}$$

K = 0.938 (50% Open valve) ------------- (3.2)

The process time constant (T_p) of the system is defined as time required to get 63.2% of the final value. From stated definition the time constant of given response to attain,

T/Output = (46.9 * 0.632) + 6.5

T/Output = 36.14 ------------(3.3)

From Table 3.1, here 36.14 reading give,

$$\boxed{T_p = 94 \text{ sec}}$$

--------------- (3.4)

The delay time (t_d) is defined as time up to which system does not get any output for given input,

t_d = 3 sec --------------- (3.5)

Check, Simulation result on Matlab,

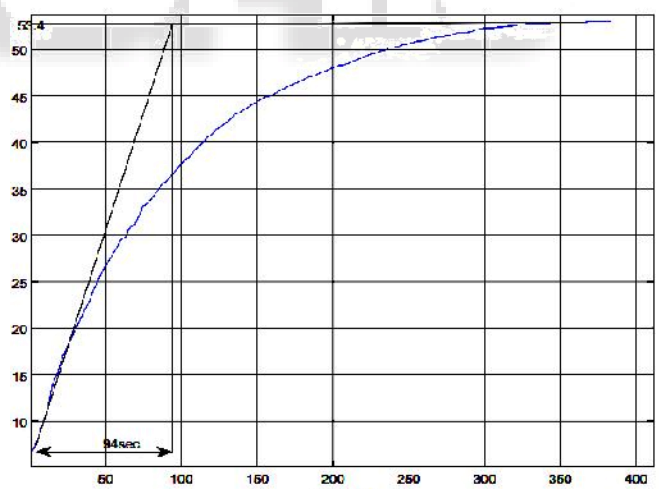

Fig. 3.1 FOPDT model identification for liquid level system

The obtained FOPDT parameters are shown in Fig. 3.1 on the open loop response.

In order to reduce the error in FOPDT model identification, we get FOPDT model for 30%,40%, 50% and 60% closing of control valve. The corresponding FOPDT parameters are given in Table 3.2.

So, the table shown below,

FOPDT Parameters	30%	40%	50%	60%
K	0.8577	0.8933	0.938	0.7425
T_p	103 sec.	96 sec.	94 sec.	79 sec.
t_d	3 sec.	3 sec.	3 sec.	3 sec.

Table 3.2 FOPDT parameters for liquid level system

IV. GENETIC ALGORITHM BASED PROCESS MODEL IDENTIFICATION

Genetic Algorithms are a stochastic global search method that mimics the process of natural evolution. The genetic algorithm starts with no knowledge of the correct solution and depends entirely on responses from its environment and evolution operators (i.e. reproduction, crossover and mutation) to arrive at the best solution [16].

Genetic Algorithms versus Traditional methods:

Genetic algorithms are substantially different to the more traditional search and Optimisation techniques. The five main differences are:

1. Genetic algorithms search a population of in parallel, not from a single point.

2. Genetic algorithms do not require derivative Information or other auxiliary knowledge, only The Objective function and corresponding fitness levels influence the direction of the search.

3. Genetic algorithms use probabilistic transition rules, not deterministic rules.

4. Genetic algorithms work on an encoding of a parameter set not the parameter set itself (except Where real valued individuals are used).

5. Genetic algorithms may provide a number of potential solutions to a given problem and the Choice of the final is left up to the user.

Genetic Algorithm Process:

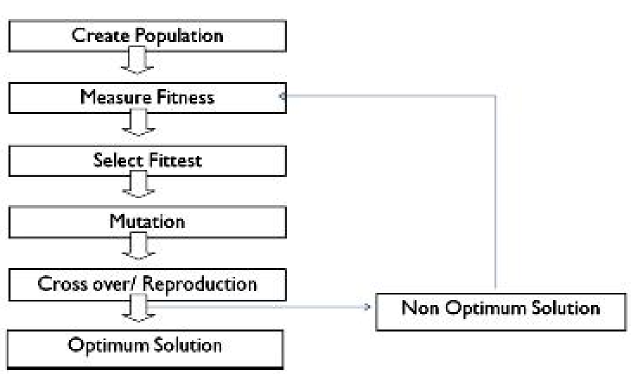

Fig.4.1.Graphical Illustration of the Genetic Algorithm Outline

There are three main stages of a genetic algorithm, these are known as reproduction, crossover and mutation.

(1)Reproduction:

- During the reproduction phase the fitness value of each chromosome is assessed. This value is used in the selection process to provide bias towards fitter individuals. Just like in natural evolution, a fit chromosome has a higher probability of being selected for reproduction.
- An example of a common selection technique is the
- '*Roulette Wheel' selection* method, Fig.4.2. Each individual in the population is allocated a section of a roulette wheel; the size of the section is proportional to the fitness of the individual.
- A pointer is spun and the individual to whom it points is selected. This continues until the selection criterion has been met. The probability of an individual being selected is thus related to its fitness, ensuring that fitter individuals are more likely to leave offspring.
- Multiple copies of the same string may be selected for reproduction and the fitter strings should begin to dominate. However, for the situation illustrated in Fig.4.2, it is not implausible for the weakest string (01001) to dominate the selection process.

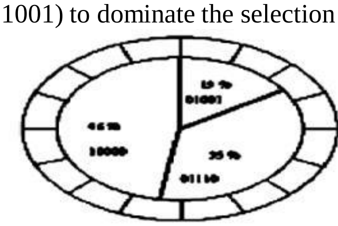

Fig.4.2 Depiction of roulette wheel selection

- There are a number of other selection methods available and it is up to the use to select the appropriate one for each process. All selection methods are based on the same principal i.e. giving fitter chromosomes a larger probability of selection.

Four common methods for selection are:

1. Roulette Wheel selection
2. Stochastic Universal sampling
3. Normalised geometric selection
4. Tournament selection

(2) Crossover

Once the selection process is complete, the crossover algorithm is initiated.

- The crossover operations swaps certain parts of the two selected strings in a bid to capture the good parts of old chromosomes and create better new ones.
- Genetic operators manipulate the characters of a chromosome directly, using the assumption that certain individual's gene codes, on average, produce fitter individuals.
- The crossover probability indicates how often crossover is performed. A probability of 0% means that the 'offspring' will be exact replicas of their

'parents' and a probability of 100% means that each generation will be composed of entirely new offspring.

1. Single Point Cross-over
2. Multi Point Cross-over
3. Uniform Cross-over

(3) Mutation

Mutation is the occasional random alteration of a value of a string position.

- It is considered a background operator in the genetic algorithm.
- The probability of mutation is normally low because a high mutation rate would destroy fit strings and degenerate the genetic algorithm into a random search.
- Mutation probability values of around 0.1% or 0.01% are common, these values represent the probability that a certain string will be selected for mutation i.e. for a probability of 0.1%; one string in one thousand will be selected for mutation.
- Once a string is selected for mutation, a randomlychosen element of the string is changed or 'mutated'.
- For example, if the G.A chooses bit position 4 for mutation in the binary string 10000, the resulting string is 10010 as the fourth bit in the string is flipped as shown in Fig.4.3.

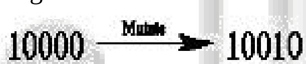

Fig.4.3 Illustration of Mutation Operation

FOPDT model parameter identification using G.A:

From Table 3.2 we have fixed value of delay time t_d = 3 sec. But the other parameter value are change for different closing of control valve.

Now, we used G.A to obtain optimal value of that parameters. In G.A coding we define fitness function, two unknown variables like Process gain K, Process time constant T_p and delay time t_d is fixed in all readings so, only two unknown value will optimize by using G.A. then after selection function uniformly, mutation uniformly and the integral square error based objective function are used to obtain parameters with minimum and maximum values derived from Table 3.2 as,

$K_{max.} = 0.938$ and $K_{min.} = 0.7425$

$T_{p\,(max.)} = 103$ sec. and $T_{p\,(min.)} = 79$ sec.

By, using G.A coding with help of Integral of the Square of the Error (ISE), objective function obtained FOPDT model is,

Tank Transfer function:

$$\exp(-3*s) * \frac{0.9341}{79.76\,s + 1} \qquad \text{---------------} (4.1)$$

And we get the best value,

$K = 0.9341$

$T_p = 79.76$ sec.

$t_d = 3$ sec.

The comparison of obtained model and open loop results is shown in Fig.4.4

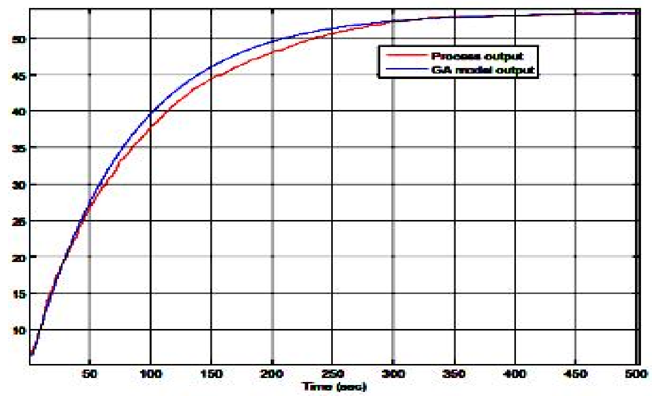

Fig.4.4.Comparison of obtained model and open loop results

V. Conclusion

This report is focused on the G.A based FOPDT model identification. The main contribution of this work is to propose a methodology of G.A based FOPDT model identification and Based on the analysis of real time response following broad conclusion can be made.

- A G.A based FOPDT model identification methodology is applied on liquid level system.
- Obtained FOPDT model is compare with open-loop response of liquid level system.

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