# A Self Tuning Fuzzy Logic Control for Industrial Temperature Regulation (Dyeing Washing Range)

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# Summary

Many chemical reactions, industrial processes and experiments require temperature to be maintained at predetermined value. There are many modes to regulate the temperature like ON/OFF, Proportional (P), Proportional Integral (PI) and Proportional Integral Derivative (PID).
Currently, the classical PID (Proportional, Integral and Derivative) control is widely used with its gains manually tuned based on the thermal mass, the temperature set point and expert knowledge of the operator. Equipment with large thermal capacities requires different PID gains at different operating points than equipment with small thermal capacities. In addition, equipment operates over wide ranges of temperatures (140ºC to 500ºC), for example, requires different gains at the lower and higher end of the temperature range to avoid overshoots and oscillation. Generally, tuning the Proportional, Integral, and Derivative constants for a large temperature control process is costly and time consuming. The task is further complicated when incorrect PID gains are sometimes entered due to the lack of understanding of the temperature control process.

The difficulty in dealing with such temperature regulation problems is compounded with variable time delays existing in many such systems. Variations in equipment quality and physical constraints i.e. placing the RTD temperature sensor at different locations, induces variable time delays (dead time) in the system. It is also well known that PID controllers exhibit poor performance when applied to systems containing unknown nonlinearity such as dead zones, saturation and hysteresis. It is well-known that temperature control processes are nonlinear.
The complexity of these problems and the difficulties in implementing conventional controllers to eliminate variations in PID tuning motivate us to investigate intelligent control techniques such as fuzzy logic control (FLC) with adaptation algorithm as a solution to controlling systems in which time delays, nonlinearities, and manual tuning procedures need to be addressed.
Fuzzy Logic Control (FLC) has become very popular over the conventional control Logic (CCL), mainly because the process of FLC is simply to put the realization of human control strategy, where CCL heavily relies on the mathematical formulations. In this study FLC is used for Temperature regulation & control with self-tuning adaptation algorithm of extremely utilized and common chemical process in current textile industry i.e. bleaching.

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# Chapter 1

# 1. Introduction

## 1.1 Types of Commercial Feedback Classical Controller

### 1.1.1 Industrial On-Off Temperature Control

This is the simplest form of control, used by almost all domestic thermostats,(Frank.L.Lewis, 1994).When the process is cooler than the set-point temperature the system is turned on at maximum power, and once the process is hotter than the set-point temperature the system is switched off completely. The turn-on and turn-off temperatures are deliberately made to differ by a small amount, known as the hysteresis *H*, to prevent noise from switching the heater rapidly and unnecessarily when the temperature is near the set-point.

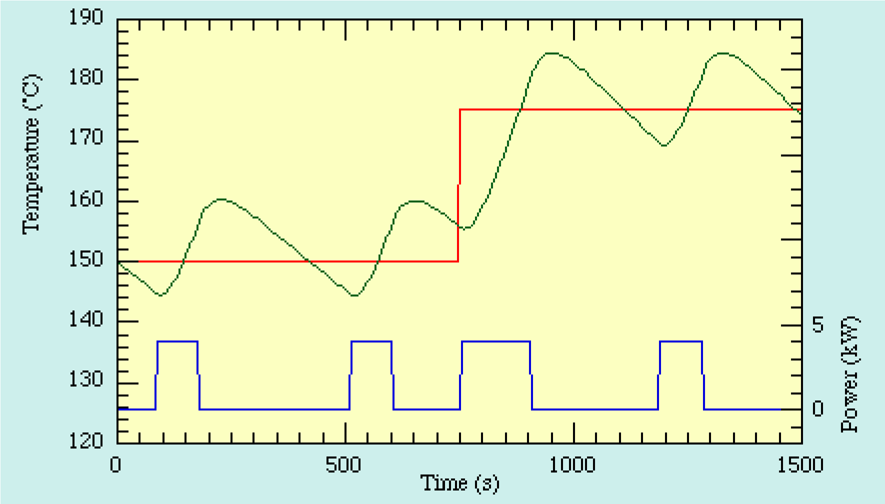


**Figure 1-1 ON/OFF Temperature Control for Cement Kiln Off-Gases (A.Berube, 2010)**

### 1.1.2 Industrial Proportional Temperature Control

A proportional controller attempts to perform better than the On-Off type by applying heat, to the process in proportion to the difference in temperature between the system and the set-point, (L.K.Wong, 2004, pp. 5-6,18-19).

$W=P\times Ts-To1-1$

Where P is known as the proportional gain of the controller. As its gain is increased the system responds faster to changes in set-point but becomes progressively underdamped and eventually unstable. The final process temperature lies below the set-point for this system because some difference is required to keep the process supplying heat. The process amount of heat must always lie between zero and the maximum *M* because it can only source, not sink, heat (Johonson Controls, 2000).

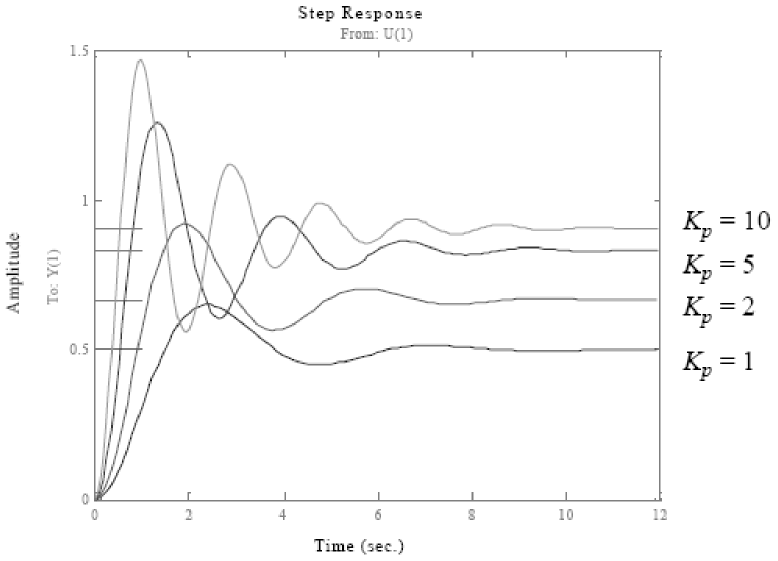


Figure 1-2 Proportional Control Process(L.K.Wong, 2004, p. 15)

### 1.1.3 Industrial Proportional+Integral Temperature Control

The paper, (LBialkowski, 1993), which describes audits of paper mills in Canada; shows that a typical mill has more than 2000 control loops and that 97% use PI control. Sometimes, particularly when the sensor measuring the temperature is susceptible to noise or other electrical interference, derivative action can cause the heater power to fluctuate wildly. In these circumstances it is often sensible use a PI controller or set the derivative action of a PID controller to zero (L.K.Wong, 2004, pp. 4,15-16).

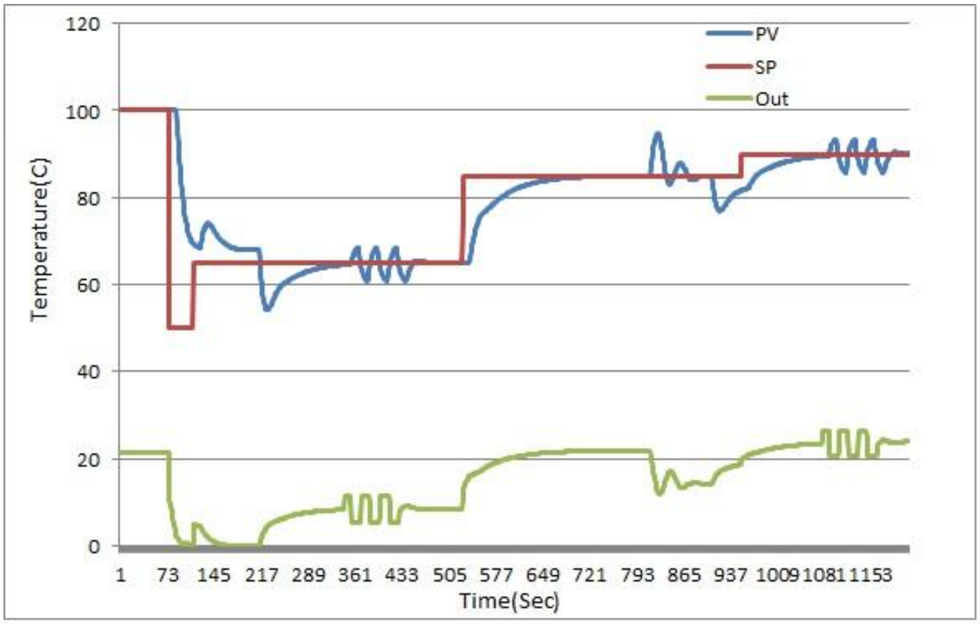


Figure 1-3 Proportional Integral Control Response on Temperature regulation problem, (Green Villey Machinery Corporation, 1985)

### 1.1.4 Industrial Proportional+Integral+Derivative Temperature Control

PID is the most common controller in industrial practice, The Japan Electric Measuring Instrument Manufacturers ‘Association conducted a survey of the state of process control systems in 1989,(Yamamoto, 1991). According to the survey more than 90% of the control loops were of the PID type. (T.Hagglund, 1995, pp. 13-15).

Although P control unable to deals neatly with the overshoot, ringing problems also it does not cure the problem with the steady-state error(Awang N.I. Wardana, 2004). Fortunately it is possible to eliminate this while using relatively low gain by adding an integral & Derivative term to the control function which becomes

$W=P\times Ts-To+D\times ddtTs-To+I\times\int Ts-Todt$ (1-2)

Where I, the integral gain parameter is sometimes known as the controller reset level. This form of function is known as proportional-integral-differential, or PID, control. The effect of the integral and Derivative term is to change the process amount of energy (Heat) until the time-averaged value of the temperature error is zero. The method works quite well but complicates the mathematical analysis slightly because the system is now third-order.(L.K.Wong, 2004, pp. 9-24)

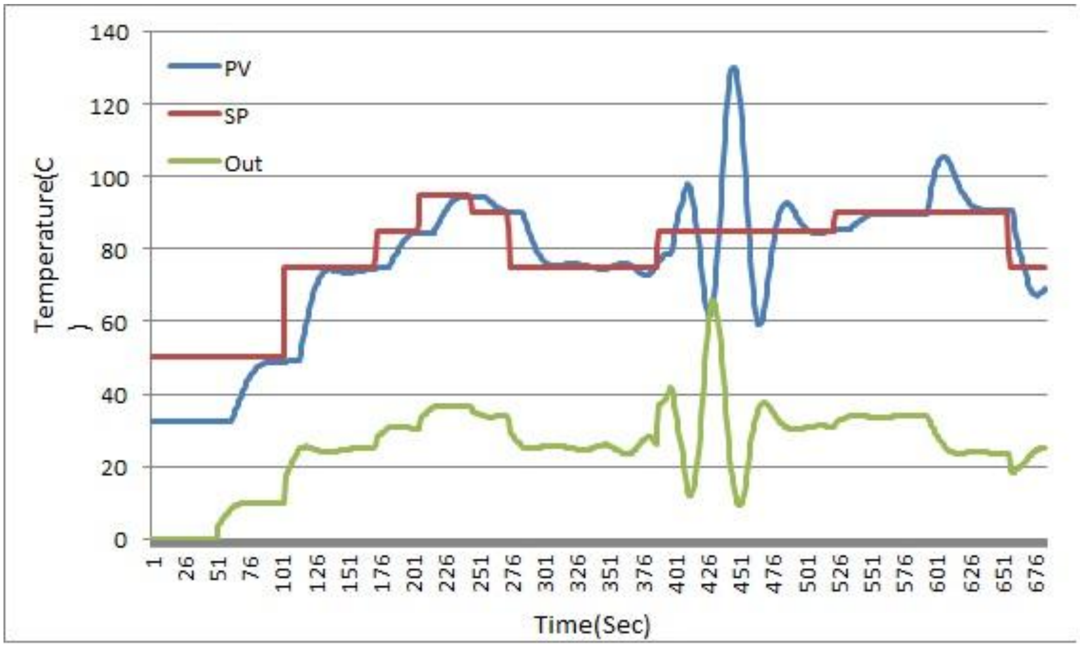


**Figure 1-4 PID Controller response on Temperature regulation problem, (Green Villey Machinery Corporation, 1985)**

## 1.2 Commercial Feedback Advanced Fuzzy Controller

The performance of the PID controllers as well as the Self-Tuning controllers is good and they have widespread industrial application. Since most of the industrial processes are highly non-linear and unpredictable, continuous manual tuning of the controller parameters is required in order to optimize the performance. This is often difficult if not impossible to achieve. With the passage of time the performance of the controller also degrades due to variations in the plant parameters. The demand for tighter control performance is enhancing day by day.(Emersson Process Management, 2011)

The seminal work by (Mamdani, 1979)on self-organizing fuzzy logic controllers opened new horizons for control engineers. Their work was based on the ‘fuzzy sets’ pioneered by(L.A.Zadeh, 1965). A fuzzy controller, which used linguistic rules to control the plant offered good performance even in the presence of nonlinearities.

A key advantage of self-organizing fuzzy logic controller is that it does not require a mathematical model of the plant and even with minimal knowledge it can offer acceptable performance. Various methodologies of neural and fuzzy control have been proposed in recent years (D. A. Linkens, 1996), (Murakam, 1992, pp. 29-42)

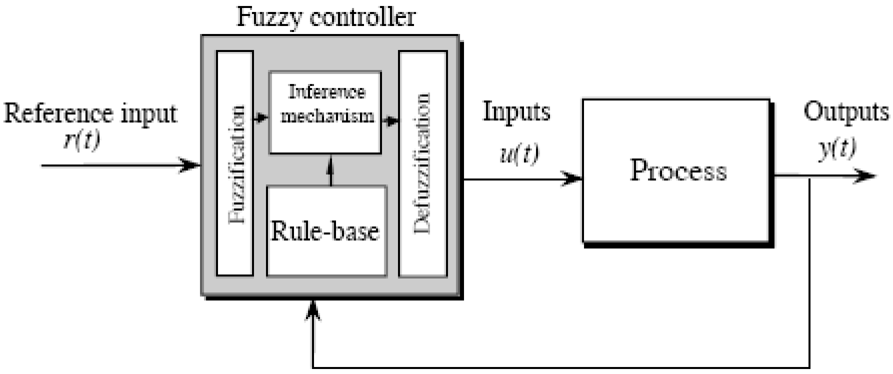


**Figure 1-5 FLC Controller Temperature regulation problem (Emerson Process Management, 2011)**

The fuzzy controller has four main components: (1) The “rule-base” holds the knowledge, in the form of a set of rules, of how best to control the system. (2) The inference mechanism evaluates which control rules are relevant at the current time and then decides what the input to the plant should be. (3) The fuzzification interface simply modifies the inputs so that they can be interpreted and compared to the rules in the rule-base. And (4) the defuzzification interface converts the conclusions reached by the inference mechanism into the inputs to the plant.(T.Hagglund, 1995, pp. 298-314),(Emerson Process Management, 2011)

## 1.3 Fuzzy Controller Design Models

Fuzzy Models can be broadly classified into Linguistic fuzzy models, Rule Based fuzzy models and the Fuzzy Relational models(R.Babuska and H. B. Verbruggen, 1996), we discuss and consider only rule based fuzzy model in this report.

### 1.3.1 Rule based Fuzzy Models

Rule based Fuzzy models are of two types.

a) Mamdani Models

The Mamdani (Mamdani, 1979) model is the simplest fuzzy model in which the inputs are associated with the rule antecedents and the outputs with the rule consequents. Both the antecedent and the consequent are fuzzy propositions. The affine form of Mamdani Fuzzy model can be represented by:

$$R_i \; : \; if \;\; \mathbf{x} \;\; is \;\; A_i \;\; then \;\; y_i \;\; is \;\; B_i, \qquad i=1,2,..,K \qquad (1.3)$$

Where:
$\mathbf{x} = [x_1, x_2, \ldots\ldots\ldots x_p]$ *x* is a vector whose elements are the antecedents variable, *Ai* is a multi-dimensional fuzzy set, *Bi* is a one-dimensional fuzzy set, and *yi* is the consequent variable of the *ith* rule.

b) Takagi Sugeno Models (Takagi and Sugeno 1985)

Takagi Sugeno Fuzzy model is a special case of a functional fuzzy system (Yurkovich, 1998). In this type of system the rule consequents are defined as functions. Therefore the rule consequent does not have associated membership functions and is a crisp value. The affine form of the T-S Fuzzy model consists of rules Ri with the following structure:

$$R_i \; : \; if \;\; \mathbf{x} \;\; is \;\; A_i \;\; then \;\; y_i \; = \mathbf{a}_\mathbf{i}^\mathbf{T}\mathbf{x} + b_i, \qquad i = 1,2,..,K \qquad (1.4)$$

where, **x** is a crisp input, *Ai* is a multidimensional fuzzy set, *yi* is the scalar output of the *ith* rule, a*i* is a parameter vector, *bi* is a scalar constant and K is the number of rules in the rule base. The output of multi input single output (MISO) 0th order TS Model can be described by:

$$y(\mathbf{x}) = \frac{\sum_{i=1}^{p} a_i(\mathbf{x}) b_i}{\sum_{i=1}^{p} a_i(\mathbf{x})} \qquad (1.5)$$

Where *bi* is the weight vector, (**x**) *i a* = (**x**) *I* μ is the degree of membership of **x** in the multi-dimensional fuzzy set *Ai*, *y(***x***)* is the crisp output.

## 1.4 Auto Tuning Methods on commercial Industrial Controllers

Once a control loop is designed and configured to govern a process it must be tuned. Making the necessary adjustments to provide for stable and responsive operation of the process is referred to as **loop tuning**. If a loop is tuned for responses that are too slow, the process is stable but not responsive. If the loop is tuned for responses that are too fast, it can be very responsive, but it might overshoot and cycle around the setpoint (SP). The objective is to achieve a reasonably responsive and stable control loop (Emersson Process Management, 2011).

The most common methods of loop tuning are **calculated tuning** and **trial and error tuning** (Emersson Process Management, 2011). The calculated method involves computing the tuning values using known constants and algorithms. The trial and error method involves manually adjusting the tuning values until the process is stable. The calculated method is superior to the trial and error method because it requires a small number of cycles to achieve the desired results. If a process is slow, using the calculated method can be extremely advantageous to using the trial and error method.(Control Loop Foundation, 2011)

Here we mention & discuss only the most out performing tuning methods used by most of commercial design controller manufacturers like ABB, AB, Siemens, Mitsubishi, Honeywell, General Electric, Emerson, Fisher, Rosemount etc.(Yokogawa Electric Corporation, 2010),(Ascon Corporation),(Emerson Process Management, 2011),(HoneyWell, 1994),(Fisher Controls, 1994).

### 1.4.1 Commercially Implemented Trial &Error (Model Free) Tuning Method

Many of the commercial industrial process controllers implemented Trial and error(model free) method for an effective tighter loop control, However due to technological enhancement after 90’s each manufacturer updated these auto tuning algorithm with latest firmware releases Among them are famous YOKOGAWA 9000 Series(Yokogawa Electric Corporation, 2010), Omron CNI SERIES, Honeywell ASCON series(Ascon Corporation)embedded process controllers,(Fisher Controls, 1994).As per survey conducted by Japan Electric Measuring Instrument Manufacturers(Yamamoto, 1991) almost 95 % commercial process controllers has Ziegler-Nichols & Astrom-Hagglund methods implemented in their industrial commercial process controllers.

#### a) Ziegler-Nichols

The 1942 Ziegler-Nichols tuning rules provided a relatively simple and effective method for determining the parameter values for the proportional, integrative, and derivative blocks of the PID Process controller (Ziegler and Nichols 1942),(T.Hagglund, 1995, pp. 135-159).

The Ziegler-Nichols tuning rules remain in widespread use today for tuning PID controllers. Several improvements reported Controllers tuned by this method tend to have large overshoot Two methods - time and frequency domain based. Improvements reported (DePoor & I’Malley, 1989; Manz & Taconi, 1989; Chen, 1989; Hang & in, 1991, Astrom et al, 1992, (Lelic, 1999).

$$u_c = k_c\left[(\beta y_r - y) + \frac{1}{T_i}\int e dt - T_d \frac{dy_f}{dt}\right]$$

$$0 < \beta < 1$$

| Controller | K | $T_i$ | $T_d$ |
|---|---|---|---|
| P | 1/a | | |
| PI | 0.9/a | 3L | |
| PID | 1.2/a | 2L | L/2 |

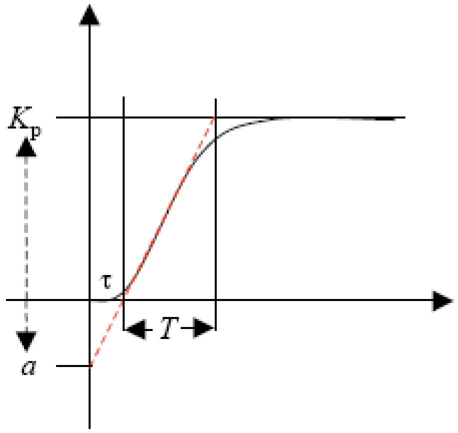


**Figure 1-6 Ziegler Nichols Tuning Method [ (Lelic, 1999)]**

### b) Astrom and Hagglund (Relay Tuning)

Astrom and Hagglund developed a method in their 1995 book for automatically tuning of feedback controllers for all four types of families of plant that represents the dynamics of typical industrial process (T.Hagglund, 1995, pp. 212-218).

Astrom and Hagglund use two frequency-domain parameters, namely the ultimate gain, Ku, and the ultimate period, Tu. Astrom and Hagglund describe a procedure for estimating these parameters from the plant's response to a step input (T.Hagglund, 1995, pp. 212-219).

Further improvement in Relay Tuning considering two-parameter nonlinearity purposed by (Friman and Waller, 1995) Enhanced relay tuning by using the estimate at the two points of the Nyquist plot (Sung and Lee, 1997).Additionally Relay tuning that identifies three frequency data sets (Tan et al., 1996) using one feedback relay test multiple-point frequency response fitting based on relay tuning (Wang et al., 1999),(Lelic, 1999).

Further Enhancement is proposed by two relays working in parallel (Friman and Waller, 1997)
Further methods proposed in A specialized book on relay tuning (Yu, 1999).
Relay tuning (T.Hagglund, 1995, pp. 10-11)is one of the most important methods commercially used.

## 1.4.2 Calculated Tuning Methods (Model based)

Commercial software tools exist for auto-tuning based on an estimated process model developed from a sequence of logged data or time-series of the control variable u and process measurement. The process model is a “black-box” input-output model in the form of a transfer function.

The controller parameters are calculated automatically on the basis of the estimated process model. The time-series of input and measured output may be logged from the system being in closed loop or in open loop. These types of methods are un demanding due to hardware computational requirement and cost in terms of software licenses offered by various manufacturers.

a) Commercial Model Based Adaptive Tuning Methods (Open Loop)

Uses normal operator changes in setpoint or output to identify process models and provide tuning recommendations when automatic tuning request initiated. Process Controller learns the process by continuously evaluating your plant performance, evaluating controller tuning, and calculating Process models based on normal day-to-day operations.

b) Commercial Model Based Adaptive Tuning Methods (Closed Loop)

Includes all of the Adaptive Tuning capabilities plus the ability to create models in up to 5 regions and to automatically change control loop tuning. The model quality is validated by taking into account the most recent adaptation and the last several adaptations. A high quality model and the expected operation with the recommended tuning is used as criteria for setting Adaptive Control.(Emersson Process Management, 2011)

## 1.5 Aims and scope of the Project

The aim of the project is to program and implement a Self-Tuning Model Free(Murakam, 1992) Fuzzy Controller using Emerson MD plus program free hardware(Emerson Process Management, 2009),Utilizing its fuzzy block(Emerson Process Management, 2011) and write software program based on these functions, Tune them (Emersson Process Management, 2011) to obtain best possible results on DYE washing machine (Green Villey Machinery Corporation, 1985), which is able to cope with the nonlinearities of the system as well as the external disturbances.

The controller should be robust in order to minimize the effect of external disturbances. One of the important facts of the controller is that it neither has a model of the system *a priori*, nor does it tries to build a model of the system. Adaptive Model-Free Fuzzy Controller hasn’t been reported much in the literature. Researchers have demonstrated the worth of these controllers by simulating them on hypothetical test-beds. The aim is to model and implement an Adaptive Model-Free Fuzzy Controller with acceptable performance in most demanding Temperature industrial process control loop.(K.Mcmillan, 2011)

## 1.6 Report Outline

Chapter 1 lays the foundation and overview for the different types of Commercial industrial classical (PID), advanced controllers (FUZZY) and briefly discusses their types. Since the controllers are required to be self-tuned, so a brief introduction to the most commonly in practice self-tuning algorithm schemes offer by the top of industrial process controller manufacturers is also given with references.

Chapter 2 explains fuzzy controller architecture as well as the Implemented Mathematical equations and descriptive Controller design flow on Emerson process MD plus DCS (Distributive control system) in detail.

The simulation and analysis of implemented and programmed Astrom Hagglund algorithm(T.Hagglund, 1995), which is to be used in the Model Free Controller along with self-tuning approaches(Emersson Process Management, 2011)are presented in Chapter 3.

Chapter 4 explains industrial Plant model, type of regulation problem, and System dynamics in detail.

Chapter 5describes the real time implementation, testing and results of the implemented Model Free self-tuning FLC Controller with controller structure discussed in chapter 2 combines with self-tuning algorithm as discussed in chapter 3 on an industrial washing range(Green Villey Machinery Corporation, 1985). The experimental practical results are presented on system having variable system dynamics. Finally concludes this report and suggests a future research direction.

# Chapter 2

## 2. Fuzzy Logic Controller Structures

The FLC developed here is a two-input single-output controller. The two inputs are the deviation from setpoint error, e(k), and error rate, De(k).

The Deltav MD Plus controller (Emerson Process Management, 2009) powered by 2 GHZ embedded RISC Based Cpu,128 mb Ram, The controller has the capabilities to program up to 800 points with 100 individual process loops.

### 2.1 Function Block:

The Fuzzy Logic Control (FLC) function block provides the control capability of the PID block with the added benefit of superior response for both set point changes and external load disturbances. By using fuzzy logic, the FLC function block minimizes overshoot and provides good load disturbance rejection.

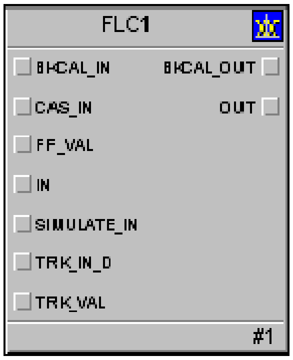


Figure 2-1 **Fuzzy Logic Control Function Block (Emerson Process Management, 2011)**

The FLC function block operates by using predefined fuzzy rules, membership functions, and adjustable parameters known as scaling factors. The FLC function block translates the loop's absolute values into fuzzy values by calculating the scaled error ($e$) and scaled change in error ($\Delta e$) in addition to the degree of membership in each of the predefined membership functions. It then applies the fuzzy rules and, finally, retranslates the values into a control move.

## 2.2 Function Block Fuzzy Embedded Architecture:

The following diagram shows the internal components of the Fuzzy Logic Control function block:

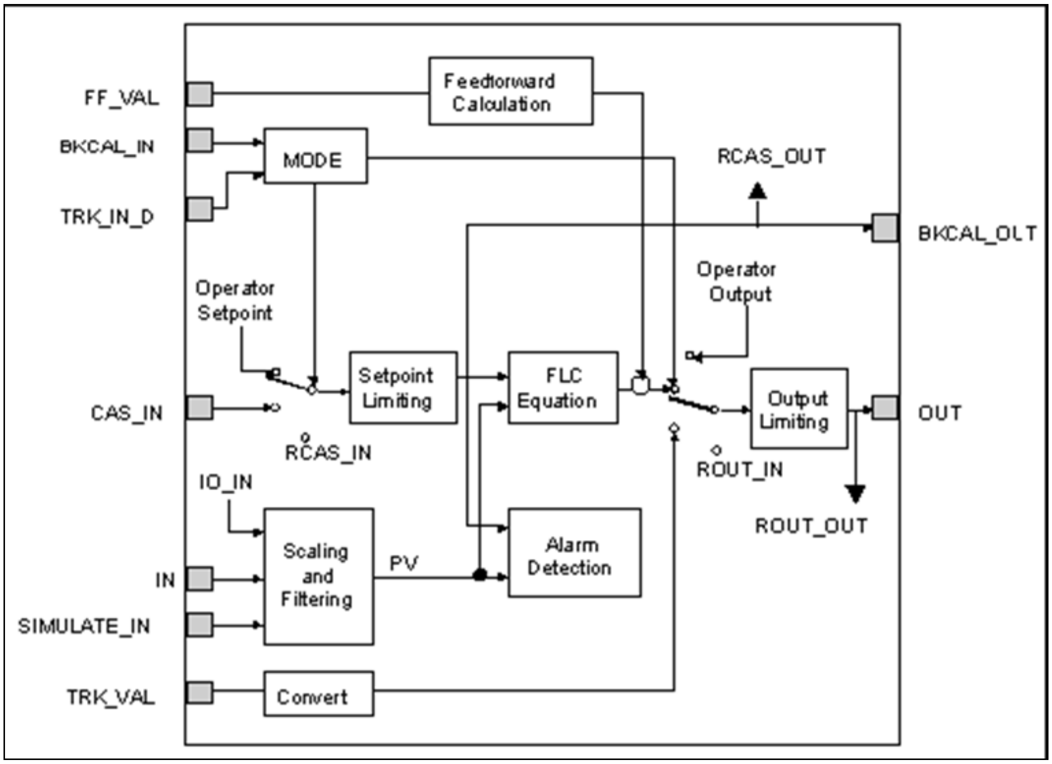


Figure 2-2 Fuzzy Logic Control Function Block Schematic Diagram (Emerson Process Management, 2011)

We utilized only IN, BKCAL_IN & OUT for a specific FUZZY function block, The detail for these inputs & output parameters are as follows.

BKCAL_IN is the analog input value and status feedback from another block's BKCAL_OUT output that is used for backward output tracking.
IN is the connection for the process variable (PV) from another function block.
OUT is the block output value and status.

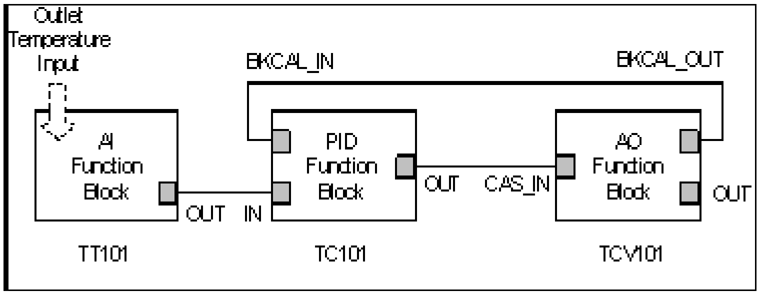


Figure 2-3 Typical Loop Control Schematic Diagram (Emerson Process Management, 2011)

## 2.3 Block Execution of Fuzzy Logic Control Function Block

A typical FLC function block has three basic operations (Yurkovich K. M., 1998, pp. 51-69):
1. Translation from input signals to fuzzy logic values or fuzzification.
2. Rule inference based on input states.
3. Retranslation of the fuzzy logic values to continuous signals or defuzzification.

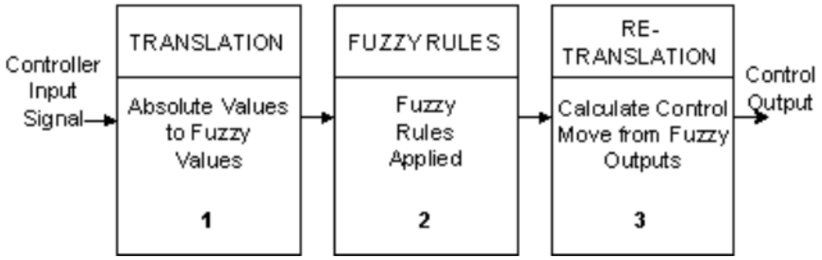


**Figure 2-4 Typical FLC Function Block Components (Emerson Process Management, 2011)**

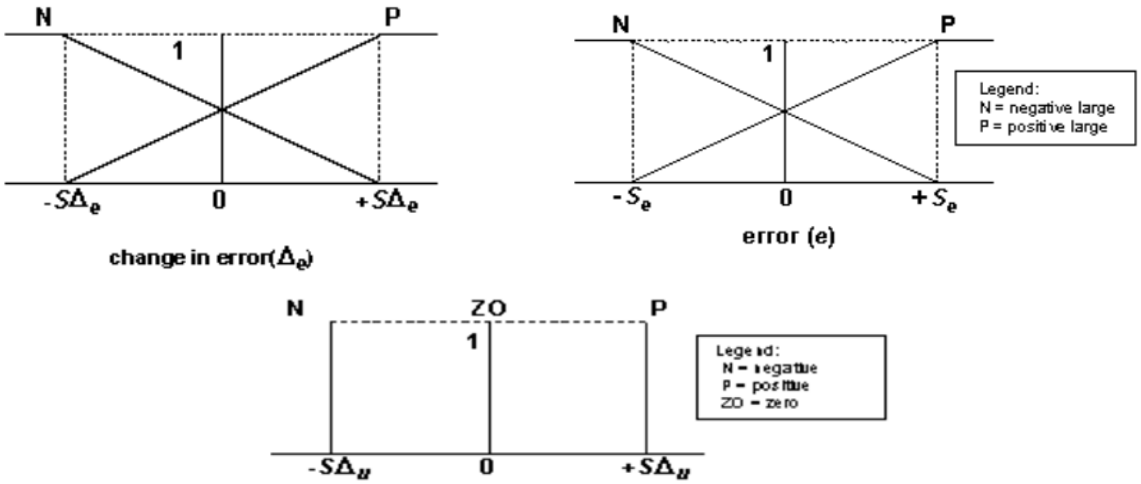
This section describes how the Fuzzy Logic Control block functions.

### 2.3.1 Translation (Absolute Values to Fuzzy Values-Fuzzification)

Two Membership Functions:

Fuzzy logic uses mathematical functions to describe the degrees of membership in various states or conditions. One mathematical function describes each state. These states are called membership functions and are usually represented graphically as triangles that overlap.

The FLC function block uses two membership functions(Emerson Process Management, 2011). The two membership functions for error (e), change in error (Δe) and change in output are negative (-ve) and positive (+ve). The membership scaling (Se and e) and the error value and change in error, respectively, determine the degree of membership.



**Change in Output (Δu)**

**Figure 2-5 Fuzzy Membership functions (Emerson Process Management, 2011)**

## 2.4 Fuzzy Rules

The FLC function block operates by using predefined fuzzy rules(Emerson Process Management, 2011). There are four fuzzy logic rules that the FLC function block uses for a reverse acting controller.

**Number** **Rule**
Rule 1 ------------>If error is N and change in error is N, make change in output P.
Rule 2 ------------>If error is N and change in error is P, make change in output ZO.
Rule 3 ------------>If error is P and change in error is N, make change in output ZO.
Rule 4 ------------>if error is P and change in error is P, make change in output N.

## 2.5 Non Linear Fuzzy controller

In order to enhance the capabilities of FLC block(Emerson Process Management, 2011)to make the program process controller robust when dealing with real-time disturbances and plant nonlinearities* additional scaling blocks used in absolute change in error along with derivative action introduce in feedback path to suppress noise generated due to nearby electric field instruments.

### 2.5.1 Introduction (Programming) Of Scaling Blocks

For regions where the absolute error is greater than the error scaling factor or the absolute change in error is greater than the change in error scaling factor, the values for error and change in error are clipped at the error scaling factor and change in error scaling factor, respectively. The following figure shows an example FLC curve that illustrates how the change in controller gain is smooth and continuous using only two input membership functions and three output membership functions.

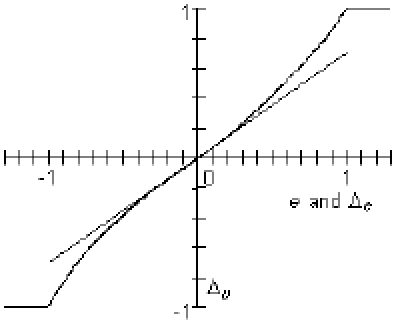


**Figure 2-6 FLC Function Block's Nonlinear Relationship**

### 2.5.2 Derivative Action in Feedback Path

The nonlinearity built into the FLC function block reduces overshoot and settling time, achieving tighter control of the process loop. To help anticipate a rapid change in the process with the FLC function block, derivative action is provided in the feedback path of the loop, as shown in the following figure.

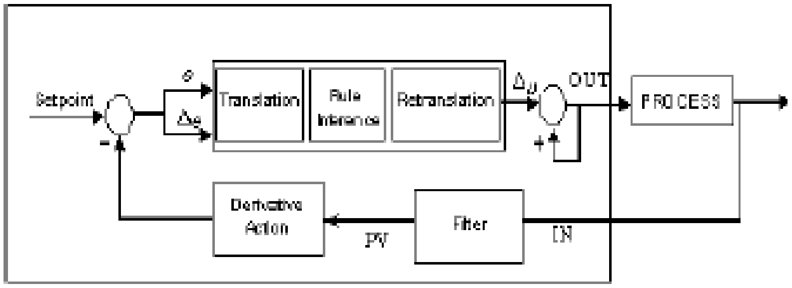


**Figure 2-7 Fuzzy Logic Control block with applied Derivative Action**

The FLC function block treats small control errors differently from large control errors and penalizes large overshoots more severely. It also severely penalizes large changes in the error, helping to reduce the oscillation.

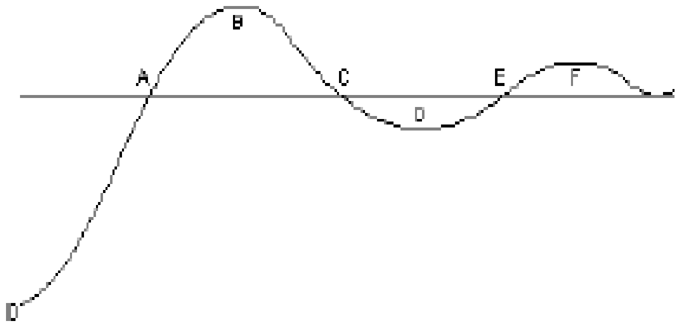


**Figure 2-8 Process Variable Oscillation Example**

The above figure depicts how an FLC function block reacts to overshoot and oscillation. At points B, D, and F, where overshoot occurs, the FLC function block applies stronger control actions to bring the variable back to the setpoint. At points A, C, and E, where large changes in error occur and are dominant, the FLC function block applies stronger corrective actions to reduce oscillation.

This type of nonlinearity allows the FLC function block to provide better control performance than standard PID control and this combination make this controller demanding.

### 2.5.3 Scaling Factors for Non Linear PI Relationship.

Scaling factors (Se, e, and Su)(Emerson Process Management, 2011) are used to tune FLC controller response and make the controller robust for unknown non linearity's existing in the system. For a small control error and setpoint change less than a nominal value ($\Delta Y_{SP}$), the FLC function block scaling factors are related to the proportional gain ($Kp$) and reset ($Ti$).

When the setpoint change is greater than the nominal setpoint change ($\Delta Y_{SP}$), these scaling factors are internally increased by the Fuzzy Logic Control function block. This internal scaling is changed in the ratio of actual setpoint change to the nominal setpoint change. These larger scaling factors are used while the control error (PV–SP) remains large due to the change in setpoint. When the control error has returned to a small value and remains small for a period of time, the scaling factors used by the fuzzy algorithm are once again the block scaling parameter values.

Refer to the following equations:

$$S\Delta_e = \beta \Delta Y_{SP} \qquad (2\text{-}1)$$

$$S\Delta_{U=}2S\Delta_E Kp \qquad (2\text{-}2)$$

$$S_e = S_{e0} = TiS\Delta_e \qquad (2\text{-}3)$$

Where:
$S\Delta_e$ = change of error scaling.
$S_e$ = error scaling.
$S\Delta_{U=}$ = change of controller output scaling.
$S_{e0}$ = error scaling for a one (1) second scan rate.

Beta is a function of process deadtime (DT) and ultimate period or time constant (TC) and has values in the following range:

$$0.2 < \beta < 0.5 \qquad (2\text{-}4)$$

The approximate formula for calculating beta is as follows:

$$\beta = 0.2 + DT/TC \qquad (2\text{-}5)$$

The Fuzzy Logic Control function block accounts for the scan rate and recalculates the error scaling factor (Se), which depends on the scan rate appropriate tothe function block scan (t).

$$S\_e = S\_e0/\Delta\_t = (TiS\Delta\_e)/\Delta\_t \qquad (2\text{-}6)$$

The function block scan rate is set to 200 msec.The nominal setpoint change value for $\Delta Ysp$ is one percent.

## 2.6 Comments and Conclusion

In this chapter we discuss in detail an overview of the MD Plus multifunction industrial controller, The available program block of FLC ,Fuzzy architecture with the program parameters we used, The predefined membership functions and rules with brief overview. Finally three state program modification add-in on FLC block with all parameters and equation in detail.

Introduction of scaling block and derivative block in series with feedback (PV) improve the controller response mainly when we talk about coping with large disturbances and non-linearity during production cycle of Large Dyeing Washing machine.

# Chapter 3

## 3. Self-Tuning Algorithm

## 3.1 Introduction

Once a control loop is designed and configured to govern a process it must be tuned. Making the necessary adjustments to provide for stable and responsive Operation of the process is referred to as loop tuning. If a loop is tuned for responses that are too slow, the process is stable but not responsive. If the loop is tuned for responses that are too fast, it can be very responsive, but it might overshoot and cycle around the setpoint (SP). The objective is to achieve a reasonably responsive and stable control loop.

The most common methods of loop tuning on commercial industrial controllers are calculated tuning and trial and error tuning. The calculated method involves computing the tuning values using Known constants and algorithms. The trial and error method involves manually adjusting the tuning values until the process is stable. The calculated method is Superior to the trial and error method because it requires a small number of cycles to achieve the desired results. If a process is slow, using the calculated method can be extremely advantageous to using the trial and error method.

## 3.2 Loop Tuning Approaches

Here we discuss the loop tuning approaches classified in categories accumulated from most of the famous industrial process controller’s manufacturers (HoneyWell),(Emerson Process Management, 2009) ,(Yokogawa Electric Corporation, 2010),(Ascon Corporation).

### 3.2.1 On Demand Tuning(Model Free)

Uses an on-demand test of the process to automatically provide tuning recommendations. Tuning recommendations are available on-demand by initiating automatic testing of the process. When testing is requested using On-Demand tuning, the FLC block's actual mode switches to Local Override (LO). Once in LO mode, the operation of the loop’s primary control algorithm is suspended and the controller resident relay identification adjusts the control block output (OUT).

### 3.2.2 Adaptive Tuning (Open Loop-Model Based)

Uses normal operator changes in setpoint or output to identify process models and provide tuning recommendations. When automatic model identification is requested using Adaptive Tuning, there is no impact on the block mode and block mode is based on normal operating conditions. The Controller learns the process by continuously evaluating your plant performance, evaluating controller tuning, and calculating process models based on normal day-to-day operations.

The model quality is validated by taking into account the most recent adaptation and the last several adaptations. A high quality model and the expected operation with the recommended tuning is used as criteria for setting adaptive control.

We choose On demand (Model Free) tuning method for our controller and implement program customized algorithm to initiate self-tune for 5 % sp changes because of its simplicity in implementation and ideal results. Next we discuss on demand tuning algorithm in detail regarding our FLC controller design.

## 3.3 On Demand Tuning (Aström-Hägglund Algorithm)

The On-Demand tuning capability is based on the patented Aström-Hägglund Algorithm (T.Hagglund, 1995)for calculating the tuning parameters of a process control loop.

During tuning, the output of the Fuzzy Logic Control (FLC) block that is selected for tuning is determined by a known function that acts as a relay with hysteresis. This relay provides two-state control and causes the process to oscillate with small, controlled amplitude(Lelic, 1999, pp. 13-17). Using the amplitude and the frequency of this oscillation, we calculate the Ultimate Gain and Ultimate Period of the process. The controller settings are then computed based on the defined process parameters and selected process type.

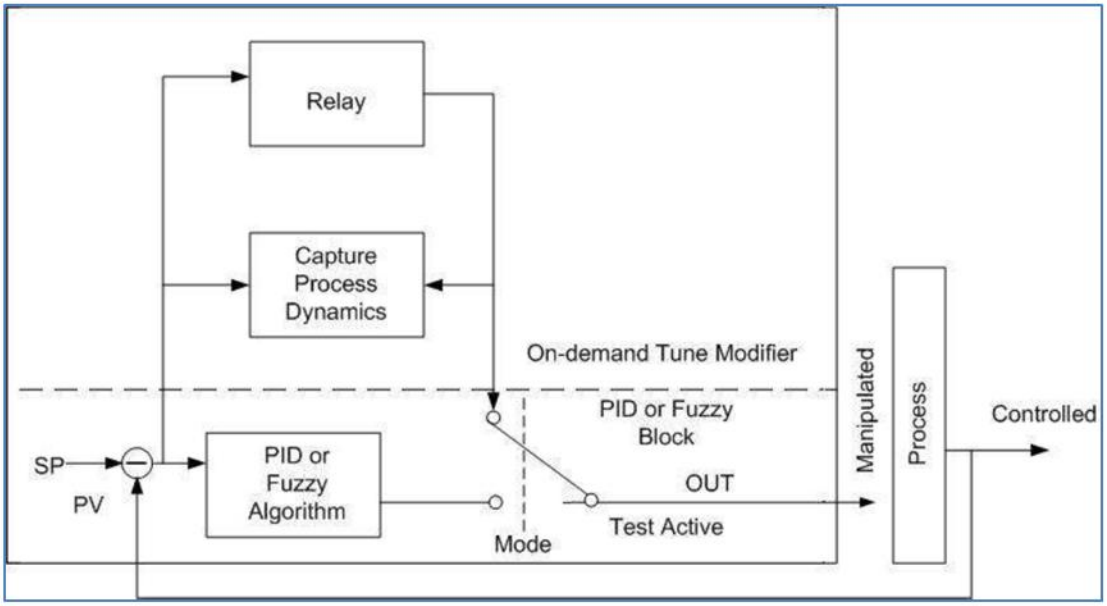


Figure 3-1 **Aström-Hägglund Relay Test Algorithm (Lelic, 1999, pp. 13-17)**

### 3.3.1 Algorithm Design & Implementation

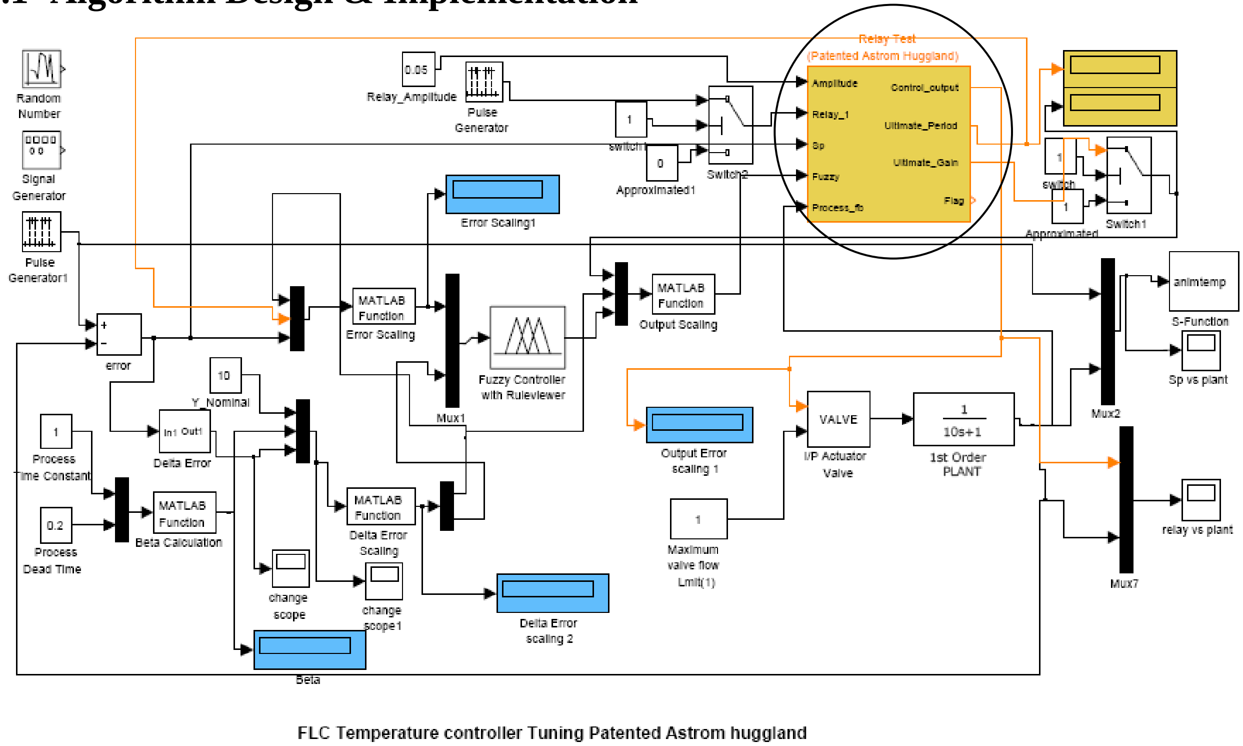


**Figure 3-2 Aström-Hägglund Design & Implementation (Matlab)**

Where

Amplitude – Applies the desired amplitude of Relay 0.1-10.

Sp – Connects to desired setpoint.

Relay – Activates Relay Test Patented by Astrom Huggland.

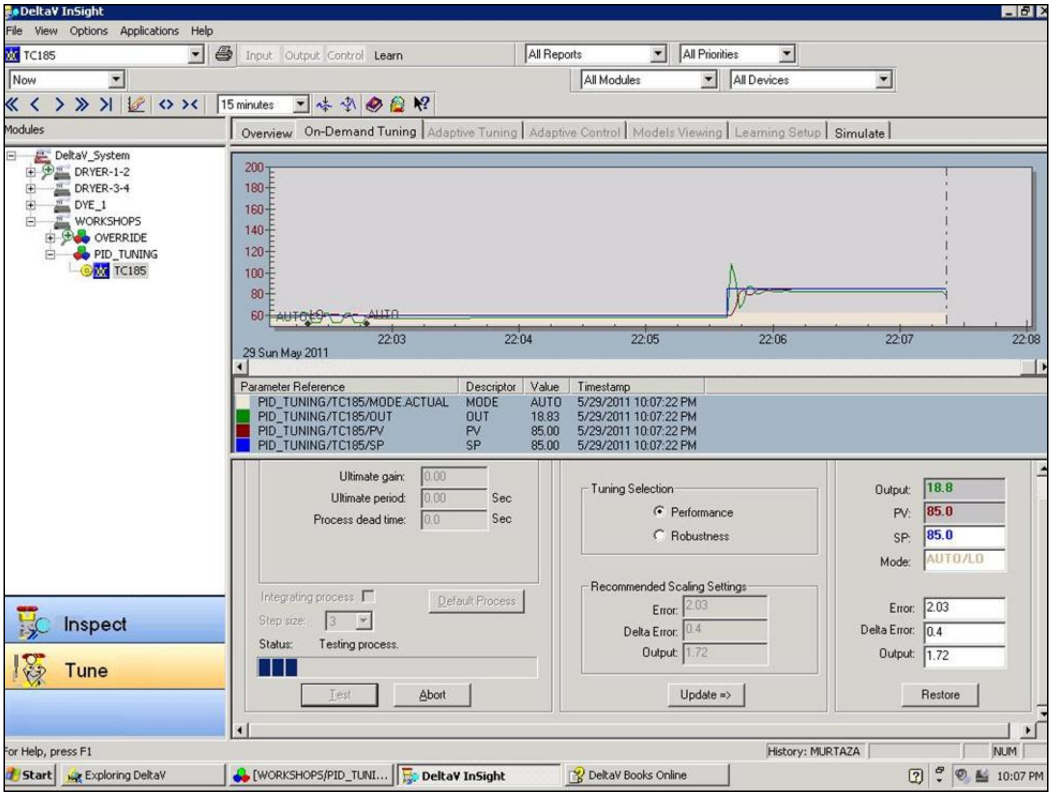
Fuzzy – Connects to Control Output of Controller.

Process_fb – Feedback from Plant.

## 3.4 Loop Tuning Program Procedure

The typical On-Demand Tuning procedure involves:

1. Identifying the process dynamics. This is done automatically by the test initiated manually or as per program call.
2. Selecting the basis for tuning either by specifying the process type or the tuning rule to be used.
3. Validating the tuning results using the Simulate selection.
4. Updating and applying tuning recommendation to the current controller.



| | Parameter Reference | Descriptor | Value | Timestamp |
|---|---|---|---|---|
| ⬜ | PID_TUNING/TC185/MODE.ACTUAL | MODE | AUTO | 5/29/2011 10:07:22 PM |
| 🟩 | PID_TUNING/TC185/OUT | OUT | 18.83 | 5/29/2011 10:07:22 PM |
| 🟥 | PID_TUNING/TC185/PV | PV | 85.00 | 5/29/2011 10:07:22 PM |
| 🟦 | PID_TUNING/TC185/SP | SP | 85.00 | 5/29/2011 10:07:22 PM |

Ultimate gain: 0.00
Ultimate period: 0.00 Sec
Process dead time: 0.0 Sec
Integrating process ☐
Step size: 3
Status: Testing process.

Tuning Selection
● Performance
○ Robustness

Recommended Scaling Settings
Error: 2.03
Delta Error: 0.4
Output: 1.72

Output: 18.8
PV: 85.0
SP: 85.0
Mode: AUTO/LO
Error: 2.03
Delta Error: 0.4
Output: 1.72

**Figure 3-3 Program Loop Tuning GUI MD-Plus Controller**

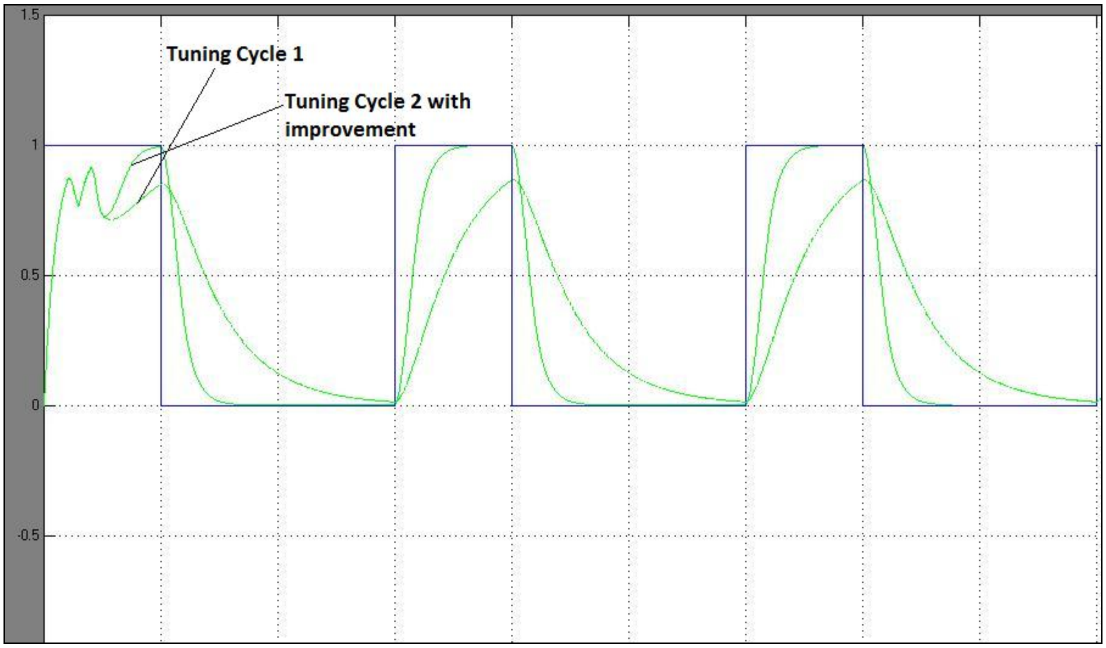


**Figure 3-4 Program Loop Tuning GUI MATLAB**

## 3.5 Determination of Process Dynamics

The On-Demand tune modifier identifies the process dynamics using the relay oscillation principle (T.Hagglund, 1995). During the identification procedure of loop tuning, the mode of the FLC block forces to LO(Local Override from Auto To Manual) and the output is determined by a two-state (or relay) function(Emersson Process Management, 2011). During this phase of tuning, the loop is under two-state control. As indicated previously, loops under two-state control exhibit slight oscillations. The amplitude of these oscillations defines the Ultimate Gain. The oscillation period defines the Ultimate Period.

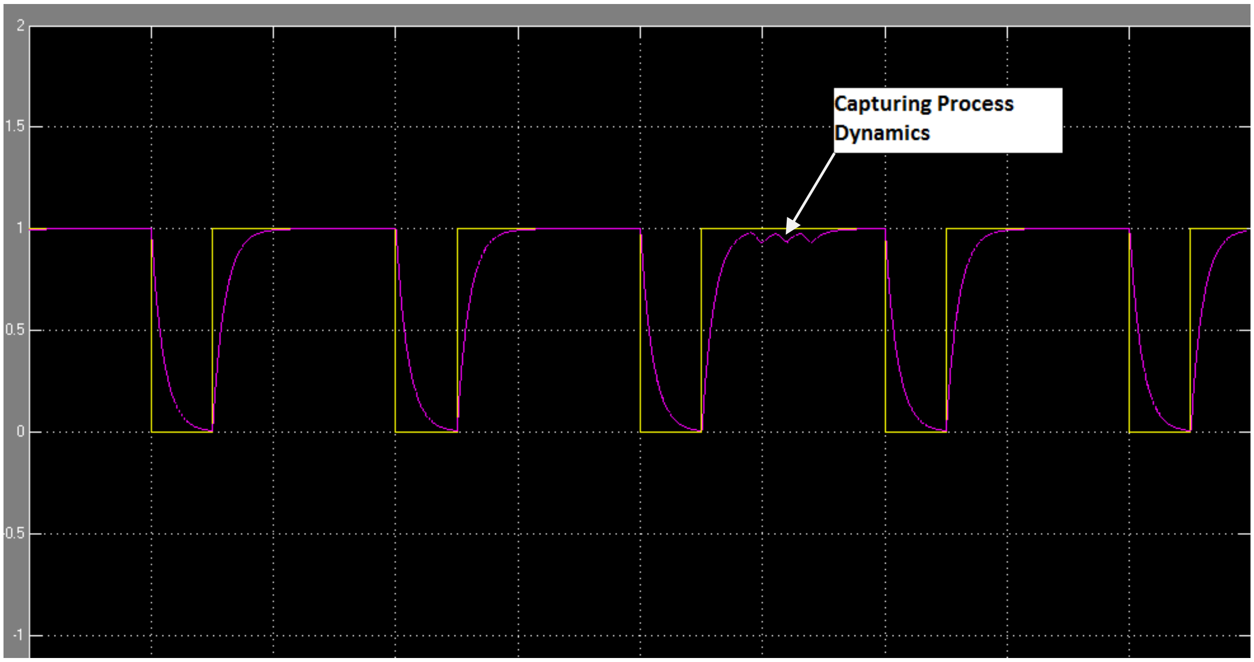


Figure 3-5 **Program Loop Tuning** 'SP vs. PV'

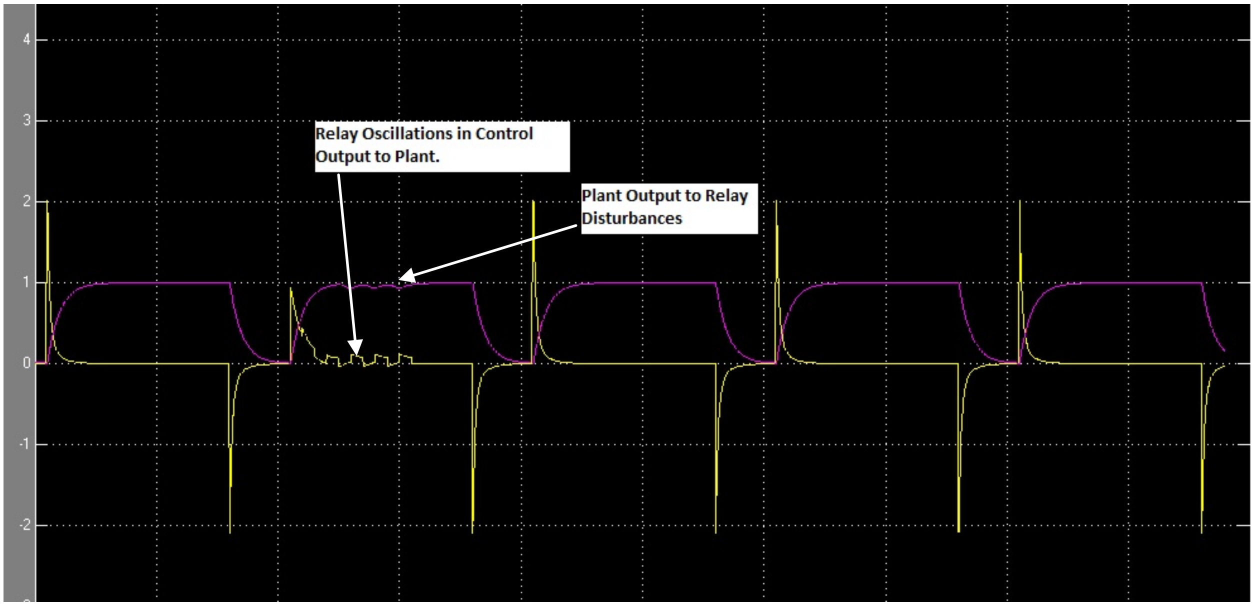


Figure 3-6 **Program Loop Tuning 'Relay Disturbances vs. Plant Response'**

Oscillations must continue for at least one period after initialization.FLC program for four periods tuning periods by default and defines the amplitude of the oscillations as the average amplitude.

During the oscillation periods after initialization (the tuning periods), relay switching is disabled at the start of each half period to increase the tuner's resistance to noise. The duration that the relay switching is disabled depends on the deadtime of the tuned loop, which is defined during the initialization period.

For very noisy processes, we adjust the amount of relay hysteresis for additional noise protection. With hysteresis, the relay switches only if the PV passes through the SP by a specified amount only.

### 3.5.1 The Ultimate Gain (Ku)

The Ultimate Gain (*Ku*) is defined by the following equation:

$$\boldsymbol{Ku = 4d/\pi a} \qquad \textbf{(3-1)}$$

Where
*d* - Relay amplitude
*a* - Amplitude of the oscillation of the process variable (PV)

### 3.5.2 Tuning Period

The following figure illustrates a typical time plot of the relay output and the process variable (PV) during tuning. Note that the relay is triggered at the point when the PV passes through the SP.

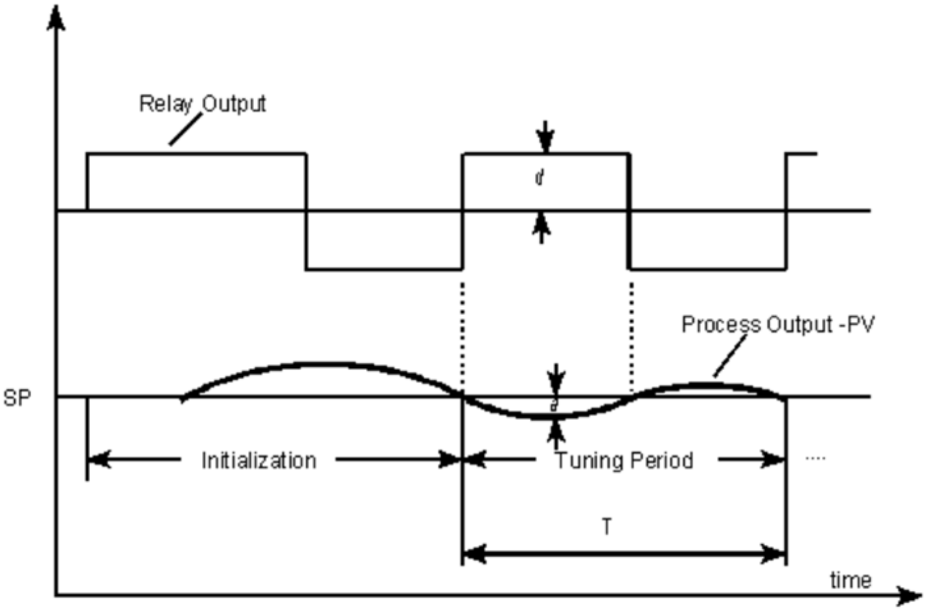


Figure 3-7 **Loop Tuning Schematic Diagram (Emersson Process Management, 2011)**

### 3.5.3 Beta ($\boldsymbol{\beta}$)

Beta is a function of process deadtime (DT) and ultimate period or time constant (TC) and has values in the following range:

$0.2 < \beta < 0.5$ (3-2)

The approximate formula for calculating beta is as follows:

$\boldsymbol{\beta = 0.2 + DT/TC}$ **(3-3)**

$\boldsymbol{S\Delta_e = \beta\Delta Y_{SP}}$ **(3-4)**

$\boldsymbol{S\Delta_{U=}2S\Delta_E Kp}$ **(3-5)**

$\boldsymbol{S_e = S_{e0} = TiS\Delta_e}$ **(3-6)**

Where:
Se = change of error scaling
e = error scaling
Su = change of controller output scaling
Se0 = error scaling for a one (1) second scan rate

### 3.5.4 Hysteresis

Several recent surveys indicate that control performance is not as good as one might think( D. B.Ender, 1993),(M. A. Hersh Johnson, 1997) and control valves contributed significantly to the poor performance (G. K.McMillan, 1994) Due to reducing cost, many control valves are not properly installed (e.g., with positioner or flow controller) or maintained. This is unfortunate since the true value of the final control element in terms of quality, yield, and productivity usually is not recognized (Yu-Chang Cheng, and Cheng-Ching Yu, 2000).Therefore, in process industries, we encounter many imperfect valves (e.g., valves with a dead-zone, stick/slip, hysteresis).

Hysteresis is a dynamic response to change that causes the path of movement to be different when the response is increasing than when the response is decreasing. Control loops depending upon control valves (most) see hysteresis as a dead-time in their dynamic response and compensate by applying additional reset (integral) action. When the hysteresis becomes too large, the control loop may become unstable and oscillate about the setpoint more than desired. The "cure" is to rebuild the control valve - a costly maintenance operation.

## 3.6 Comments and Conclusion.

In this chapter we discuss the type of loop tuning algorithm offered by commercial process control manufacturers. Since we have known and unknown non linearity’s and disturbances exist in our plant discussed separately so instead of good performance by FLC implemented controller we required a self-tuning algorithm either model based or model free that can tune the controller automatically without any requirement of skilled human intervention and can compensate for non-linearity’s specially Hysteresis due to imperfect valves .We choose to go for Astrom Hagglund (Astrom and T.Hagglund, 1995) relay test tuning algorithm due to its simplicity, computational cost and proven results particularly for this case.

# Chapter 4

## 4. Plant Description& Regulation Problem

### 4.1 Processing Machinery Overview

A dye washing machine with the capacity of processing fabric up to 100 meter/minute. Total 4 washers available each having 2 inch water line for water inlet in to machine & 1.5 inch steam line for heating the liquid inside (Green Villey Machinery Corporation, 1985) as shown in fig.

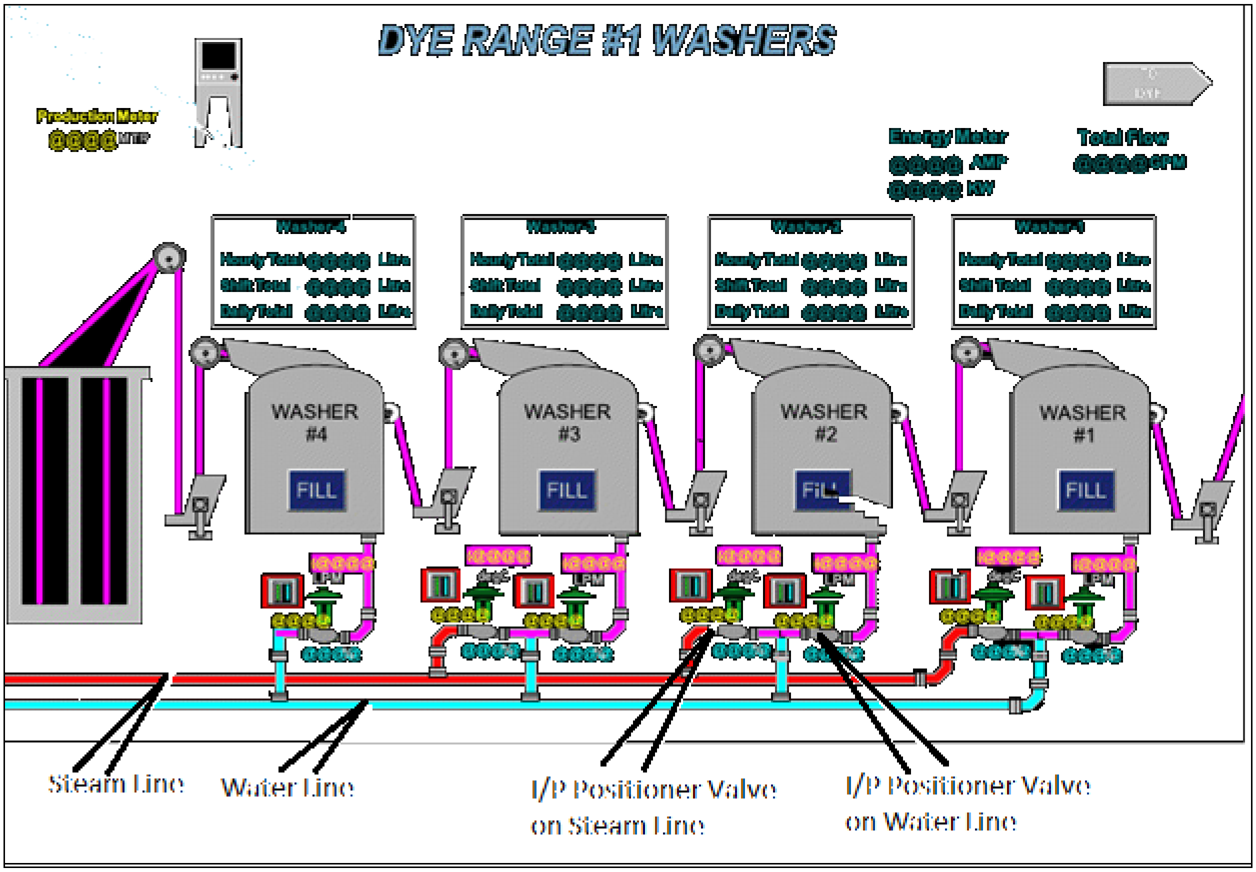


Figure 4-1 **DCS Based Upgraded DYE RANGE FABRIC WASHER (Green Villey Machinery Corporation, 1985)**

Each steam and water line has I/P positioner valve installed completely controlled by a feedback DCS controller (DeltaV). The DeltaV controller actuates and control precise amount of steam (In Kg/Hr) and water (In Gallon/Minute).For this range we implemented total 8 feedback loops on single DCS controller based on different techniques (PID & FLC).

Due to critical nature and precise accuracy requirement due to high quality standards we choose to implement FLC for temperature control and regulation with self-tuning algorithm due to its perfect and precise results as compare to other classical control techniques. In this report descriptive detail of that FLC controller implemented is discussed.

### 4.1.1 Machine Standard Operating Procedure:

**Step 1 Filling:**

Fill the ranges with water and set water flow in Gallon per Minute (GPM) as per requirement.

**Step 2 Heating:**

Set Temperature setpoint and activate the machine from manual to auto.

**Step 3 Dosing (Mixing Chemicals):**

7~12 chemicals are dosed as per shade requirement in ml namely (MRC, 2FSR, POJ, H202, NAOH, RCL, Liquid Bleach).

**Step 4 Speeds:**

Set desired speed for fabric processing in to the ranges in Meter per Minute.

**Step 5 Modes Select (Auto/Manual):**

On auto mode all closed loop and open loop controllers regulate the control parameter accordingly. The machine is processing product on auto mode with tighter and secure process control.

With implementation of advanced control techniques and automation on processing machinery we are able to log steam water and power consumption on machine more over different alarms and error entry codes are introduced to facilitate the plant processing team for evaluating time and work efficiency. Due to implemented tighter control FLC with less than 2 % overshoot we manage to reduce the steam consumption more than 30 % in temperature regulation when compare with other classical control technique.

## 4.2 Temperature Regulation Problem

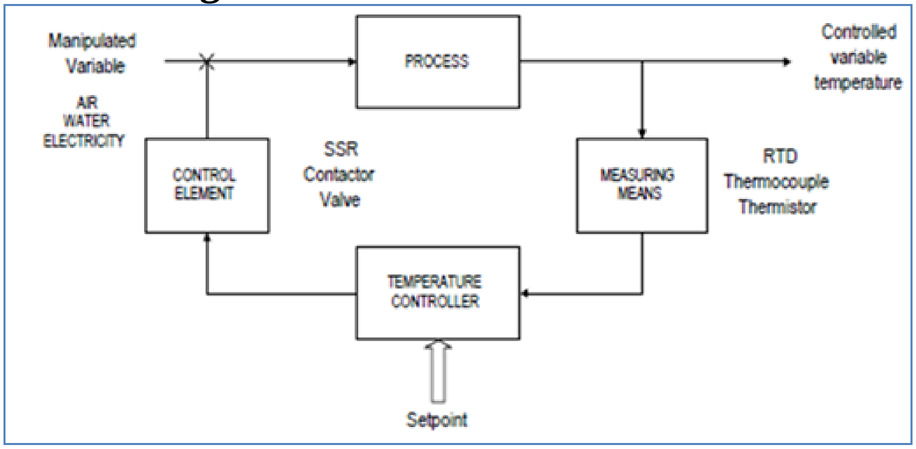


Figure 4-2 **A typical Industrial temperature regulation problem (Trautzsch, 2002)**

### 4.2.1 Model Descriptions (Process):

The process is a single input single output (SISO) based temperature control system for individual washing ranges. The desired temperature regulation is achieved by transferring amount of heat in to the liquid with precise I/P actuator valve, Steam is used as a source for heat. Temperature is feedback in to the closed loop controller by standard RTD PT100 which senses actual temperature of liquid in degree centigrade.

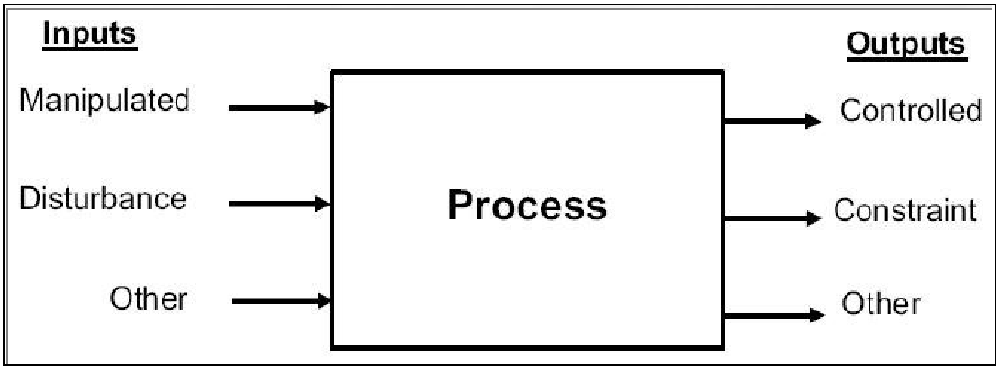


**Figure 4-3 Standard Process Block Diagram**

**Controlled output (controlled parameter)** –Process output that is to be maintained at a desired value by adjustment of process input(s).

**Setpoint**–Value at which the controlled parameter is to be maintained by the control system.

**Manipulated input (manipulated parameter)** –Process input that is adjusted to maintain the controlled parameter at the setpoint.

**Disturbance input**–Process input, other than the manipulated input, which affects the controlled parameter.

**Constraint output (constraint parameter)–**Process output that must be maintained within an operating range.

**Constraint limit**–Value that a constraint parameter must not exceed for proper operation of the process.

**Other input**–Process input that has no impact on controlled or constraint outputs.

**Other output**–Process output other than controlled or constraint outputs.

### 4.2.2 Actuator I/P Transducer (Control Element):

A “current to pressure” converter (I/P) converts an analog signal (4 to 20 mA) to a proportional linear pneumatic output (3 to 15 psig). Its purpose is to translate the analog output from a control system into a precise, repeatable pressure value to control pneumatic actuators/operators, pneumatic valves, dampers, vanes, etc.(InTech Working control valve).Current to Pressure Transducer (I/P) applied parameters for above plant are as follows:

Input: 4-20 mA scaled to 0-100% inside DeltaV controller.

Output: Pneumatic pressure (3-15 bars) required to produce from 7/16 to 4 1/8 inch valve plug travel.

Supply Pressure: 5 PSIG higher than upper range limit of input signal.

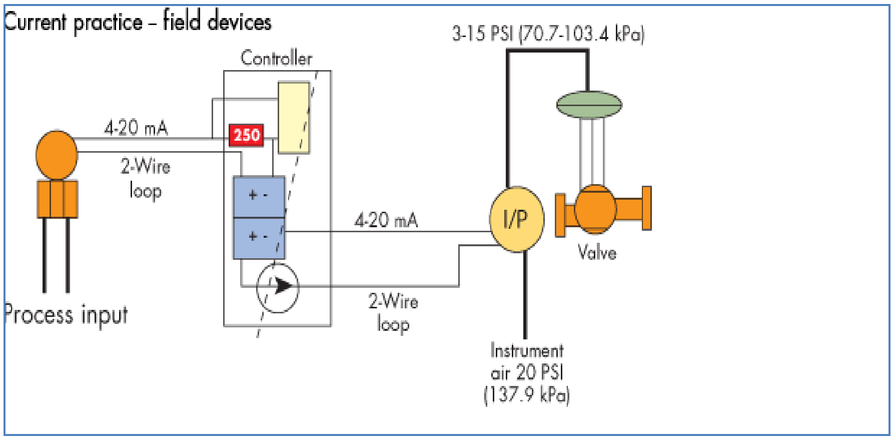


Figure 4-4 **Block Diagram of I/P Transducer Connected with Controller (InTech Working control valve)**

### 4.2.3 Sensor (Measuring Means):

Resistance Temperature Detectors or RTDs for short, are wire wound and thin film devices that measure temperature because of the physical principle of the positive temperature coefficient of electrical resistance of metals. The hotter they become, the larger or higher the value of their electrical resistance.RTD sensor transmitter connected for reading mixture temperature.

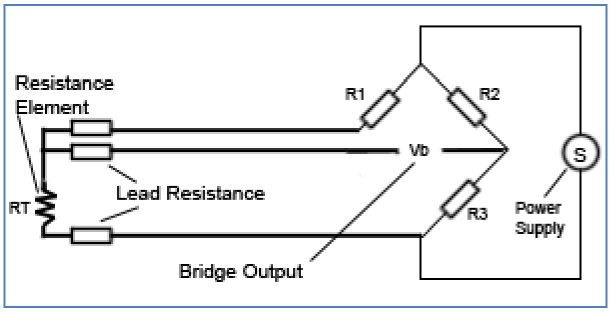


**Figure 4-5 RTD temperature sensor connected in 3 wire configuration**

### 4.2.4 Controller (Temperature):

The MD plus Controller provides communication and control between the field devices and the other nodes on the control network.

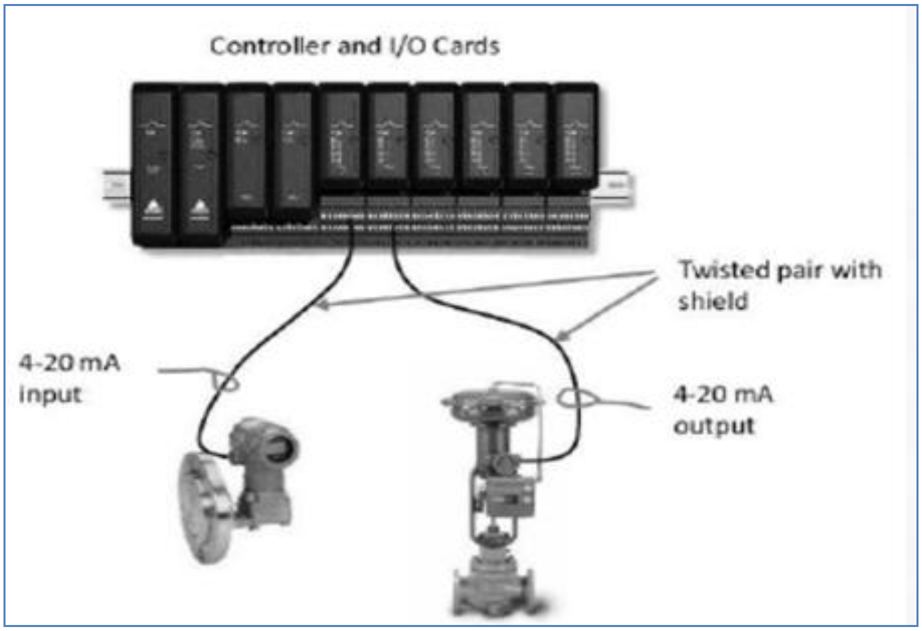


**Figure 4-6 Steam valve (I/P current to pressure) is operated on reference 4-20 ma (0-100%) (Emerson Process Management, 2009)**

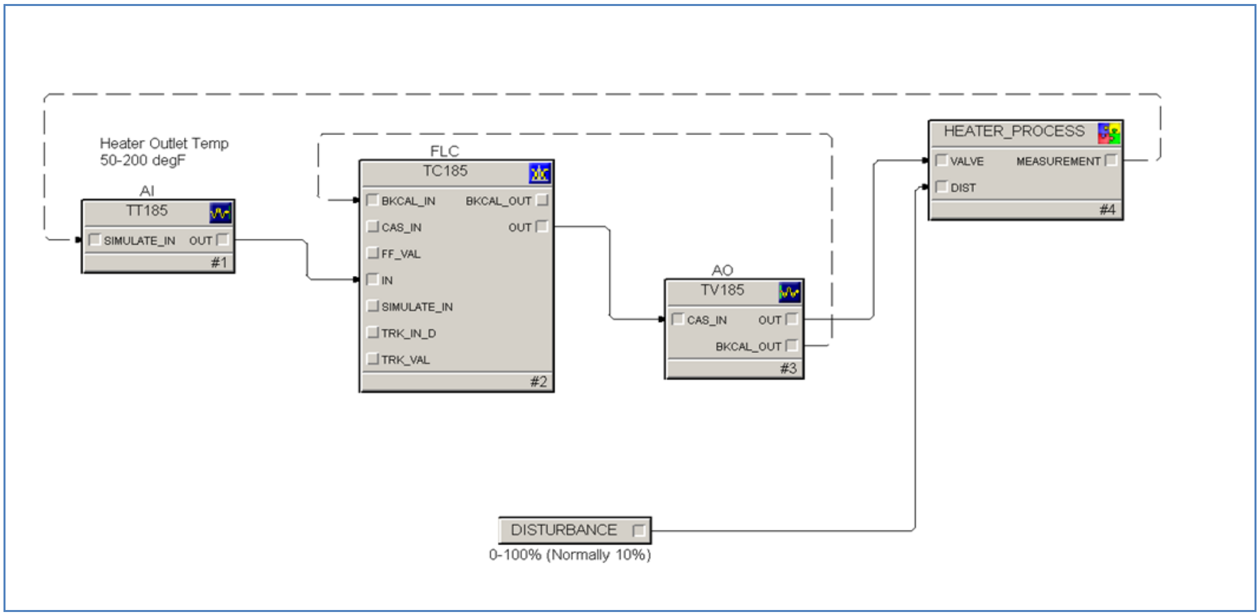


**Figure 4-7 Functional Block Diagram of FLC controller in offline mode (Control Loop Foundation, 2011)**

Temperature is feedback in to the controller through RTD block. The process output regulation is continuously observed by intelligent program controller at BKCAL_IN.

## 4.3 Model Disturbances

The Plant contain known and unknown disturbances, practically we observed the following major disturbances during machine operational working. There are three options available for the machine water distribution line in order to take water as per requirement and need. The options are:

- Water from KDA line (Average Temperature in ranges 25-35(c)).
- Water from Condensated Line (Average Temperature in 80-90(c)).
- Water from recycled plant.(Average Temperature in ranges 15-25(c)).

These lines are connected by union joint and control of water will be made by a solenoid valve actuator. The controller has programmed to take given amount of water in % as per given program recipe. The standard unit of water is in LPM (liter per minute) readed by a flow transmitter in to the controller.

Above options creates two types of major observed disturbances that interrupt the controller in the form of following.

- Disturbance due to adding of warm water.
- Disturbance due to adding of cold (recycled) water.

### 4.3.1 Addition of Warm water (Condensated)

The machine has separate line that can additionally supply water from steam return line (Condensated).The Condensated water has temperature ranges between 80 to 90 deg(C), Using warm water will significantly save the amount of steam consumption in (Kg/hr) as warm water required less amount of steam as a form of energy.

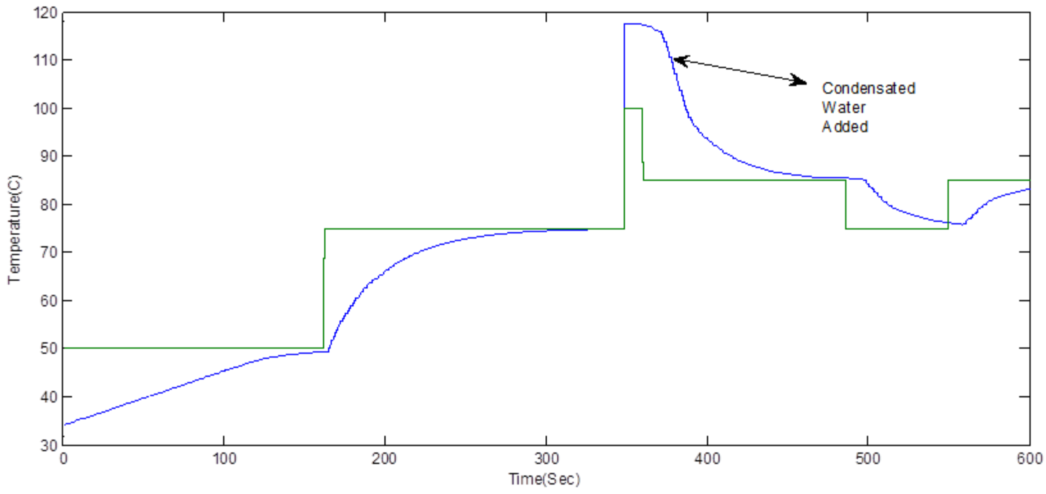


**Figure 4-8 Condensated water adding in to System & rise in temperature(c)**

The Condensated water line will supply water automatically by switching solenoid valve automatically by controller. The amount of usage of Condensated water from steam line will be decided by user written recipe program. Adding warm water during process will consider as external energy source and hence disturb the controller feedback response. The FLC self-tuning controller is design to overcome such type of disturbances efficiently without any human intervention.

### 4.3.2 Addition of Fresh water (Recycled)

The machine has separate line that can additionally supply recycled and well filtered water from filterization plant. This water has normally temperature ranges between 15 to 25 degree(C).

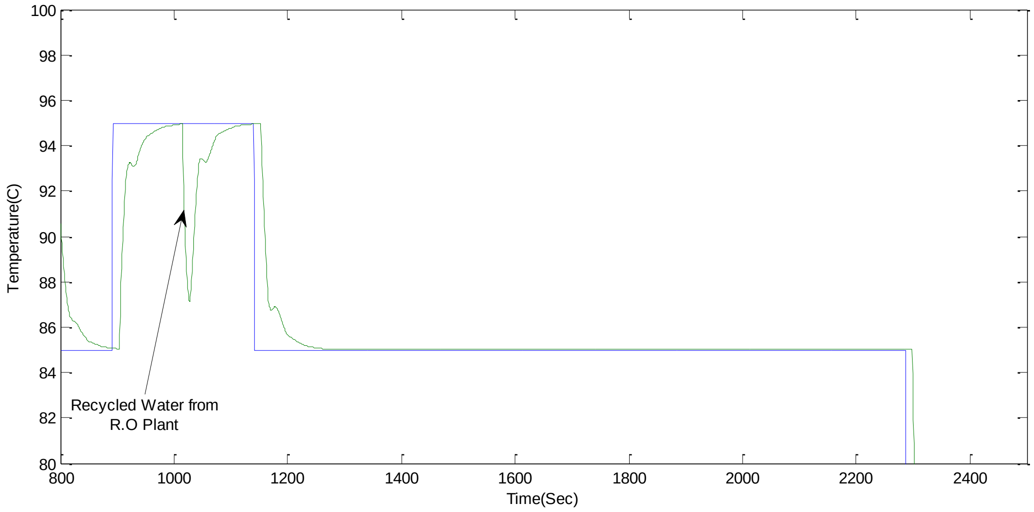


Figure 4-9 Fresh water adding in to System & Fall in temperature(c)

## 4.4 Conclusion

In this chapter we discuss in brief Dye machine Plant, Control Problem, Plant operational constraints, the Known disturbances and non-linearity’s. Astrom and Hagglund suggest the relay feedback test to generate sustained oscillation as an alternative to the conventional continuous cycling technique. We found it very effective in determining the ultimate gain and ultimate frequency (Yu-Chang Cheng, and Cheng-Ching Yu, 2000). The obtained gain than used to calculate the scaling factor and in this way we achieve an FLC temperature regulation process controller with computationally cost effective self-tuning algorithm.

# Chapter 5

# 5. Self-tuning Fuzzy Logic Temperature Controller with Practical Results on Dye Washer

The programmed and tuned controller based on structure as explained in chapter 2 along with model free tuning algorithm explains in chapter 3 applied to temperature regulation problem as described in chapter 4.The controller is tested randomly on different occasion's day or night and with different physical constraints that directly affects the process on long production hours. The results and experiments are observed and logged.

## 5.1 Control Performance without Self-Tuning Algorithm large dead time (8-10 sec)

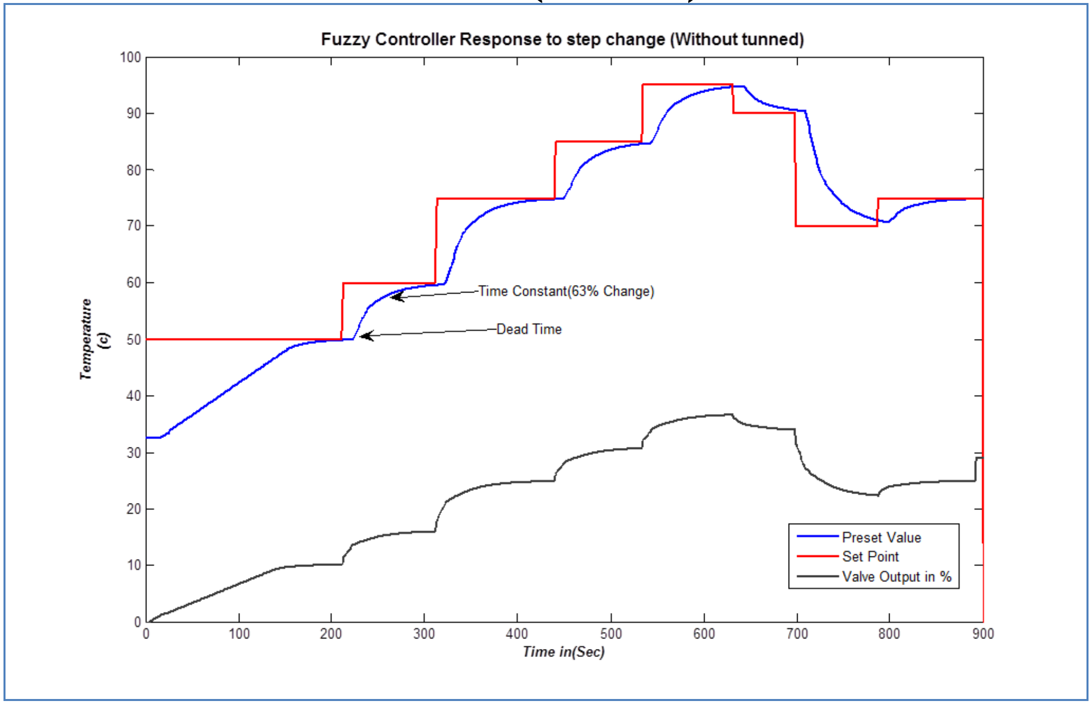


Figure 5-1: Control Performance with large dead time without tuning algorithm.

| Parameter | Value | Scaling Applied | Value |
|---|---|---|---|
| **SP** | 50 - 200 °C | Error | 2.00 |
| **PV** | 50 - 200 °C | Delta Error | 0.20 |
| **OUTPUT** | 0 - 100 % | Output | 0.20 |
| **MODE** | AUTO /AUTO | | |

**Table 5-1**
**Loop Operation & Scaling Applied without Relay Test on process with large dead time**

### Discussion (Case 1):

Initially we start without relay test algorithm .We consider the case when machine is programmed to take both fresh and recycled water feeded with equal ratio under that circumstances machine has comparatively large time constants and dead time observed greater than 8 sec approximately.

With large dead times the FLC is scaled to optimum i.e. scaling applied based on approximations and human knowledge as shown in table 5-1 such that it maintain the process loop under control despite the disturbances and non-linearity's as seen from sudden rise and fall in temperature Figure 5-1.

As the controller is tested practically and enhances further (Scaling & Derivative action with error) even with large time delay's controller perform under control at the cost of high rise time approx. 100 sec. Next we see the same controller behavior with small dead time.

## 5.2 Control Performance without Self-Tuning Algorithm small Dead time (2-4 sec )

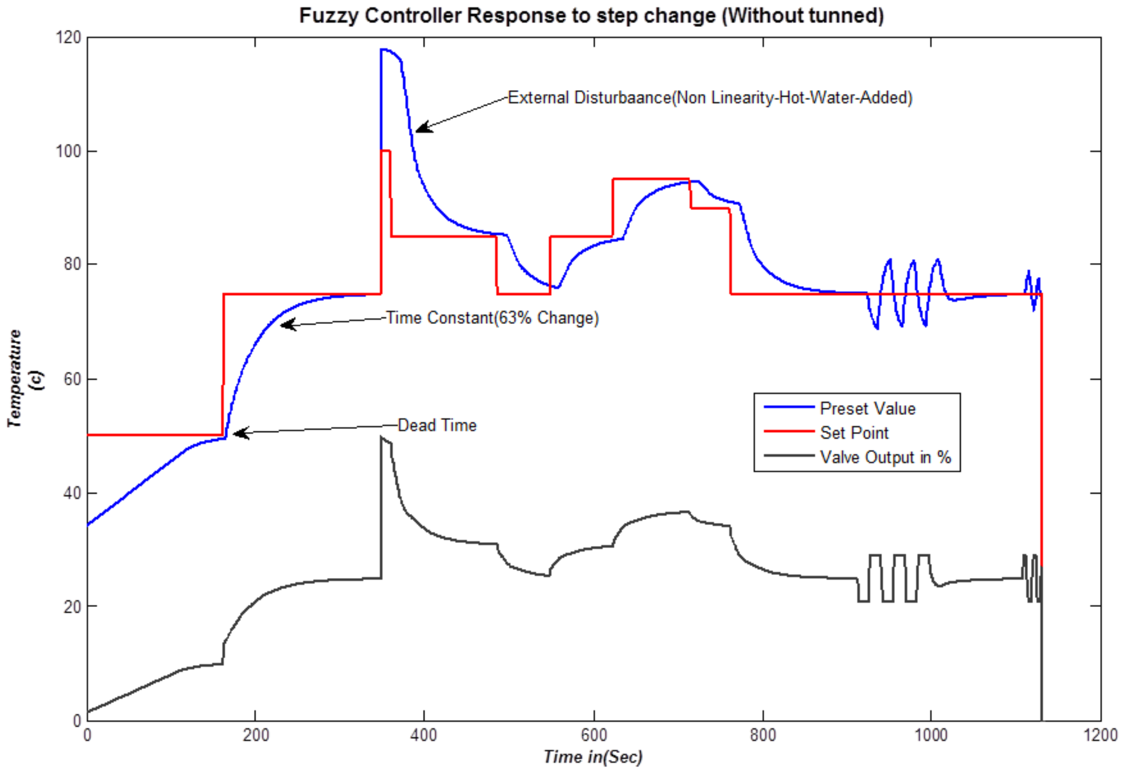


**Figure 5-2: Control Performance without Relay Test on Process with small dead time.**

| Parameter | Value | Scaling Applied | Value |
|---|---|---|---|
| **SP** | 50 - 200 °C | Error | 2.00 |
| **PV** | 50 - 200 °C | Delta Error | 0.20 |
| **OUTPUT** | 0 - 100 % | Output | 0.20 |
| **MODE** | AUTO /AUTO | | |
| | | | |

**Table 5-2: Control Performance without Relay Test on Process with small dead time.**

### Discussion (Case 2):

Now in case 2 the mode of machine is changed, this time machine has feeded the program recipe to take water from Condensated water line under that circumstances we have warm water and the amount heat required to be added in to the process is now reduced this results in smaller time constant and dead time typically < 4 sec approximately.

Under these constraints and external disturbances the controller preform satisfactory Fig 5-2 with scaling applied based on assumption and process knowledge see Table 5-2.

## 5.3 Control Performance with Self-tuning & large dead times (8-10 sec)

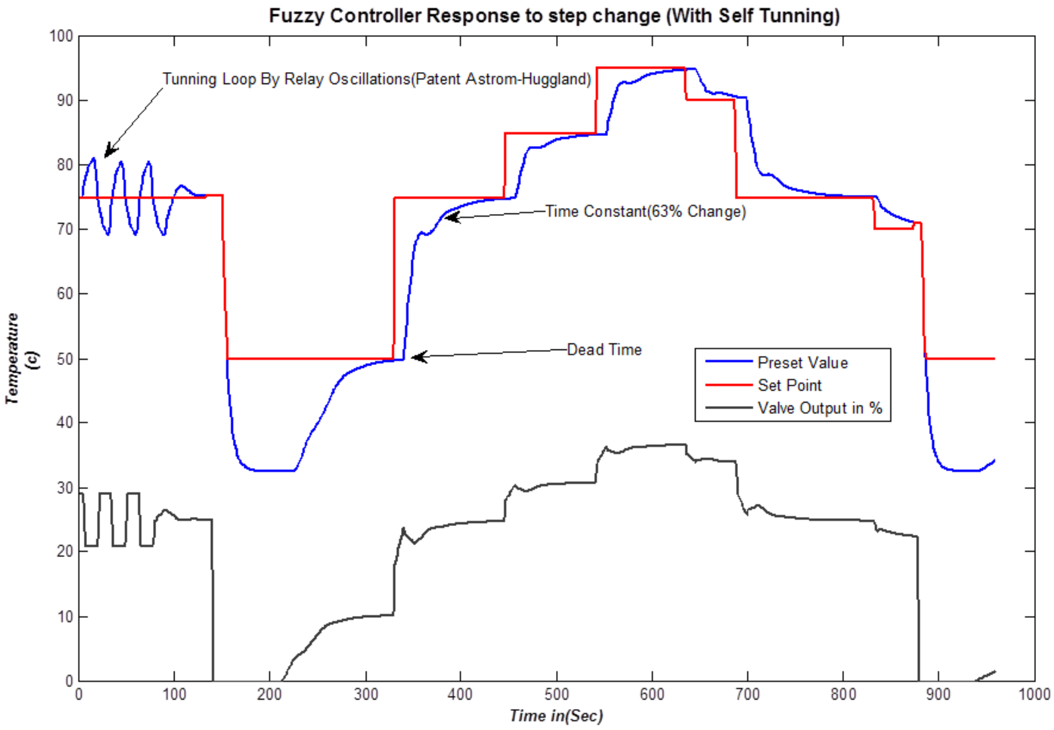


**Figure 5-3:Control Performance with large dead time with tuning algorithm Active.**

| Parameter | Value | Scaling Applied | Value | Process Dynamics | Captured |
|---|---|---|---|---|---|
| **SP** | 50 - 200 °C | Error | 4.60 | Ultimate gain | 1.58 |
| **PV** | 50 - 200 °C | Delta Error | 0.40 | Ultimate period | 29.00 sec. |
| **OUTPUT** | 0 - 100 % | Output | 0.58 | Process dead time | 9.40 sec |
| **MODE** | AUTO /AUTO | | | Process gain | 1.50 |

**Table 5-3: Control Performance with Relay Test on Process with large dead time.**

## Discussion:

Now the control performance is checked randomly for both cases with online Model Free self-tuning (Relay Test) algorithm patented (T.Hagglund, 1995) with slight improvement suggested by (Yu-Chang Cheng, and Cheng-Ching Yu, 2000). With relay test initiated for 3 periodic cycles see Fig 5-3 for x-axis scale 20-100(Relay test in process),we calculate ultimate gain and ultimate period using programmed equations function blocks and on basis of these calculated gains tuning recommendation in terms of scaling applied on to Fuzzy logic controller input and output see Table 5-3.

Based on above scaling applied the controller response over extremely high dead time improves significantly see Fig 5-4.The system further maintain stability when suddenly system in take fresh water from outside.

## 5.4 Control Performance with self-tuning & small dead times

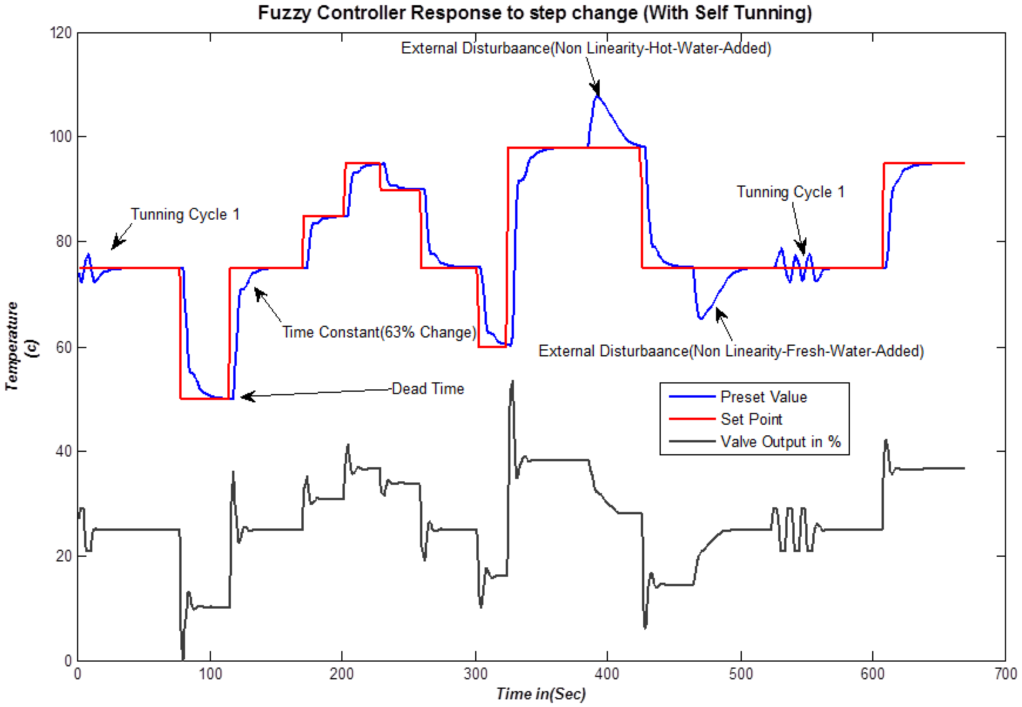


**Figure 5-4: Control Performance with Small dead time with tuning algorithm Active.**

| Parameter | Value | Scaling Applied | Value | Process Dynamics | Captured |
|---|---|---|---|---|---|
| **SP** | 50 - 200 °C | Error | 2.18 | Ultimate gain | 4.42 |
| **PV** | 50 - 200 °C | Delta Error | 0.40 | Ultimate period | 10.00 sec. |
| **OUTPUT** | 0 - 100 % | Output | 1.15 | Process dead time | 1.30 sec |
| **MODE** | AUTO /AUTO | | | Process gain | 1.80 |
| | | | | Process Time Constant | 12.70 |

**Table 5-4: Control Performance with Relay Test on process with small dead time.**

### Discussion:

This is very rare case when the machine is program to take Condensated (Hot) water only so results in shorter dead time, and with the self-tuning algorithm enabled the controller tune itself at the beginning of program change see Fig 5-4 at tuning cycle 1.With the shorter dead time the controller performance improving as compare to process with Case 1 larger dead time.

## 5.5 Programming Model Free Tuning Algorithm Automatic Self execution

To prevent the self-tuning relay test initiated uncontrolled or when there is no need, Two interlocks are programmed.

1ST = Initiated only when PV exceeds +5 % from current SP& -5% decline from current SP for more than 20 seconds.2nd = Relay test executed with step size 5% magnitude for system with small time constants and 3% for system with large time constant.To make relay test immune to noise a safety Hysteresis function block introduces with 0.50 % value. The above two interlocks and parameters estimated from human knowledge and are designed after several trial demo test on actual plant.

## 5.6 Control Performance with self –tuning & variable deadtime

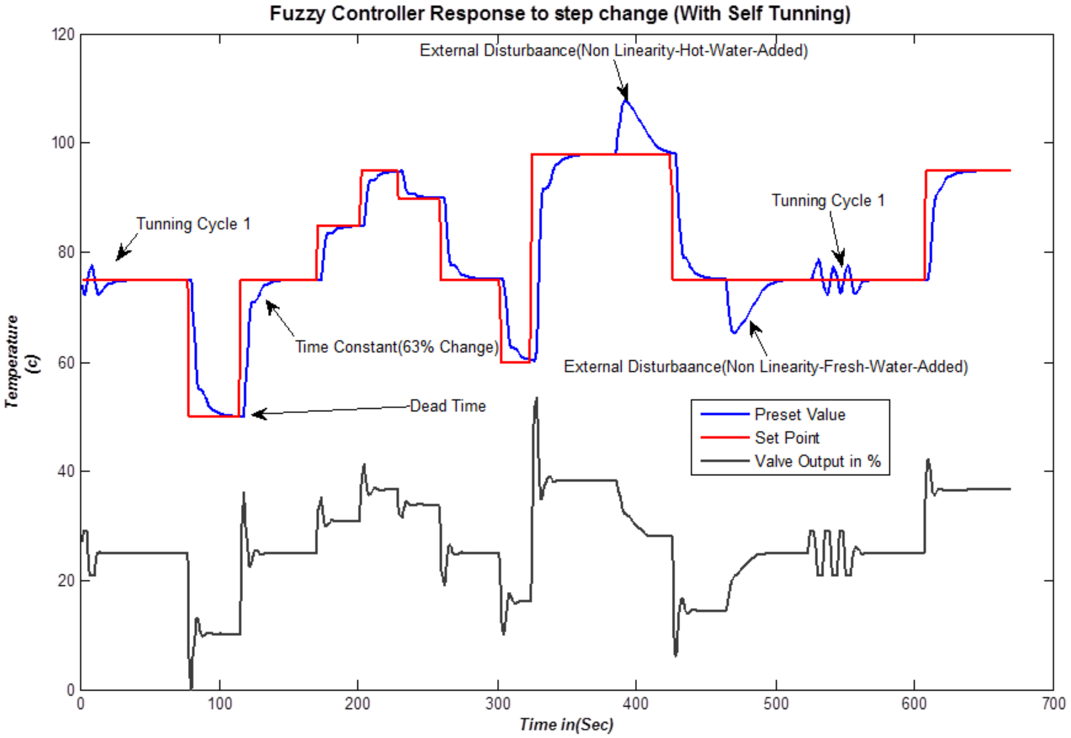


**Figure 5-5: Control Performance with variable time delays with tuning algorithm active.**

### Discussion:

Now finally the machine is programmed to take water randomly from Condensated (Hot)-Case 1, Recycled R.O and K.D.A water line. With different time delays observed randomly see figure 5-5, the controller perform outstanding and meets the regulation problem requirement of less than 5 % overshoot, sharper rise time and stable loop.

## 5.7 Control performance Self Tuned PID VS FLC with various disturbances & non-linearity's

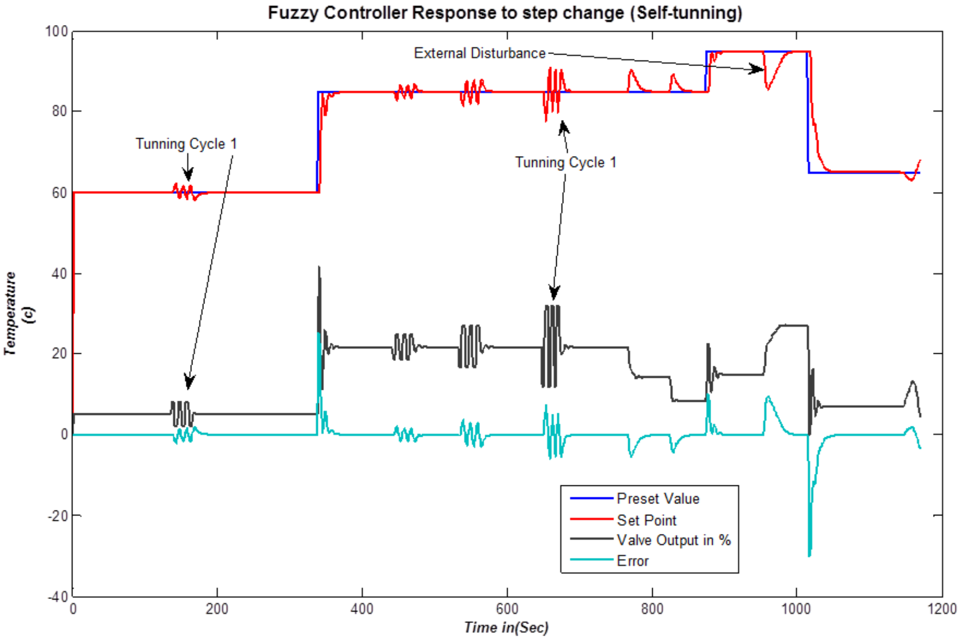


**Figure 5-6: Control Performance of FLC with variable time delays, Disturbances with tuning algorithm Active.**

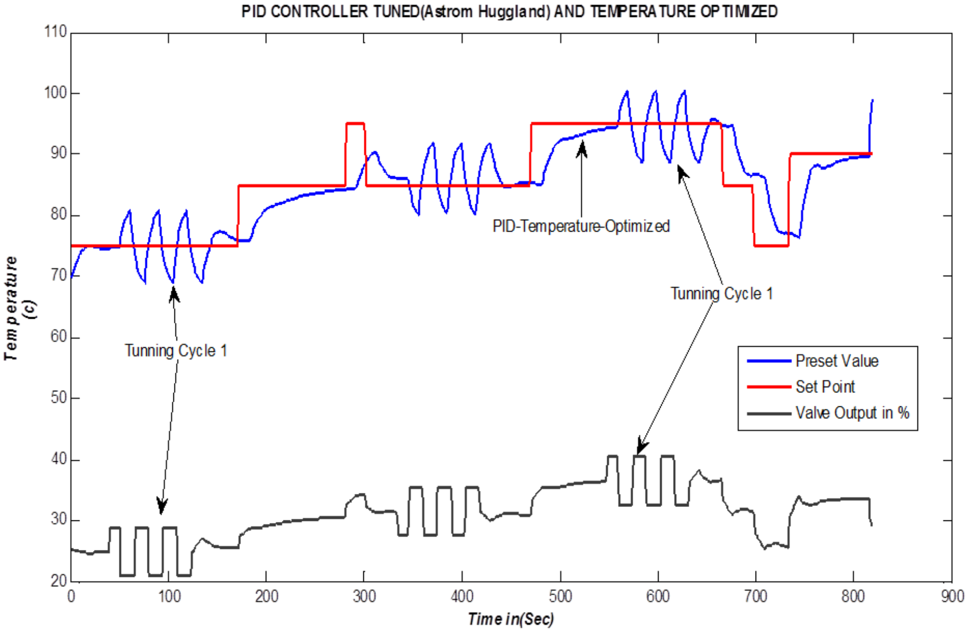


**Figure 5-7: Control Performance of PID with variable time delays, Disturbances with tuning algorithm Active.**

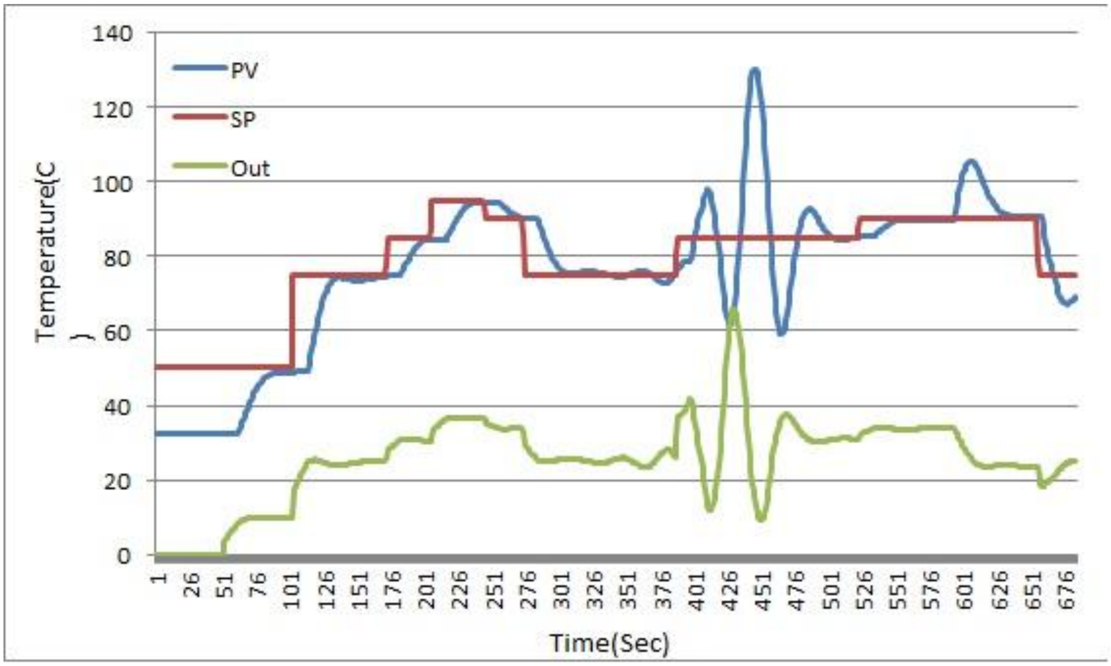


**Figure 5-8: Control Performance of PID with variable time delays, Disturbances with tuning algorithm Active.**

## Discussion (Fig 5-6, 5-7, 5-8):

Finally a comparative comparison between optimized self-tuning FLC controllers Fig-5-6 with PID Fig 5-7,Fig 5-8.The results outclasses the classical controller widely used in commercial industries. On a continuous long run with automatic water selection as discussed in case 1 and case 2 the PID controller is unstable and disturb at some point Fig 5-8 whereas FLC runs smooth and under control.

## 5.8 Conclusion

We come to know this truth by several demonstration demos, trials & test of commercial controllers and due to control engineering background as many of the industrial control loops based on classical PID with several self-tuning algorithm implemented and running for example Gain Scheduling, Relay Test, Ziegler Nichols have these loops instability exist which is never ever examined and un noticed for long time.

## 5.9 Future Research Direction

We observed the improved performance by fuzzy logic controller as compare to conventional PID process controllers commonly used in industries. We are limited by predefined module and blocks offer by Emerson software development tool and limited in hardware modification like number off inputs,outputs,rules by time .It will be suggested to future control and design engineers to develop and design an ASIC(Application specific integrated circuit) on FPGA(Field Programmable Gate Array) .With knowledge and background of control engineering and expert level of RTL(Register Transfer Language)programming future engineer can easily design a process controller with more rules ,more no of inputs and advanced and improved computationally demanded tuning algorithms. Solution design on FPGA will be cost 80% reduction in overall design budget but at the cost of time and strong Research and development.

# Chapter 6

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