Model based Analysis of Temperature Process under Various Control Strategies

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Abstract

This paper analyze the temperature process in an empirical model. From the empirical model the system behavior is determined by transfer function and the basic controller strategies Ziegler-Nichols & Cohen-Coon method are implemented in it. With these tuning methods the best control strategies are obtained at the final stage by interfacing the system with NI-myRIO kit.

Keywords: PID - ZN II, CC, System Identifications

I. Introduction

Nowadays, Proportional-Integral-Derivative (PID) control is the most common control algorithm used in industry and it has been universally accepted in industrial control purposes. The PID controllers plays a vital role in industrial applications for its robust performance in a wide range of operating conditions and for its functional simplicity, which allows the engineer to operate them in a simpler and easier way. As the name suggests, PID algorithm comprises three basic coefficients: proportional, integral and derivative, which are varied accordingly to get optimal response. Closed loop systems, the theory of classical PID and the effects of tuning a closed loop control system are discussed in this paper. To make the control loops work accurately, the PID loop must be tuned. The entire idea of this algorithm lies in manipulating the error which is the difference that occurs between the Process Variable and Set point [1].

The Ziegler - Nichols tuning method is a heuristic method of tuning a PID controller. It was developed by John G. Ziegler and Nathaniel B. Nichols. The Ziegler-Nichols tuning creates a "1/4 wave decay" which is an acceptable result for certain conditions, but not optimal for all the applications. This results in a loop that overshoots its set point after the disturbance or a set point change in it. The response is a semi oscillatory function, with a marginal loop and it can withstand for small changes in process controller [2].

The Cohen-Coon tuning rules are next to the Ziegler-Nichols tuning rules. Cohen and Coon published the tuning method in 1953, which is eleven years later than the Ziegler-Nichols tuning rule. The Cohen-Coon tuning rule is widely applied, where the dead time is less than twice that of the time constant. The Cohen-Coon rule is used to obtain a quarter - amplitude damping response. Even though quarter - amplitude damping type tuning provides very fast disturbance rejection, it tends to be very oscillatory and frequently interacts with the other tuned loops present in the system. Quarter - amplitude damping type tuning also makes the loop to be unstable if the process gain or dead time increases twice of its value. However, this can be minimized by reducing the controller gain into half of its value obtained [3].

Skogestad's method principle is similar to the dead-time compensation and approximation cannot be achieved in time delay. With dead-time compensation, Skogestad's method gives good set point tracking and also formula for the integral time Ti can be obtained, through which slow disturbance compensation can be reduced. Other controller design methods which are based on pole-zero cancellations have a chance for the occurrence of slow disturbance compensation if the cancelled pole is close to zero (corresponding to cancellation of a large process time constant using a large Ti)[4].

In this paper, the important and proposed work is to interface the temperature trainer kit with a virtual instrumentation workbench LabVIEW, via myRIO kit. The process variable is obtained from the temperature sensor and sent to the software via NI-myRIO. The obtained variable is processed with the three basic control strategies namely ZN, C-C, SKOGESTAD. Even these had been implemented earlier by many researchers, our proposed work is to calculate its efficiency in virtual software or via virtual instrumentation workbench.

II. TEMPERATURE PROCESS

Temperature control is important in heating processes as it can make the materials to react accordingly to its physical properties. Proportional -Integral - Derivative (PID) controllers are the workhorses of many industrial controllers, the frequently used method is Ziegler Nichols, also called as ZN. The need for improved performance of the process has led to the development of robust and optimal controllers. The objective of the work is to maintain the temperature of water in the liquid tank in a desired value. System identification of this temperature process is done by empirical method, which is a nonlinear response and it approximated to be a (First Order plus Dead Time) FOPDT model. In this paper, the major process is to maintain the temperature in the desired value with a help of basic controller strategies and a solid state relay.

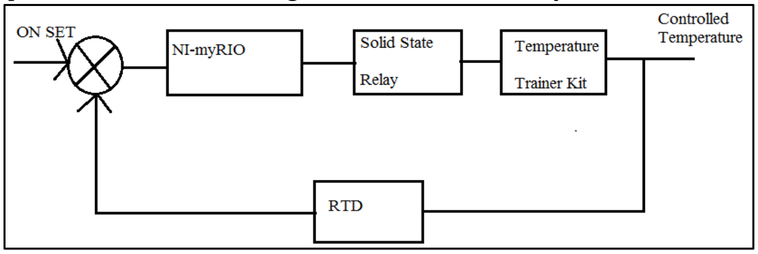

Fig. 1.1: Block Diagram of Temperature Process

The real time temperature values are obtained through RTD sensor and fed to NI-myRIO were the signals are manipulated in the virtual instrument and the control output is fed to the solid state relay to turn on the heater placed in the temperature trainer kit. In the process of controlling, the water is heated by a heater which is controlled by the controller.

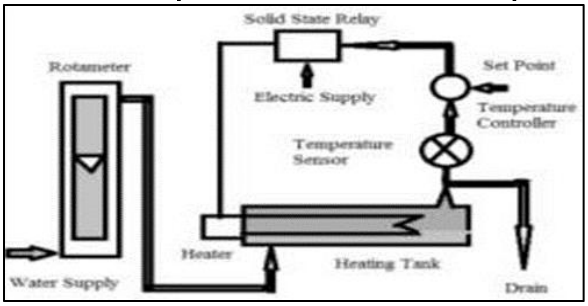

Fig. 1.2: Experimental Setup for Temperature Process

III. SYSTEM IDENTIFICATION

Empirical modeling is a useful approach for the analysis of different problems across numerous areas/fields. This type of modeling is particularly used when parametric models cannot be constructed due to some physical constraints. Based on different methodologies and approaches, empirical modeling allows the analyst to obtain an initial understanding of the relationships that exist among the different variables that belong to a particular system or process. In some cases, the results from empirical models can be used in order to make decisions about control variables, with the intent of resolving a given problem in the real-life applications. The most commonly used model to describe the dynamics of the industrial temperature process is a general First Order plus Time Delay Process (FOPTD). And the FOPTD model structure is given in equation as,

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

Where, t_d – Time delay, K – Process gain, τ - Time constant.

IV. CONTROLLER DESIGN

In the general, the controller set point (r) and process variable (y) is fed to the comparator and the variable (e) represents the tracking error. This error signal (e) is fed to the PID controller, and the controller computes both the derivative and the integral coefficient of this error signal with respect to time. The control signal (u) of the process is equal to the proportional gain (K_p) times the magnitude of the error plus the integral gain (K_i) times the integral of the error plus the derivative gain (K_d) times the derivative of the error.

This control signal (u) is fed to the plant and the controller output (y) is obtained. The controller output (y) is given as s feedback signal to compare with the reference signal and to find the error signal (e). The controller considers this error signal and computes the control input. The general relation for obtaining the proportional gain, integral gain and derivative gain is given below

$$K_p + \frac{K_i}{s} + K_d s = \frac{K_d s^2 + K_p s + K_i}{s}$$

Where K_p = proportional gain, K_i = integral gain, and K_d = derivative gain.

A. Ziegler-Nichols Method

It is performed by setting the *I* (integral) and *D* (derivative) gain to be zero. The proportional gain K_p is then increased (from zero) until it reaches the ultimate gain K_u, at which the output of the control loop has a stable and consistent oscillations. K_u and the oscillation period T_u are used to set the P, I, and D gains depending on the type of controller used:

Table - 4.1
Zn Controller Tunning

Controller	*K*	*Ti*	*Td*	*kp*
PID	*98.1*	*4.686*	*1.1715*	*58.86*

B. Cohen-Coon Method

By performing a step test at initial steady state conditions, the parameters of a FOPTD (first order plus time delay) model are obtained. This process is carried out to until the process settles at a new steady state and the process parameters t1, τ, τ_{del}, K, r are calculated by,

$$t1 = t2 - \frac{(\ln(2))t3}{1-\ln(2)}$$

$$T = t3 - t1$$

$$T = t1 - t0$$

$$K = \frac{B}{A}$$

$$r = \frac{\tau_{del}}{\tau}$$

Table - 3.2
Cohen-Coon Tunning

Controller	*K*	*Ti*	*Td*	*Kp*
PID	98.1	7.418	1.10	66.20

V. PERFORMANCE INDEX

The objective function considered is based on the error performance criterion. The performance of a controller is best evaluated in terms of error criterion. Such criterions are available in the proposed work and the controller performance is evaluated in terms of Integral of Absolute Errors (IAE) criterion, given by

$$I_{IAE} = \int_0^T |e(t)| dt$$

The IAE weighs the error with time and hence emphasizes the error values over the range of 0 to T where T is the expected settling time.

VI. RESULTS & COMPARISON

The tuned values through the traditional as well as the proposed techniques are analyzed for their responses to a unit step input, with the help of simulation and the real time application for the liquid heating tank is made. A tabulation of the time domain specifications comparison and the performance index comparison for the obtained models with the designed controllers is represented.

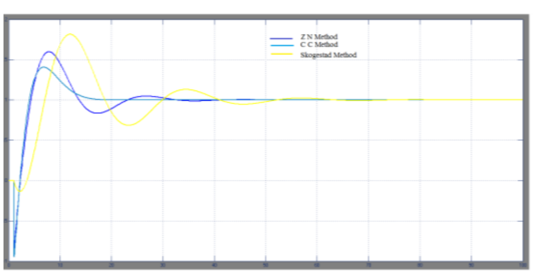

Fig. 6.1: MATLAB Simulated Output

It is clear from the responses that the C-C based controller has the advantage of a better closed loop time constant, which enables the controller to act faster with a minimum overshoot and settling time. The response of Skogestad's controller is unstable than the CC based controller. The time domain specification comparison is done for the C-C and Skogestad's based controllers for the responses obtained and it is tabulated below.

Table - 6.1
Time Domain Spefication Comparison

	Pid ZN-II	*Skogestad*	*CC-Method*
Rise time (seconds)	*3.45*	*30*	*6.285*
Peak time (seconds)	*7.8*	-	*6.8*
Overshoot	*0.6*	-	*0.4*
Settling time (seconds)	48.5	*1009*	*2.7*

VII. CONCLUSION

The developed controller tuning for various set points can be suitably tracked by providing a program which can allow the system to choose that value based on the set point selected. The various results presented prove that C-C tuned PID settings are better than the Skogestad's tuned values. The simulation responses for the models validated reflect the effectiveness of the C-C based controller in terms of time domain specifications. The performance index under the various error criterions for the proposed controller is always less than the tuned controller. In addition to it, the real time responses confirm the validity of the proposed C-C based tuning for the liquid heating tank system. C-C presents multiple advantages to a designer by operating with a reduced number of design methods and parameters to establish the type of the controllers, giving a possibilities of configuring the dynamic performance of the control system with ease and starting the design with a reduced amount of information about the controller, also it focuses on the performance of the control system. These features are illustrated in this work by considering the problem of designing a control system for a plant of first-order system with time delay and deriving the possible results. The future scope of the work is aimed at providing an on-line self-tuning PID controller with the proposed algorithm so as to solve complex issues in real time problems.

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