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An Auto-tuning Scheme of Pressure Control for PID Controllers

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Abstract:-In today's modern day and age the world is moving towards automation and an increase in global competition is demanding efficient ways of process control which is an important factor for any Industry. To regulate process variables like temperature, pressure, etc. the widely used controller is the Proportional Integral Derivative (PID) Controller, but this controller comes with its own set of disadvantages namely tuning of its control parameters and thus auto-tuning can be very beneficial. The optimal method to extract the peak performance of the PID controller by tuning the parameters is still an open question. In this paper, we have worked on various approaches and used tuning methods such as Ziegler Nichols Method, Modified Ziegler Nichols Method, Internal Model Control Method, and Tyreus-Luyben Method are considered while designing the algorithm in MATLAB of the PID Controllers.

Keywords: *PID Controller, Auto-tuning, Tuning Methods.*

1. Introduction

Proportional-integral-derivative (PID) controller is widely utilized in various industrial applications worldwide owing to its versatility and user-friendliness. The proportional aspect of the PID incorporates necessary relative changes according to the error and these changes are implemented in the control output. The integral element evaluates the process variable over a specific time and modifies the output by reducing the offset from the process variable [1]. The derivative element comes into the picture when there are unusual variations in the output, then the controller modifies the output by sensing the rate of change of process variables[2]. The tuning process of PID is a time-consuming and mistake-prone process. Auto-tuning in PID is used to overcome these particular shortcomings of the PID controller. An Auto-tuner is a computer program, which computes the tuning parameter with the help of various algorithms based on various plant models or plant data [3]. Auto-tuning can reduce human error and save a lot of time in the computation of controller gain making the PID controller more accurate and the tuning process less costly.

PID controller uses three parameters: proportional gain (Kp), integral time (Ti), and derivative time (Td). It is a method used to adjust the controller parameters. It is essential to get a controller with reliable performance. To achieve this, several PID tuning techniques had been devised. The best suitable method for tuning is chosen by analyzing the aspects of the method and requirements of the performance [4]. Ziegler and Nichols (Z-N) had given two empirical techniques for finding controller parameters in 1942. The Ziegler and Nichols method is a very simple method because it uses very little information for determining the controller parameters. Hence this method has several real-time applications. Ziegler Nichols method uses very little knowledge to characterize process dynamics. The formula for Z-N is implemented on the closed-loop system [5], [6]. When the closed-loop Z-N method is implemented, initially the PID controller is configured to the proportional mode by adjusting the integral gain and derivative gain to zero [4-7]. After this, the proportional gain is increased continuously until the plant reaches a state where oscillations can be sustained at which the closed-loop system becomes critically stable. This is the ultimate gain (Ku) and the corresponding period of oscillation is the ultimate time period (Tu) [8]. By the values of Ku and Tu, the measurement of the PID parameters can be done by the Z-N closed loop method formula as shown in Table 1[5], [7]. There are major problems with the Z-N method, in which very little information is used and the design method used provides systems with poor robustness and poor damping [4], [9]. Internal Mode Control (IMC) is a modern, effective, influential, and simple method for the study of system performance [10-11]. The IMC method is a simple tuning rule due to which it has many industrial users over time [6]. This method is developed keeping robustness in mind. The IMC-based tuning rule produces a controller having just one defined parameter, which is the IMC filter λ referred as a closed loop time constant [7-10]. λ is used to accomplish the tradeoff between performance and robustness [10]. Table 1 shows the values of Kp, Ti, and Td[6],[10]. In 1997, the Tyreus-Luyben tuning process was introduced [11],[12],[13]. It has similar steps to the Z-N approach until the ultimate gain and time period are attained. To improve control loop performance, various adjustments are made to the controller parameter formulas when compared to the Z-N technique [14],[15]. A system process is forced to marginal stability through the use of the Ziegler-Nichol frequency response approach, which makes it risky for delicate systems to operate[14],[16]. The modified Ziegler-Nichol method comes up with ¼ decay ratio oscillations. In this method, initially, the proportional gain is set low with the Ti being infinity and the Td being 0 [14]. The proportional gain continues to rise until the $(1/4)^{th}$ decay ratio is attained in the subsequent output response.[14]. So to obtain the reduced overshoot in response, Ziegler Nichols came up with changes in their basic PID closed-loop tuning strategy which is known as the modified Ziegler-Nicholas method [14],[21]. Modified Ziegler-Nichols tuning method formulas are given in Table 1.

Table 1: Comparison of Closed Loop PID Tuning Form

Tuning Method	K_p	T_i	T_d
Ziegler Nichols	$0.6K_u$	$0.5T_u$	$0.125T_u$
Internal Mode Control	$\frac{2\frac{\tau_p}{t_d}+1}{K(2\frac{\tau}{t_d}+1)}$	$\frac{t_d}{2}+\tau_p$	$\frac{\tau_p}{2\frac{\tau_p}{t_d}+1}$
Tyreus-Luyben	$0.45K_u$	$2.2T_u$	$T_u/6.3$
Modified Z-N	$0.33K_u$	$T_u/2$	$T_u/3$

Automatic tuning of PID controllers has been studied in-depth in the vast literature and it is an ingrained feature in industrial PID controllers. However, there is still a lot of research being done in order to increase the resilience and usability of current autotuners. The fundamental characteristic of autotuners is some experimental approach by which plant information is gathered in order to compute the controller settings. The development of auto-tuning features in PID controllers has reduced the time needed to commission control systems and made the process of control system optimization much easier. [17], [19],[20].

2. Objectives

The transfer function of our pressure-controlling system is a First Order Plus Dead Time (FOPDT). The transfer function (Gp(s)) on which we performed calculations is the following.

$$G_p(s) = \frac{9.2}{85.5s+1}e^{-1.6s}$$

Here 85.5 is the time constant and 1.6 is the time delay. For the expected algorithm the value of parameters is unknown. The control objective is to implement the algorithm in systems such as steam delivery systems, LPG filling stations etc.

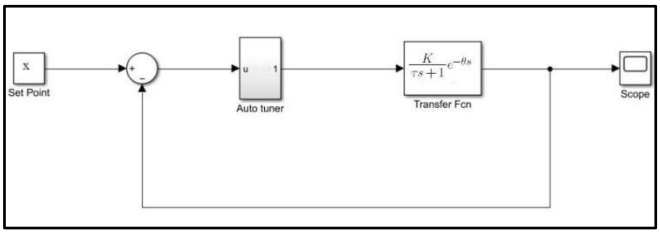

Fig. 1 Block diagram of the proposed auto-tuning scheme

MATLAB model of the auto-tuning scheme consists of an autotuner which incorporates the algorithm. The operation started off by taking a set point as 3 bar based on the real life kit, which is considered as the input for the system. The autotuner consists of the parameters for it to get the desired results. The response of the system is obtained in the form of graphs which helps us get the response parameters.

3. Methods

The inaccuracies related to existing tuning methods inspired authors to develop a new Auto-tuning Algorithm. To develop the current algorithm we calculated the values of Kp, Ki &Kd using the above-mentioned methods and performed various arithmetic operations to test different sets of parameter values to extract the most accurate results. Eight different sets of results is calculated:

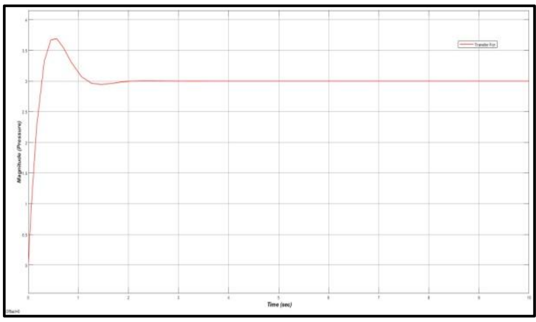

Fig. 2 Parameter value Output - Set I

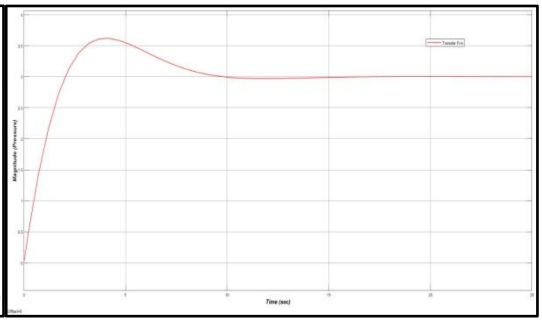

Fig. 3 Parameter value Output - Set II

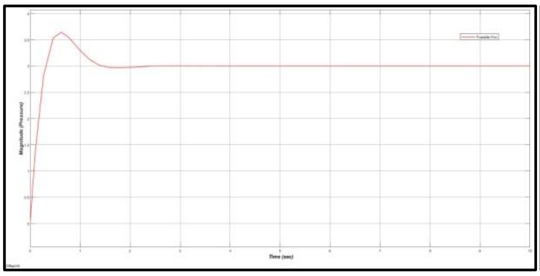

Fig. 4 Parameter value Output - Set III

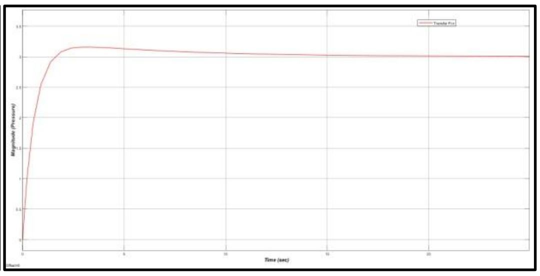

Fig. 5 Parameter value Output - Set IV

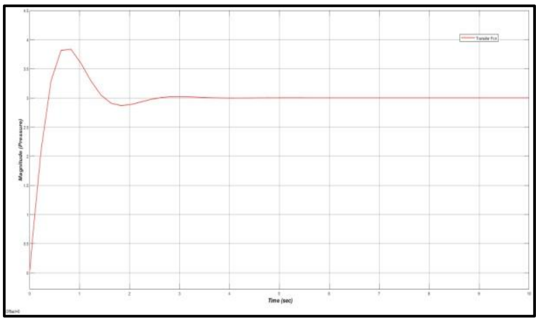

Fig. 6 Parameter value Output - Set V

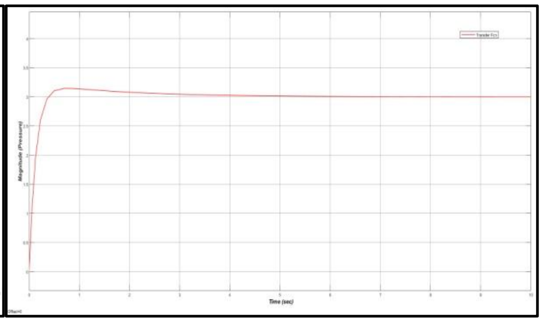

Fig. 7 Parameter value Output - Set VI

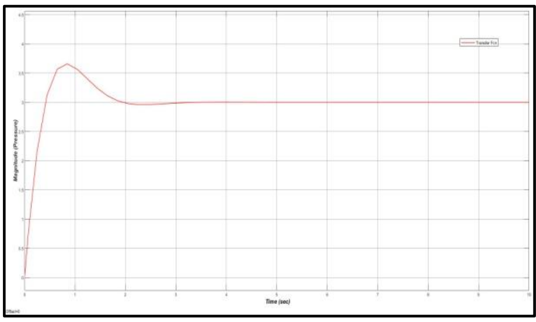

Fig. 8 Parameter value Output - Set VII

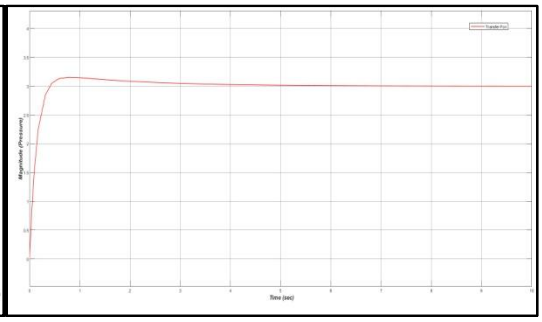

Fig. 9 Parameter value Output - Set VIII

- Set I: Maximum values of all the control parameters calculated using the mentioned Tuning methods were used to check the accuracy of those parameters together.
- Set II: Minimum values of all the control parameters calculated using the mentioned Tuning methods were used to check the accuracy of those parameters together.
- Set III: All 4 different values of K_p,K_i&Kd each were arranged in descending order, and the mean of the first two values are calculated and the results were checked.
- Set IV: All 4 different values of K_p,K_i&Kd each were arranged in descending order, and the mean of the last two values are calculated and the results were checked.
- Set V: From all the different values of K_p,K_i&K_d, the mean of one maximum value and one minimum value is calculated from the extreme values available. These calculated results were put into the simulation model and the outputs were checked.
- Set VI: From all the different values of K_p,K_i&K_d, the mean of one maximum value and one minimum value is calculated from the mean values available. These calculated results were put into the simulation model and the outputs were checked.
- Set VII: Of all the different values of K_p,K_i&$K_d$obtained, the mean of all these values is calculated. These calculated results were put into the simulation model and the outputs were checked.
- Set VIII: From all the different values of K_p,K_i&K_d calculated thus far, the $K_p$andK_i values from set number VI and the value of K_d from set number 5 are put in the simulation model and the outputs were checked.

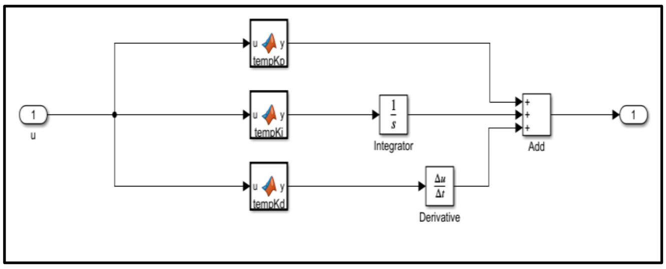

Fig. 10 Block diagram of the proposed auto-tuning algorithm

From the above set values Set VI came out to be most accurate. Thus the algorithm was constructed on furthermore enhancement of those parameter values giving the desired results.

4. Results

The simulations were performed in MATLAB/Simulink for step changes in the set point and in the disturbance. The response for the best outcome is shown in the figure. The overshoot from the desired algorithm came out to be 8.2%, the settling time is roughly 10 sec with the offset being almost negligible. These results can be improved according to application. The result presented in fig.10 shows the most balanced values of overshoot, settling time and offset.

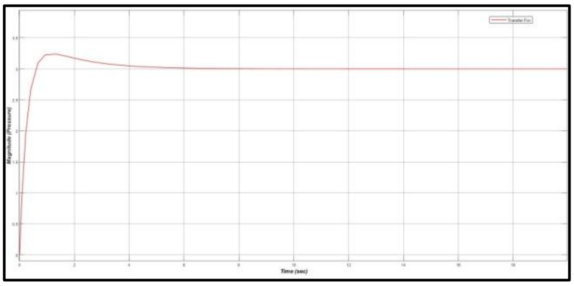

Fig. 10 Response under developed auto-tuning PID control

The results also indicate that this tuned PID controller provides optimum settling time and reduced overshoot in comparison with other tuning techniques.

5. Discussion

An auto-tuning algorithm for PID control settings is devised in this research. PID controller parameters that are optimal have been calculated. As a result, the proposed auto-tuning PID control method is best suited because it offers overall performance. The algorithm is suitable for any set point value of the above. Further work on the hardware model and generic auto-tuning of other transfer function-based models can be done.

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