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OVERVIEW OF DIFFERENT APPROACHES OF PID CONTROLLER TUNING

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ABSTARCT:
In this paper, a brief introduction of the process controllers is given followed by the detailing of principles of proportional ,integral and derivative controllers. A detailed description of PID controller is given next. An overview of methods for PID tuning is given briefly. The methods discussed are Manual tuning on-site, Ziegler-Nichols Reaction Curve Method,Ziegler-Nichols Oscillation Method and Cohen-Coon Method. These methods are compared based on their performance.

Keywords: *Proportional Integral Derivative controllers, tuning, Ziegler–Nichols Tuning Rule, S-curve*

1. INTRODUCTION

As the complexity of the industrial processes has increased, there has been a consequent increase in the number of process variables such as pressure, temperature, level, flow etc.to be controlled. Further development would be difficult without the aid of controlling devices which would automatically measure and control these process variables. Automatic control does not replace the human operator but rather supplements them.
The essence of simple automatic control is

- The state of the process is measured which is the process variable or process value (PV)and compared to the desired value which is the set point
- The controller responds in a predefined way to reduce any discrepancy between the measured value and the set point which is the error.
- The output of the controller is translated by a correcting unit to alter the state of the process and thus, the error is rectified.

The Proportional Integral Derivative (PID) controller is still the most popular in the industry of process control despite the advances in technology, control theory and the abundance of sophisticated tools, controlling more that 95% of closed-loop industrial processes. The success of PID is due to its simple structure, efficient performance and applicability to abroad class of practical control systems. When the mathematical model of the plant is not known and therefore analytical design methods cannot be used, PID controls prove to be most useful.

1. CONTROL ALGORITHMS

The pre-defined response of the controller to the error is known as the controller Algorithm. PID controller is the most commonly used controller Algorithm. PID stands for ‘proportional, integral, derivative’. These 3 terms describe the basic elements of a PID controller. Each of these performs different task and has a different effect on the functioning of the system. In a typical PID controller, these elements are driven by a combination of the system command and the feedback signal from the object that is being controlled (ie.plant). Their outputs are added together to form the system output.

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2.1. ***The proportional Controller***

The proportional term produces an output value that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant *Kp*, called the proportional gain constant. If the proportional gain is too high, the system can become unstable. If the proportional gain is too low, the control action may be too small when responding to system disturbances. Tuning theory and industrial practice indicate that the proportional term should contribute the bulk of the output change.

The proportional term is given by:

$$P_{\text{out}} = K_p e(t)$$

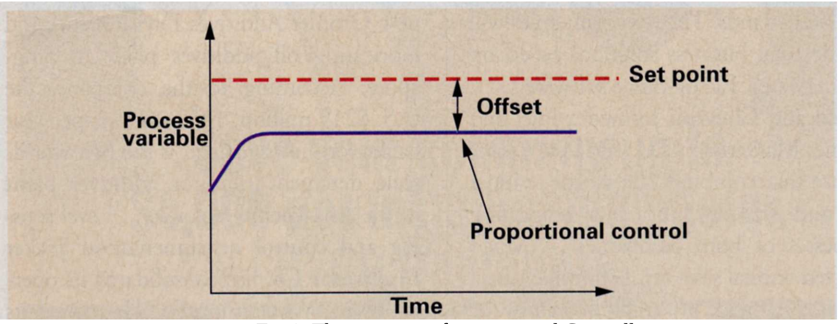

Fig 1: The response of proportional Controller

2.1.1. *Offset*

Offset, also called *droop*, is deviation that remains after a process has stabilized. Offset is an inherent characteristic of the proportional mode of control. In other words, the proportional mode of control will not necessarily return a controlled variable to its set point. Droop may be mitigated by adding a compensating *bias* term (setting the set point above the true desired value), or corrected by adding an integral term.

2.2. ***The Integral Controller***

The integral in a PID controller is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain and added to the controller output. The integral term accelerates the movement of the process towards set point and eliminates the residual steady-state error that occurs with a pure proportional controller. However, since the integral term responds to accumulated errors from the past, it can cause the present value to overshoot the set point value.

The integral term is given by:

$$I_{\text{out}} = K_i \int_0^t e(\tau)\, d\tau$$

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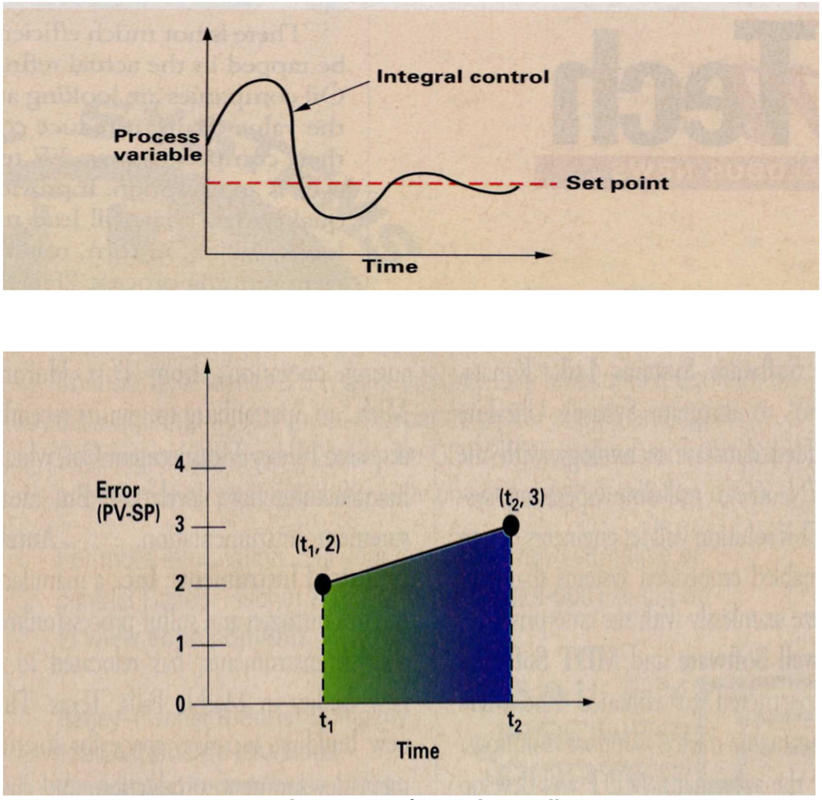

Fig 2: The response of integral Controller

2.3. *The Derivative Controller*

Derivative control is used to reduce the magnitude of the overshoot produced by the integral component and improve the combined controller-process stability. However, the derivative term slows the transient response of the controller.

The derivative term is given by:

$$D_{\text{out}} = K_d \frac{d}{dt} e(t)$$

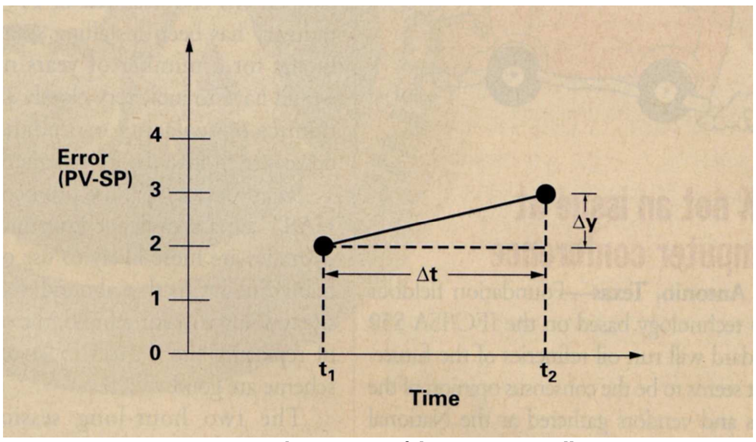

Fig 3: The response of derivative Controller

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2. PID CONTROLLERS

A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs.
Defining $u(t)$ as the controller output, the final form of the PID algorithm is:

$$\mathrm{u}(\mathbf{t}) = \mathrm{MV}(\mathrm{t}) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{d}{dt} e(t)$$

where
K_p: Proportional gain, a tuning parameter
K_i: Integral gain, a tuning parameter
K_d: Derivative gain, a tuning parameter
e: Error = $SP - PV$
t: Time or instantaneous time (the present)

3.1 *Laplace form of the PID controller*

PID controller in Laplace transform form:

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

Having the PID controller written in Laplace form and having the transfer function of the controlled system makes it easy to determine the closed-loop transfer function of the system.

3.2 *PID Pole Zero Cancellation*

The PID equation can be written in this following form:

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

When this form is used it is easy to determine the closed loop transfer function.

$$H(s) = \frac{1}{s^2 + 2\zeta\omega_0 s + \omega_0^2}$$

If, $\dfrac{K_i}{K_d} = \omega_0^2$, $\dfrac{K_p}{K_d} = 2\zeta\omega_0$ then,

$$G(s)H(s) = \frac{K_d}{s}$$

This can be very useful to remove unstable poles.

3. PID CONTROLLER TUNING

Tuning a control loop is the adjustment of its control parameters (gain/proportional band, integral gain/reset, derivative gain/rate) to the optimum values for the desired control response. Stability (bounded oscillation) is a basic requirement, but beyond that, different systems have different behaviour, different applications have different requirements, and requirements may conflict with each.

Each of the three mathematical control functions in PID- Proportional, Integral &Derivative is governed by a user-defined parameter. These parameters need to be adjusted to optimize the precision of control. The process of determining the values of these parameters is known as PID Tuning. The goal of good tuning is to have the fastest response possible without causing instability.

Designing and tuning a PID controller appears to be conceptually intuitive, but can be hard in practice, if multiple (and often conflicting) objectives such as short transient and high stability are to be achieved. Usually, initial designs obtained by all means need to be adjusted repeatedly through computer simulations until the closed-loop system performs or compromises as desired.

Some processes have a degree of non-linearity and so parameters that work well at full-load conditions don't work when the process is starting up from no-load; this can be corrected by gain scheduling (using different parameters in different operating regions). PID controllers often provide acceptable control using default tunings, but performance can generally be improved by careful tuning, and performance may be unacceptable with poor tuning.

There are several methods for tuning a PID loop. The most effective methods generally involve the development of some form of process model, then choosing P, I, and D based on the dynamic model parameters. Manual tuning methods can be relatively inefficient, particularly if the loops have response times on the order of minutes or longer.

The choice of method will depend largely on whether or not the loop can be taken "offline" for tuning, and the response time of the system. If the system can be taken offline, the best tuning method often involves subjecting the system to a step change in input, measuring the output as a function of time, and using this response to determine the control parameters.

Commonly used methods of tuning rules :

- Manual tuning on-site
- Ziegler-Nichols Reaction Curve Method
- Ziegler-Nichols Oscillation Method
- Cohen-Coon Method

4.1 *Manual tuning*

If the system must remain online, one tuning method is to first set integral constant K_i and derivative constant K_d values to zero. Increase the proportional constant K_p until the output of the loop oscillates, then the K_p should be set to approximately half of that value for a "quarter amplitude decay" type response. Then increase K_i until any offset is corrected in sufficient time for the process. However, too much K_i will cause instability. Finally, increase K_d, if required, until the loop is acceptably quick to reach its reference after a load disturbance. However, too much K_d will cause excessive response and overshoot. A fast PID loop tuning usually overshoots slightly to reach the setpoint more quickly; however, some systems cannot accept overshoot, in which case an *over-damped* closed-loop system is required, which will require a K_p setting significantly less than half that of the K_p setting causing oscillation.

Table1: Effects of increasing a parameter independently

Parameter	Rise time	Overshoot	Settling time	Steady-state error	Stability
K_p	Decrease	Increase	Small change	Decrease	Degrade
K_i	Decrease	Increase	Increase	Decrease significantly	Degrade
K_d	Minor decrease	Minor decrease	Minor decrease	No effect in theory	Improve if K_d small

4.2 *Ziegler–Nichols tuning method*

The most commonly used method is **Ziegler–Nichols.** In order to understand this method, the relationship of the constants Kp,K_I and K_D with the 4 major characteristic of the closed loop responses such as ***rise time, settling time, overshoot and steady state error*** of the system should be analyzed. This is shown below:

Table2: The relationship of the constants Kp,K_I and K_D with characteristic of the closed loop responses

Response	Rise Time	Overshoot	Settling Time	S-S Error
Kp	Decrease	Increase	NT	Decrease
K_I	Decrease	Increase	Increase	Eliminate
K_D	NT	Decrease	Decrease	NT

NT:No definite trend. Minor change

Typical steps for designing a PID controller are:

- Determine what characteristicsnof the system needs to be improved
- Use Kp to decrease the rise time
- Use K_D to reduce the overshoot and settling time
- Use K_I to eliminate steady state error.

This works in many cases,but to have a good starting point, a good set of initial parameters need to be found out easily and quickly. It can be done with Ziegler-Nichols tuning rule. Ziegler and Nichols proposed rules for determining values of the proportional gain K_p, integral time T_i, and derivative time T_d based on the transient response characteristics of a given plant. Such determination of the parameters of PID controllers or tuning of PID controllers can be made by engineers on-site by experiments on the plant. Such rules suggest a set of values of K_p, T_i, and T_d that will give a stable operation of the system. However, the resulting system may exhibit a large maximum overshoot in the step response, which is unacceptable. Series of fine tunings are needed until an acceptable result is obtained.

4.3.1 *Ziegler-Nichols Reaction Curve Method (for open loop system)*

The Ziegler–Nichols tuning method is a heuristic method of tuning a PID controller, that attempts to produce good values for the three PID gain parameters. Most PID tuning rules are based on the assumption that the plant can be approximated by a first-order plus time delay system whose unit-step response resemble an S-shaped curve with no overshoot. The step response is termed as the Process Reaction Curve in process. This method applies to plants with neither integrators nor dominant complex-conjugate poles, whose unit-step response resemble an S-shaped curve with no overshoot. This S-shaped curve is called the **reaction curve.** Such step response curves can be generated experimentally or from a dynamic simulation of the plant.
The S-shaped reaction curve can be characterized by two constants, delay time L and time constant T, which are determined by drawing a tangent line at the inflection point of the curve and finding the intersections of the tangent line with the time axis and the steady state level line.
For a system, if we assume the system can keep the maximum response speed all the time, then the system will take exact the time of the time constant to reach its steady-state.
Therefore, the time constant can be identified by taking the maximum slope and measuring the time period between the points where the maximum slope line crosses the initial and final response lines.

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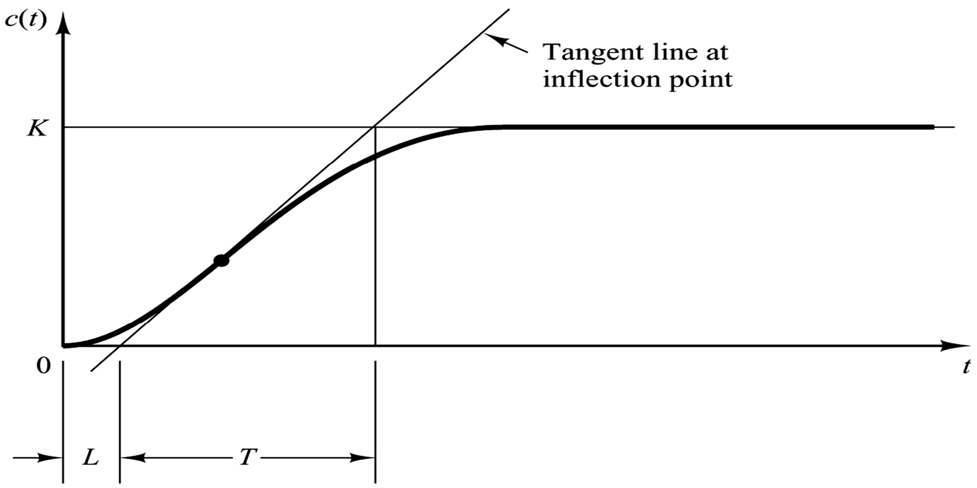

Fig 4: Reaction curve

Transfer Function:

$$\frac{C(s)}{U(s)} = \frac{Ke^{-Ls}}{Ts+1}$$

Table3: Ziegler–Nichols Tuning Rule Based on Step Response of Plant

Type of Controller	K_p	T_i	T_d
P	$\frac{T}{L}$	∞	0
PI	$0.9\frac{T}{L}$	$\frac{L}{0.3}$	0
PID	$1.2\frac{T}{L}$	$2L$	$0.5L$

4.3.2 *Ziegler-Nichols Oscillation Method (for closed loop system)*

This procedure is carried out through the following steps:

Set the true plant under proportional control, with a very small gain.

Increase the gain until the loop starts oscillating.

Note that linear oscillation is required and that it should be detected at the controller output.

Set $T_i = \infty$ and $T_d = 0$ using the proportional control action only (see Figure below).

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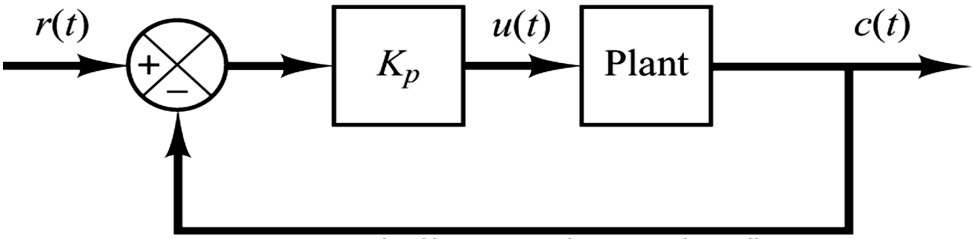

Fig 5: Closed loop system with proportional controller

Increase K_p from 0 to a critical value K_{cr} at which the output first exhibits sustained oscillations.

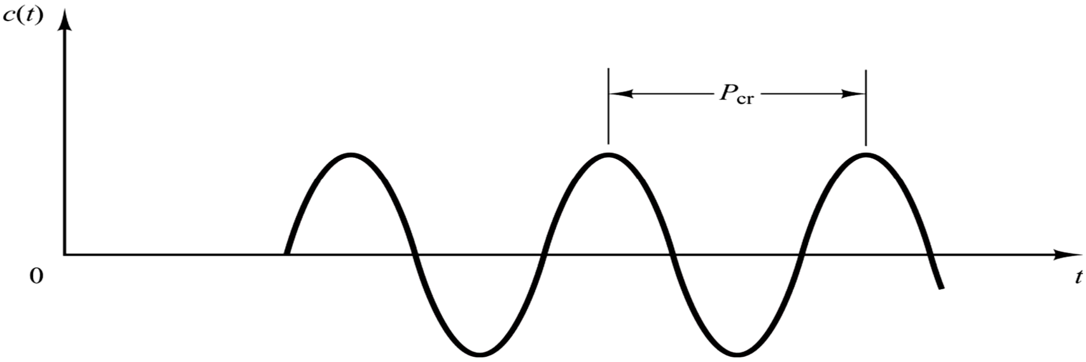

Fig 6: Sustained oscillation with period P_{cr}. (P_{cr} is measured in sec.)

Ziegler and Nichols suggested that the values of the parameters K_p , T_i, and T_d should be set according to the formula shown in Table below:

Table 4: Ziegler–Nichols Tuning Rule Based on Critical Gain K_{cr} and Critical Period P_{cr}

Type of Controller	K_p	T_i	T_d
P	$0.5K_{cr}$	∞	0
PI	$0.45K_{cr}$	$\frac{1}{1.2} P_{cr}$	0
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

4.3 *Cohen-Coon Reaction Curve Method*

Cohen and Coon carried out further studies to find controller settings which, based on the same model, lead to a weaker dependence on the ratio of delay to time constant.

Table 5: Comparison of different tuning methods

Method	Advantages	Disadvantages
Manual Tuning	Online method.	Requires experienced personnel. No math required
Ziegler–Nichols	Proven Method. Online method.	Process upset, some trial-and-error, very aggressive tuning. Used only for process control systems.
Software Tools	Consistent tuning. Online or offline method. May include valve and sensor analysis. Allow simulation before downloading. Can support Non-Steady State (NSS) Tuning.	Some cost and training involved.
Cohen-Coon	Good process models.	Offline method. Only good for first-order processes.

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References

[1] www.auma.com
[2] www.google.co.in/picturesofPID
[3] www.eetindia.com
[4] PID controller tuning: a short tutorial by JinghuaZhong.
[5] Modern control engineering by K.Ogata
[6] K.j.Astrom,R.M.Murray; Feedback system-an introduction for scientists and engineers
[7] www.mathworks.com