PID CONTROLLER : DESIGN & IMPLEMENTATION

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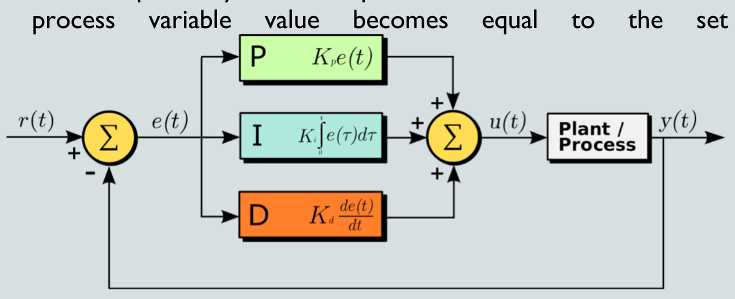
Abstract

The PID controller has been used in and dominated the process control industries for a long time as it provides the control action in terms of compensation based on present error input (proportional control), on past error(integral control) and on future error if recorded by earlier experience or some means(derivative control). A PID controller is designed and simulated using appropriate analog circuit components on multisim. The output plot for different variations of PID gain values were studied and tabulated. The hardware components and implementation of the above circuit is described. The different methodologies used for tuning the PID controller are reviewed. The various industrial applications that make use of a PID controller are listed and an example of a cascaded PID controller designed for the temperature control of an industrial heating furnace is studied.

Introduction

PID controller is a Close loop system which has feedback control system and it compares the feedback with set point and generates an error signal and according to that it adjusts the output of system. This process continues until this error gets to zero or process variable value becomes equal to the set point.

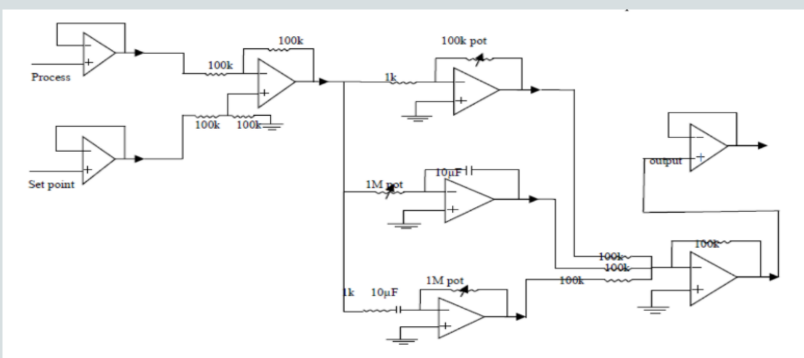


$$u(t) = K_p e(t) + K_i \int_0^t e(t')\,dt' + K_d \frac{de(t)}{dt}$$

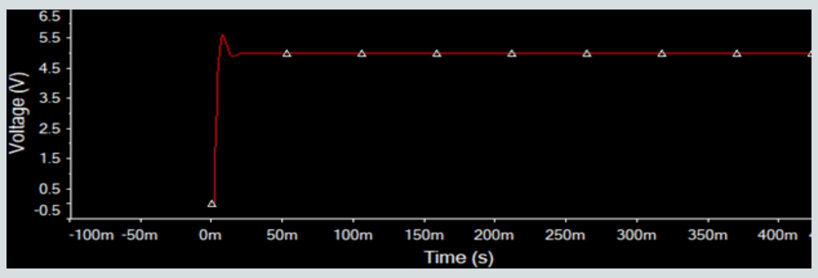
Which is then passed to the plant, for control.
Every process has unique characteristics, even when the equipment is essentially identical. The PID settings (principally the gain applied to the correction factor along with the time used in the integral and derivative calculations, termed "reset" and "rate") must be selected to suit these local differences.
Many rules have evolved over the years to address the question of how to tune a PID loop. Probably the first, and certainly the best known are the Zeigler-Nichols (ZN) rules.
Zeigler and Nichols described two methods of tuning a PID controller. These work by applying a step change to the system and observing the resulting response. The first method entails measuring the lag or delay in response and then the time is taken to reach the new output value. The second depends on establishing the period of a steady-state oscillation. In both methods, these values are then entered into a table to derive the values for gain, reset time and rate for the control system.

Simulation

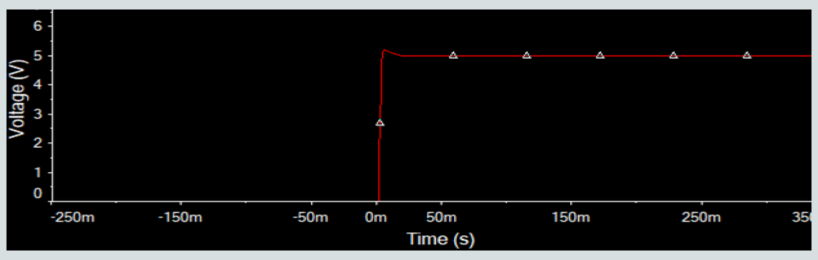
PID controller is a closed loop feedback control system. It compares the process variable (feedback variable) with set point and generates an error signal according to which it adjusts the output of system. This process continues until this error gets to zero or process variable value equals the set point value.



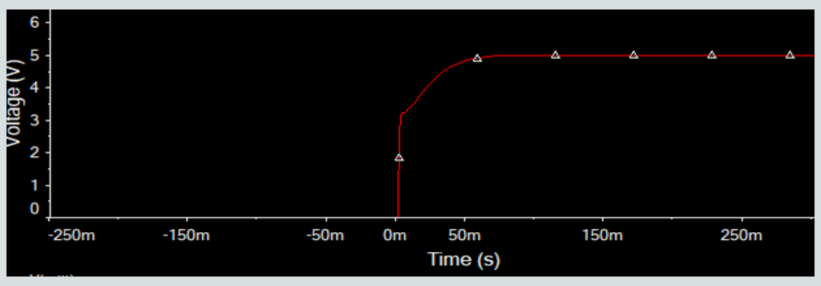
Output



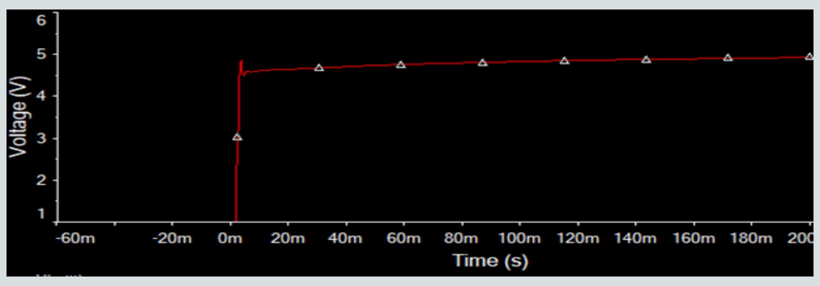
Increasing Kd



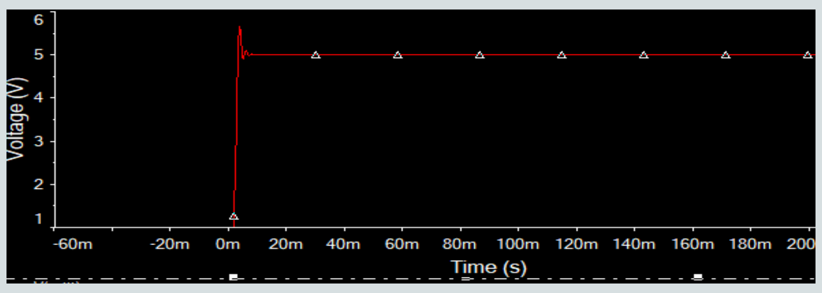
Decreasing Ki



Increasing Kp



Increasing Ki



Closed-Loop Response	Rise Time	Overshoot	Settling Time	Steady-State Error	Stability
Increasing Kp	Decrease	Increase	Small Increase	Decrease	Degrade
Increasing Ki	Small Decrease	Increase	Increase	Large Decrease	Degrade
Increasing Kd	Small Decrease	Decrease	Decrease	Minor Change	Improve

Tuning Methods

There have been several ways in which PID Controllers have been tuned. They've been divided into two main types:
Classical techniques
Computational or Optimization Techniques

- **Classical Techniques:**
  - **Ziegler - Nichols Method**
  - **Podlubny Method**
  - **Cohen Coon Method**
- **Computation and Intelligent Optimization Techniques:**
  - **Immune Algorithm**
  - **Ant Colony Optimization**
  - **Genetic Algorithm**
  - **Particle Swarm Optimization**

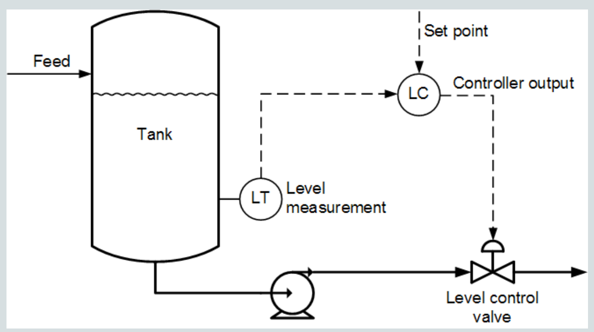
Different industrial Applications

Proportional-Integral-Derivative (PID) controllers are used in most automatic process control applications in industry today to regulate flow, temperature, pressure, level, and many other industrial process variables. Some of the existing industrial applications of PID include:

1. PID Controller for pH Neutralization Plant
Controlling pH in a neutral region is an important process as small change in input gives a huge change in the output. A PID controller is used for the pH neutralization process. pH neutralization process is more important in wastewater treatment, pharmaceuticals, food production etc.

2. PID Tuning Rule For Pressure Control Applications
In pressure control applications, servo-valves or variable displacement pumps are used to meter the flow into a supply line or a chamber with relatively constant capacity, thereby controlling its pressure under the influence of disturbances such as flows in and out of the controlled volume. The PID controller is used for the pressure control process.

3. Level Control of Tank with Flow Control using PID
The water level of the tank is measured by a level sensor. The level control valve is operated via the PID. When the level is detected to go over a certain amount, the error is fed into the PID and the valve is adjusted accordingly.



Industrial Application - Case Study

Furnace Cascade Control System

The constituents of a furnace temperature control system are shown in figure.1. T1C is the primary controller and T_2C is the secondary controller. T_1T represents the measure temperature for the exports of raw materials, and T_2T represents the measure temperature of the furnace hearth. The basic operation of the furnace temperature control system is as follows:

The output of the primary controller (T1C) is given as set point to the secondary controller (T2C).
T2C controls the fuel flow. In the heating process, material which is placed in the crucible is heated up to a specified temperature from the entrance to the exit.
From the fuel Combustion chamber to the raw material export, there are three capacity components in System temperature. They are furnace, hearth and the heated raw materials.
The main controlled variable is the temperature of raw material in the export and sub controlled variable is the temperature of the hearth in the furnace.

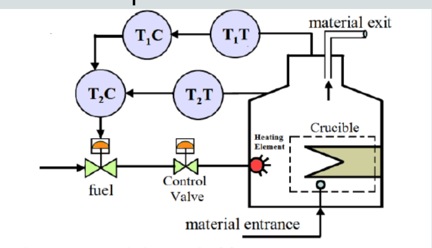


Figure.1 Cascaded control of furnace temperature system

Cascaded PID Design:

$$G_1(s) = \frac{1/90}{(s+1/30)(s+1/3)}$$

$$G_2(s) = \frac{1/10}{(s+1/10)(s+1)^2}$$

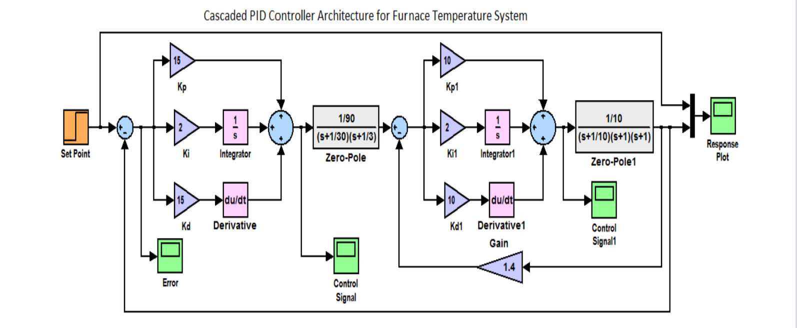


Figure.3 MATLAB/Simulink model of cascaded PID controller design for furnace temperature control

Tuning Procedure:

First published in 1942, Zeigler and Nichols described two methods of tuning a PID controller. These work by applying a step change to the system and observing the resulting response. The first method entails measuring the lag or delay in response and then the time is taken to reach the new output value. The second depends on establishing the period of a steady-state oscillation. In both methods, these values are then entered into a table to derive the values for gain, reset time and rate for the control system.
The Ziegler-Nichols rule is a heuristic PID tuning rule that attempts to produce good values for the three PID gain parameters:

Kp - the controller path gain
Ti - the controller's integrator time constant
Td - the controller's derivative time constant
given two measured feedback loop parameters derived from measurements:
the period Tu of the oscillation frequency at the stability limit
the gain margin Ku for loop stability
with the goal of achieving good regulation (disturbance rejection).

Given the magnitude and phase open-loop response curves of the plant, you can fit the assumed model in the following manner:

- The ratio of output level to input level at low frequencies determines the gain parameter K of the model.
- Observe the frequency F_u at which the phase passes through -pi radians (-180 degrees). The inverse of this frequency is the period of the oscillation, T_u.
- Observe the plant gain K_c that occurs at the critical oscillation frequency F_u. The inverse of this is the gain margin K_u.
- Apply the frequency F_u to the plant first order lag terms to solve for the model's a term.

$$a = \sqrt{K^2 \cdot K_u{}^2 - 4\,\pi \cdot F_u{}^2}$$

- Evaluate the phase shift of the lag stage by substituting F_u into the first-order lag model.

$$\phi = -\tan^{-1}\left(2\,\pi \cdot \frac{F_u}{a}\right)$$

- The rest of the 180 degrees of phase shift are assigned to the pure time delay term.

$$T = \frac{(-\pi - \phi)}{2\,\pi \cdot F_u}$$

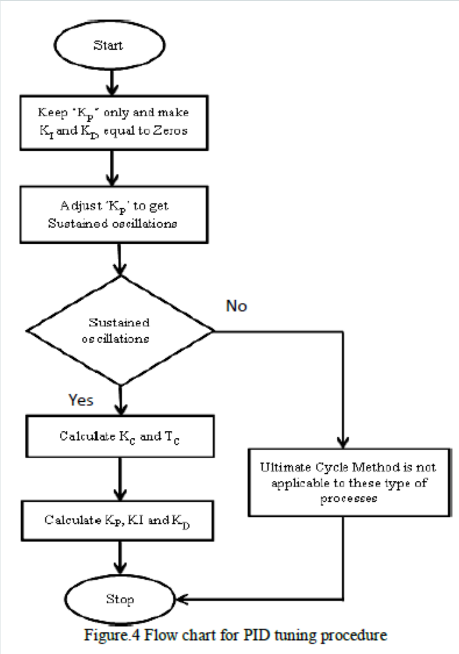


Figure.4 Flow chart for PID tuning procedure

Calculation of parameters:

Parameter	Ziegler- Nichols PID controller Tuning Formula
T_I	$T_I = \frac{T_C}{2}$
T_D	$T_D = \frac{T_C}{8}$
K_P	$K_P = 0.6 \times K_C$
K_I	$K_I = \frac{K_P}{T_I}$
K_D	$K_D = K_P \times T_D$

Results and Simulation Outcomes:

S.NO	METHOD NAME	Kp	Ti	KI	TD	KD
1	Ziegler-Nichols(ZN) tuning formula	24.24	5.238	4.627	1.3095	31.742

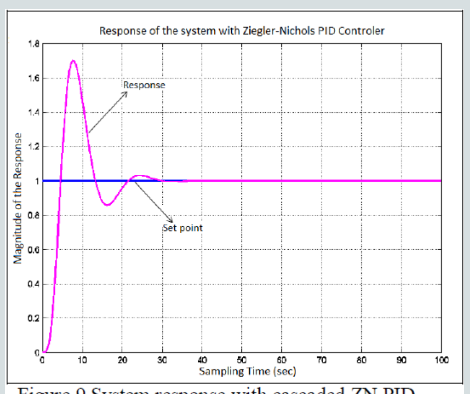


Figure.9 System response with cascaded ZN PID

Analog vs Digital PID

An analog controller is continuous and is analyzed as such. The benefits are potentially limitless resolution. An analog controller is limited by the noise of the amplifiers. The downsides of an analog controller are that they can be hard to tune, because more often then not it involves using physical components such as variable resistors and capacitors.
Digital controllers are limited by the sampling rate and by the resolution of the ADC's and DAC's. The benefits are easy tune-ability and additional control logic that can be used with programming the digital system. Digital controllers work well for most applications nowadays, it is rare to see a fully analog controller in most industries.

Conclusion

From the simulation, we can observe that error input is zero as the output tends to be equal to the set point. The graphs indicate the effect on the output of the controller by varying the gain parameters.
In the case study, we observe that the Zeigler- Nichols method is used to find the optimized output. The controller produces a response of low delay time, rise time and settling time, which is ideal, but it also has a high overshoot which may cause damage to the system. Future scope would include the usage of tuning methods like Particle Swarm Optimization and other such Genetic Algorithms which could help in reducing the overshoot and producing more efficient results.

References

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