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A thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of

MASTER OF SCIENCE

by

YOUR NAME

to the

School of xxxxxxxx Sciences

National Institute of Science Education and Research

Bhubaneswar

Date

DEDICATION (OPTIONAL)

DECLARATION

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The thesis work reported in the thesis entitled .... was carried out under my supervision, in the school of .... at NISER, Bhubaneswar, India.

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ABSTRACT

PID controllers are being widely used in industry due to their well-grounded established theory, simplicity, maintenance requirements, and ease of retuning online. In the past four decades, there are numerous papers dealing with tuning of PID controller. Designing a PID controller to meet gain and phase margin specification is a well-known design technique. If the gain and phase margin are not specified carefully then the design may not be optimum in the sense that could be large phase margin (more robust) that could give better performance. This paper studies the relationship between ISE performance index, gain margin, phase margin and compares two tuning technique, based on these three parameters. These tuning techniques are particularly useful in the context of adaptive control and auto-tuning, where the control parameters have to be calculated on-line.

In the first part, basics of various controllers, their working and importance of PID controller in reference to a practical system (thermal control system) is discussed.

In the latter part of the work, exhaustive study has been done on two different PID controller tuning techniques. A compromise between robustness and tracking performance of the system in presence of time delay is tried to achieve. Results of simulation, graph, plots, indicate the validity of the study.

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Chapter 1

Introduction

In recent years, the control system has assumed an increasingly important role in developing and advancing modern civilization and technology. Practically every aspect of our day-to-day activities is affected by some control systems. Automatic control systems are abundant in all industry sectors, such as quality control of manufactured products, automated assembly lines, machine-tool control, space technology, weapon systems, computer control, transportation systems, power systems, robotics, etc. It is essential in such industrial operations as controlling pressure, temperature, humidity, and flow in the process industries.

Recent application of modern control theory includes such non-engineering systems as biological, biomedical, control of inventory, economic and socio-economic systems.

The basic ingredients of a control system can be described by:

- Objectives of control.
- Control system components.
- Results or output.

1.1 Automatic Controllers

An automatic controller is used to compare the actual value of plant result with reference command, determines the difference, and produces a control signal that will reduce this difference to a negligible value. How the automatic controller has such a control signal is called the control action.

An industrial control system comprises an automatic controller, an actuator, a plant, and a sensor (measuring element). The controller detects the actuating error command, usually at a shallow power level, and amplifies it to a very high level. The output of the automatic controller is fed to an actuator, such as a hydraulic motor, an electric motor, or a pneumatic motor or valve (or any other sources of energy). The actuator is a power device that produces input to the plant according to the control signal so that the output signal will point to the reference input signal.

The sensor or the measuring element is a device that converts the output variable into another optimum variable, such as a displacement, pressure, or voltage, that can compare the output to the reference input command. This element is in a feedback path of the closed-loop system. The setpoint controller must be converted to reference input with the same unit as the feedback signal from the sensor element.

1.2 Classification of Industrial controllers

Industrial controllers may be classified according to their control action as:

- Two-position or on-off controllers
- Proportional controllers
- Integral controllers
- Proportional-plus-integral controllers
- Proportional-plus-derivative controllers
- Proportional-plus-integral-plus-derivative controllers

The type of controller to use must be decided depending upon the nature of the plant and the operating condition, including such consideration as safety, cost, availability, reliability, accuracy, weight, and size.

Two-position or on-off controllers:-

In a two-position control system, the actuating part has only two fixed positions, which are, in many simple cases, simply on and off. Due to its simplicity and inexpensiveness, it is very widely used in both industrial and domestic control system.

Let the output signal from the controller be u(t) and the actuating error signal be e(t). Then mathematically,

$$\mathrm{u(t) = U_1,\ for\ e(t) > 0}$$

$$\mathrm{= U_2,\ for\ e(t) < 0}$$

Where $\mathrm{U_1}$ and $\mathrm{U_2}$ are constants, and the minimum value of $\mathrm{U_2}$ is usually either zero or - U1.

1.3 Proportional Control

A proportional control system is a type of linear feedback control system. Proportional control is how most drivers control the speed of a car. If the car is at target speed and the speed increases slightly, the power is reduced slightly, or in proportion to the error (the actual versus target speed), so that the car reduces speed gradually and reaches the target point with very little, if any, "overshoot," so the result is much smoother control than on-off control. In the proportional control algorithm, the controller output is proportional to the error signal, which is the difference between the setpoint and the process variable. In other words, the output of a proportional controller is the multiplication product of the error signal and the proportional gain. This can be mathematically expressed as

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

Where

P_{out} : Output of the proportional controller

K_p : Proportional gain

$e(t)$: Instantaneous process error at time ' $t'.e(t) = SP - PV$

SP : Set point

PV : Process variable

With increase in $\mathrm{K_p}$:

- Response speed of the system increases.
- Overshoot of the closed-loop system increases.
- Steady-state error decreases.

But with a high K_p value, the closed-loop system becomes unstable.

1.4 Integral Control

In a proportional control of a plant whose transfer function doesn't possess an integrator 1/s, there is a steady-state error or offset in response to a step input. Such an offset can be eliminated if the integral controller is included in the system.

In the integral control of a plant, the control signal, the output signal from the controller, at any instant, is the area under the actuating error signal curve up to that instant. But while removing the steady-state error, it may lead to an oscillatory response of slowly decreasing amplitude or even increasing amplitude, both of which is usually undesirable [5].

1.5 Proportional-plus-integral controllers

In control engineering, a PI Controller (proportional-integral controller) is a feedback controller which drives the plant to be controlled by a weighted sum of the error (difference between the output and desired setpoint) and the integral of that value. It is a special case of the PID controller in which the derivative (D) part of the error is not used. The PI controller is mathematically denoted as:

$$\mathrm{G_c = K_p + \frac{Ki}{s}}$$

or

$$\mathrm{G_c = K_p \left(1 + \frac{1}{sT_i}\right)}$$

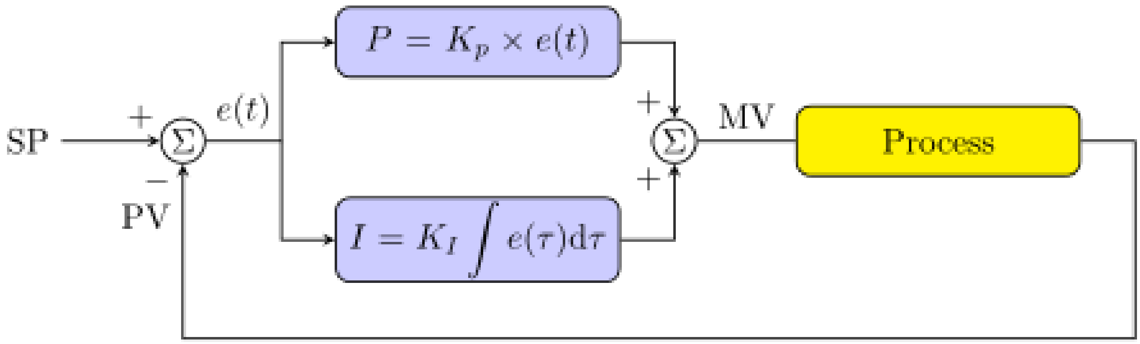

Figure 1.1: Basic block of PI Controller

Integral control action added to the proportional controller converts the original system into high order. Hence the control system may become unstable for a large value of K_p since roots of the characteristic eqn. It may have a positive real part. In this control, proportional control action tends to stabilize the system, while the integral control action tends to eliminate or reduce steady-state error in response to various inputs. As the value of T_i is increased,

- Overshoot tends to be smaller

- Speed of the response tends to be slower.

1.6 Proportional-plus-derivative controllers

Proportional-Derivative or PD control combines proportional control and derivative control in parallel. Derivative action acts on the derivative or rate of change of the control error. This provides a fast response, as opposed to the integral action, but cannot accommodate constant errors (i.e., the derivative of a constant, nonzero error is 0). Derivatives have a phase of +90 degrees leading to an anticipatory or predictive response. However, derivative control will produce large control signals in response to high-frequency control errors such as set point changes (step command) and measurement noise [5].

In order to use derivative control, the transfer functions must be proper. This often requires a pole to be added to the controller.

$$\mathrm{G_{pd}(s) = K_p + K_d s} \text{ or}$$

$$= \mathrm{K_p\,(1 + T_d s)}$$

With the increase of $\mathrm{T_d}$

- Overshoot tends to be smaller
- Slower rise time but similar settling time.

1.7 Proportional-plus-integral-plus-derivative controllers

The PID controller was first placed on the market in 1939 and has remained the most widely used controller in process control until today. An investigation performed in 1989 in Japan indicated that more than 90% of the controllers used in process industries are PID controllers and advanced versions of the PID controller. PI controllers are fairly common since derivative action is sensitive to measurement noise

"PID control" is the feedback control method that uses the PID controller as the main tool. The basic structure of conventional feedback control systems is shown below, using a block diagram representation. In this figure, the process is the object to be controlled. The purpose of control is to make the process variable y follow the setpoint value r. To achieve this purpose, the manipulated variable u is changed at the command of the controller. As an example of processes, consider a heating tank where some liquid is heated to the desired temperature by burning fuel gas. The process variable y is the temperature of the liquid, and the manipulated variable u is the flow of the fuel gas. The "disturbance" is any factor other than the manipulated variable that influences the process variable. The figure below assumes that only one disturbance is added to the manipulated variable. However, in some applications, a major disturbance enters the process differently, or plural disturbances need to be considered. The error e is defined by $e = r - y$. The compensator $C(s)$ is the computational rule that determines the manipulated variable u based on its input data, which is the error e in the case of the figure. The last thing to notice about the figure is that the process variable y is assumed to be measured by the detector, which is not shown explicitly here, with sufficient accuracy instantaneously that the input to the controller can be regarded as being exactly equal to y.

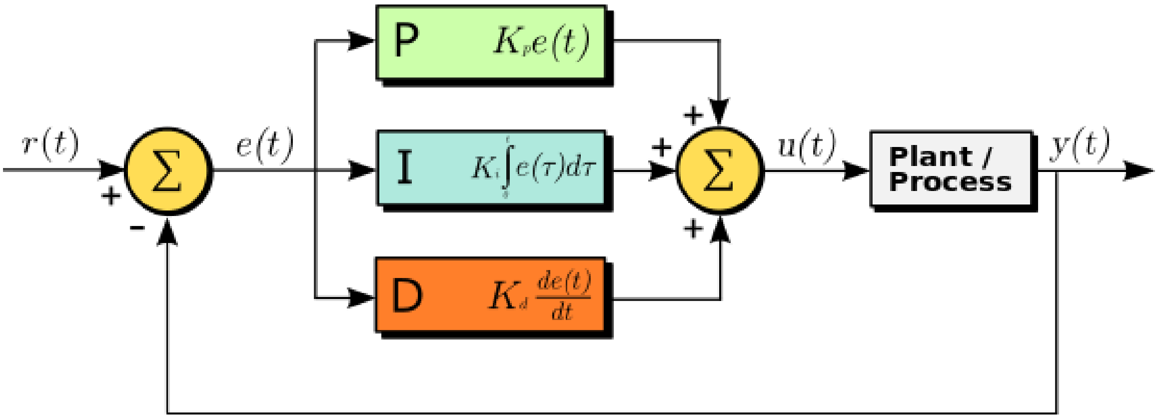

Figure 1.2: courtesy

When used in this manner, the three-element of PID produces outputs with the following nature:

- *P* element: proportional to the error at the instant t, this is the "present" error.
- *I* element: proportional to the integral of the error up to the instant t, which can be interpreted as the accumulation of the "past" error.
- *D* element: proportional to the derivative of the error at the instant t, which can be interpreted as predicting the "future" error.

Thus, the PID controller can be understood as a controller that considers the present, the past, and the future of the error. The transfer function $\mathrm{G_c}(s)$ of the PID controller is :

$$\begin{aligned}\mathrm{G_c(s)} &= \mathrm{K_p}\left(1 + \frac{1}{\mathrm{ST_i}} + \mathrm{T_d s}\right)\\ &= \mathrm{K_p} + \frac{\mathrm{K_i}}{\mathrm{S}} + \mathrm{K_d s}\end{aligned}$$

1.8 Application

In the early history of automatic process control, the PID controller was implemented as a mechanical device. These mechanical controllers used a lever, spring, and mass and were often energized by compressed air. These pneumatic controllers were once the industry standard . Electronic analog controllers can be made from a solid-state or tube amplifier, a capacitor, and a resistance. Electronic analog PID control loops were often found within more complex electronic systems, for example, the head positioning of a disk drive, the power conditioning of a power supply, or even the movement-detection circuit of a modern seismometer. Nowadays, electronic controllers have largely been replaced by digital controllers implemented with micro-controllers or FPGAs. Most modern PID controllers in the industry are implemented in programmable logic controllers (PLCs) or as a panel-mounted digital controller. Software implementations have the advantages that they are relatively cheap and are flexible with respect to the implementation of the PID algorithm [5]

Chapter 2

PID controller in python

2.1 code

```
import numpy as np

def incmatrix(genl1,genl2):
    m = len(genl1)
    n = len(genl2)
    M = None #to become the incidence matrix
    VT = np.zeros((n*m,1), int)  #dummy variable

    #compute the bitwise xor matrix
    M1 = bitxormatrix(genl1)
    M2 = np.triu(bitxormatrix(genl2),1)

    for i in range(m-1):
        for j in range(i+1, m):
            [r,c] = np.where(M2 == M1[i,j])
            for k in range(len(r)):
                VT[(i)*n + r[k]] = 1;
                VT[(i)*n + c[k]] = 1;
                VT[(j)*n + r[k]] = 1;
                VT[(j)*n + c[k]] = 1;

                if M is None:
                    M = np.copy(VT)
                else:
                    M = np.concatenate((M, VT), 1)

                VT = np.zeros((n*m,1), int)

    return M
```

```python
def PID(Kp, Ki, Kd, MV_bar=0):
    # initialize stored data
    e_prev = 0
    t_prev = -100
    I = 0

    # initial control
    MV = MV_bar

    while True:
        # yield MV, wait for new t, PV, SP
        t, PV, SP = yield MV

        # PID calculations
        e = SP - PV

        P = Kp*e
        I = I + Ki*e*(t - t_prev)
        D = Kd*(e - e_prev)/(t - t_prev)

        MV = MV_bar + P + I + D

        # update stored data for next iteration
        e_prev = e
        t_prev = t
```

```python
%matplotlib inline
from tclab import clock, setup, Historian, Plotter

TCLab = setup(connected=False, speedup=10)

controller = PID(2, 0.1, 2)         # create pid control
controller.send(None)               # initialize

tfinal = 800

with TCLab() as lab:
    h = Historian([
        ('SP', lambda: SP),
        ('T1', lambda: lab.T1),
```

```
            ('MV', lambda: MV),
            ('Q1', lab.Q1)])
        p = Plotter(h, tfinal)
        T1 = lab.T1
        for t in clock(tfinal, 2):
            SP = T1 if t < 50 else 50           # get setpoint
            PV = lab.T1                         # get measurement
            MV = controller.send([t, PV, SP])   # compute manipulated variable
            lab.U1 = MV                         # apply
            p.update(t)                         # update information display
```

Chapter 3

Results and Discussion

Chapter 4

Summary and Conclusions

References are each numbered, ordered sequentially as they appear in the text, methods summary, tables, boxes, figure legends, etc.

When cited in the text, reference numbers are **superscript**, not in brackets unless they are likely to be confused with a superscript number.

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For journal articles, list initials first for all authors, separated by a space: A. B. Opus, B. C. Hobbs. Do not use "and." Use *et al.* (italics) for more than five authors. Titles of cited articles should not be included (see samples). Journal titles are in italics; volume numbers follow, in boldface. Do not place a comma before the volume number or before any parentheses. You may give the full inclusive pages of the article. Journal years are in parentheses: (1996). End each listing with a period. Do not use *ibid.* or *op. cit.*.

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Style Examples
Journals

1. N. Tang, *Atmos. Environ.* **14**, 819-834 (1980). [one author]
2. W. R. Harvey, S. Nedergaard, *Proc. Natl. Acad. Sci. U.S.A.* **51**, 731-735 (1964). [two or more authors]
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4. D. Curtis et al., in Clinical Neurology of Development, B. Walters, Ed. (Oxford Univ. Press, New York, 1983), pp. 60-73. [use "Univ."]
5. Principles and Procedures for Evaluating the Toxicity of Household Substances (National Academy of Sciences, Washington, DC, 1977). [organization as author and publisher]

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2. F. Press, "A report on the computational needs for physics" (National Science Foundation, Washington, DC, 1981). [unpublished or access by title]
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4. U.S. Environmental Protection Agency, The Environmental Protection Agency's White Paper on Bt Plant-Pesticide Resistance Management (EPA Publication 739-S-98-001, 1998; www.epa.gov/pesticides/biopesticides/whiteo_bt.pdf). [the easiest access to this source is by Internet]

Paper presented at a meeting (not published)

1. M. Konishi, paper presented at the 14th Annual Meeting of the Society for Neuroscience, Anaheim, CA, 10 October 1984. [sponsoring organization should be mentioned if it is not part of the meeting name]

Theses and personal communications

1. B. Smith, thesis, Georgetown University (1973).
2. G. Reuter, personal communication. [Must be accompanied with a letter of permission and must not be used to support a central claim, result, or conclusion.]

Appendix A

(Optional)