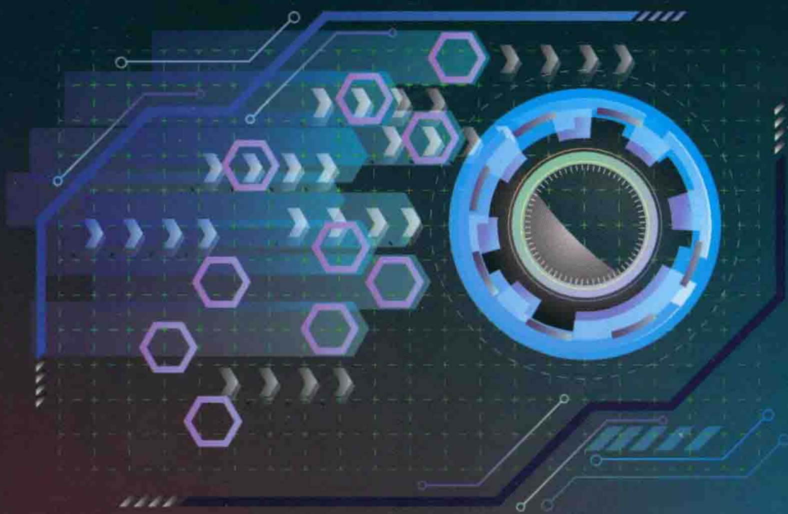

Introduction to Control Systems

BASICS AND FUNDAMENTALS

G. Venkatesan

Alpha Science

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Preface

A detailed literature search and review of standard textbooks on Control Engineering shows dearth of books on Control Engineering, which explain the Basics and Fundamentals of Control Engineering Science. The Control Engineering textbooks that are available in the market, libraries and book shops cater to the needs and requirements of graduate engineering students in the University undergraduate study written to a syllabus prescribed and set by the University Curriculum Academic Board of Studies. These textbooks presupposes and assumes that a basic knowledge and sufficient background in Mathematics to understand Control Engineering Principles, Theory and Practice.

The number of books are few and far between that do not overemphasise Mathematics background and knowledge and not expecting the reader to be already aware or familiar with Control Engineering Terms, nomenclature etc. There is a huge deficiency and a void between the standard textbooks and technical literature subject material that are available on stand alone topics feedback control, PLC programming etc.

In order to bridge the gap between these two extremes, the author felt the need for a book that will address the technical and theoretical issues faced by tradespersons, technicians working in control engineering discipline at plat level, certificate and diploma students in polytechnics who may have only high school level mathematics knowledge. With this in view, this book is written with a minimum of mathematics, equations, derivations, design aspects of control engineering starting from the basics of how to draw a block diagram etc., and broadening to actual practical examples of flow, level, pressure and temperature control. A whole chapter is devoted to the theory and practical aspects of PLC, DCS and SCADA control systems with the initial two chapters on traditional feedforward and feedback control.

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G. Venkatesan

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Control System – Introduction

1. INTRODUCTION

This chapter explains and describes the basics and fundamentals of control system along with the terms, terrminology, nomenclature and definitions that are used in control system technology. In this chapter on Introduction to Control System, the purpose of the book is given along with description of Control – types and examples. A brief introduction to Feedforward control and Feedback control is given along with applications in industry. The terms feedforward, feedback control are explained with suitable examples. The terms and definitions that are used in control system is given and the chapter ends with a section on conclusion.

2. PURPOSE AND MOTIVATION

It is quite true and common knowledge that there are many books on this topic with high mathematical and theoritical equations based on control system theory and practice for students pursueing a course in Engineering and Technology. This book addresses issues of those readers who do not have sufficient mathematical background and wish to learn control sysytem fundamentals and to have a basic introductory knowledge of the subject. The language is kept simple, easy to read and understand and all efforts are made to keep the technical jargon and mathematical symbols, notation and equations as minimum as possible. This will enable the reader at a non-professional, high school or technical certificate level to get motivated and to develop an interest to read more on the subject and its advanced topics. Extreme care is taken to explain mathematical terms like 'variable', 'parameter' etc., for example, for the benefit of non-technical reader and trade technicians working on shop floor.

3. EXPLANATION OF TERM CONTROL SYSTEM AND ASSOCIATED TERMS

A 'system' is a 'mechanism' or a collection of entities, 'which are physical with real existence, and considered as distinct, independent, or self-contained', that 'transforms', a set of clearly distiguishable quantities called 'inputs' to a set of 'outputs'. A simple example is petrol or diesel which is an input to an automobile, or coal for a steam engine. Everyone is aware and familiar with car or steam engine mechanism and their functions. The output is mechanical power which sets the car or locomotive in motion.

A control system is a device, or set of devices, that manages, commands, directs or regulates the behavior of other device(s) or system(s).

A control mechanism is a 'process' used by a control system. 'Process is physical or chemical change of matter or conversion of energy'; example: change in pressure, temperature, speed, electrical potential, etc. Process is an operation or series of operations in which the value of a quantity or condition is controlled and includes all functions which directly or indirectly affect the value. A manual or automatic mechanism is used to manage processes by adjusting or maintaining physical variables such as temperature, speed, or flow rate.

Control system is a means by which a set of 'variable' (whose numerical value can vary or change with time and can take different values due to changes that take place in the control system), quantities is held constant or caused to vary in a prescribed way to achieve a prescribed value of a variable, (quantity or condition with a process, the value of which is subject to change with time). Control systems, in general, have many features in common such as an input, output, a process or plant, a controller, a 'feedback' device and' a 'comparator' or 'detector', which are explained subsequently.

Fig. 1.1 A simple control mechanism process used by a control system

In control systems, there will be an input and an output and the Fig. 1.1 is called a 'Block diagram' that represents a process or system. Signals flow from the input, through the system and produce an output. The input will usually be an ideal form of the output. In other words, the input is really what we want the output to be and it is called the 'Desired' output.

Feedback is a process in which a system regulates itself by monitoring its own output. That is, it "feeds back" part of its output to itself. Feedback is used to control machines; a heating system, for example, uses a to monitor and adjust its output. Feedback is also used by the human brain to control various muscles and joints. "Feedback" is any 'response' or information about the result of a process.

'Response', is the behaviour of the output of a device as a function of the input, both with respect to time.

A 'comparator' or 'detector' compares the ouput with the required value or detects the difference in output value and' the desired value and' sends ('feeds') the difference, ('deviation') as 'error' back to the input.

A classic example is the sound created when a microphone or electric guitar picks up sound from a speaker connected to an amplifier (A) and regenerates it back through the sound amplifier (B) as shown in Fig. 1.2. An amplifier is a device that enables an input 'signal', (explained in Section 1.4), to control power from a source independent of the signal and thus be capable of delivering an output that bears some relationship to, and is generally greater than, the input signal.

Feedback is used to control machines; a heating system, for example, uses a thermostat to monitor and adjust its output. Feedback is also used by the human brain to control various muscles and joints through the constant flow of sensory information back to the brain. When feedback mechanisms are deficient because of sensory deprivation, 'motor' function becomes distorted, aberrant, and uncoordinated. Feedback or closed-loop system is further explained in detail in Chapter 3.

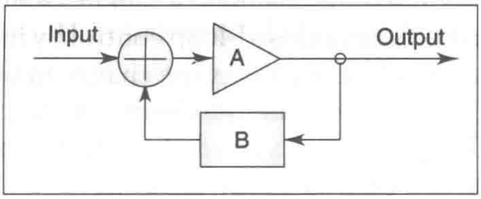

Fig. 1.2 Block diagram representation of a feedback amplifier

3.1 Types and Examples of Control System

3.1.1 Open-loop control system

A 'controller' is a device which operates automatically to regulate a 'controlled variable'. A 'controlled variable' is a quantity or condition which is measured and controlled. There are two different types of control systems, both 'open' and 'closed'. In an open control system, there is no automatic correction of its output to input. In a closed control system, the output has a direct effect on the input quantity.

If in a physical system, there is no automatic correction of the variation in its output, it is called an open-loop control system.

That is, in this type of open-loop control system, sensing of the actual output and comparing of this output (through feedback) with the desired input doesn't take place. The system on its own is not in a position to give the desired output. In these open-loop control systems, the changes in output can be corrected only by changing the input manually. These are simple in construction, stable and cost cheap. But these are inaccurate and unreliable. Moreover these systems don't initiate corrective actions automatically. Some well known examples of open-loop control are:

(i) Automatic washing machine,
(ii) Traffic signal, and
(iii) Home heating (without sensing, or sensor element feedback and control).

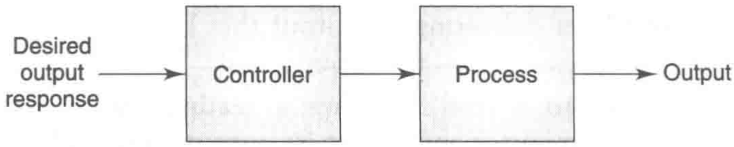

Fig. 1.3 Open-loop control system

3.1.2 Closed-loop control system

A closed-loop is a system, where the output has an effect upon the input quantity in such a manner as to maintain the desired output value.

A normal system becomes a closed-loop control by including a feedback. This feedback will automatically correct the change in output and a closed-loop control is called as an Automatic Control system. In a closed-loop, the controlled variable (output) is sensed at every instant of time, feedback and compared with the desired input resulting in an 'error' signal. This error signal directs the control elements in the system to do the necessary corrective action such that the output of the system is obtained as desired. The feedback makes the corrective action. These control systems are accurate, stable and are sophisticated and hence costly. They are also complicated to design for feedback control 'stability'. 'Stability' is the state of a controlled variable in which the variable does not cycle, or cycles with decreasing 'amplitude. The 'amplitude' of a periodic variable is a measure of its change over a single period (such as time or spatial period). It is the maximum deviation from the average or 'equilibrium', (equilibrium is the condition of a system in which all competing influences are balanced, a state of rest or balance due to the equal action of opposing forces, equal balance between any powers, influences, etc.; equality of effect), value of any repeatedly changing quantity, such as the position of a vibrating object, pressure,

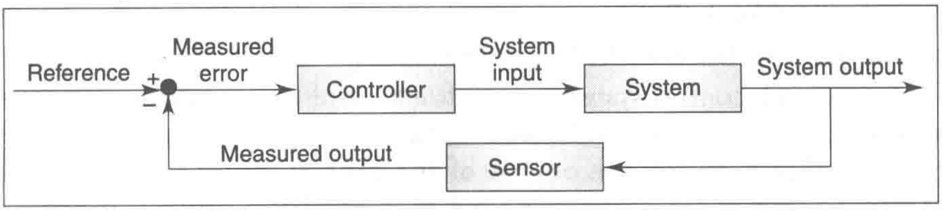

Fig. 1.4 Closed-loop control system

velocity, voltage, current and many others. For example, the amplitude of a sound wave is the maximum amount by which the instantaneous sound pressure differs from the 'ambient', (surrounding) pressure.

The concept of the feedback loop to control the dynamic behaviour of the system by means of ('negative') feedback, because the sensed value is subtracted from the desired value to create the error signal, which is amplified by the controller.

A simple example of feedback is provided by a governor on an engine; if the speed of the engine exceeds a preset limit, the governor reduces the supply of fuel, thus decreasing the speed. Electronic control systems employ feedback extensively. In voltage and current regulators, part of the output is used as a control input, providing self-'regulation', which is the attainment of equilibrium without the intervention of a controller. For example, if the output becomes too great, it acts through the feedback loop to reduce itself. The use of feedback as the fundamental control mechanism for machinery occurs in automation. Living organisms possess feedback control systems of great complexity.

For example, when the hand reaches for an object, information about its position is continuously fed back to the brain, both by the eyes and by position-sensing nerves in the arm; the brain uses the position information to guide the hand to the object. Such feedback can be termed voluntary, since it is to some extent under conscious control. Automatic, involuntary feedback is constantly taking place as well, controlling processes such as respiration, circulation, digestion, and maintenance of body temperature.

A closed-loop control system uses an additional measure of the actual output to compare the actual output with the desired output response (see Fig. 1.4).

A *feedback control system is a control system which tends to maintain a prescribed relationship of one system variable to another by comparing functions of these variables and using the difference as a means of control.*

In the case of the driver steering an automobile, the driver uses his or her sight to visually measure and compare the actual location of the car with the desired location. The driver then serves as the controller, turning the steering wheel. The process represents the dynamics of the steering mechanism and the automobile response.

A feedback control system uses a function of a prescribed relationship between the output and reference input to control the process. Often, the difference between the output of the process under control and the reference input is amplified and used to control the process in order to continually reduce the difference. The foundation for control system analysis and design is the feedback control concept.

It is possible to have combinations of feedforward and feedback control which is explained in later chapter of this book with some examples.

4. TERMS IN CONTROL ENGINEERING TERMINOLOGY

This section gives a detailed description and explanation of the terms, definitions and nomenclature that are used in Control engineering and controller technology. There are many terms similar to the ones introduced earlier and it will be good for the reader to be familiar about these terms and definitions. For further details and for more information, see:

(i) Instrument Society of America Standard on Process Instrumentation Terminology (ISA – S51.1 / 1976) and

(ii) A.S.M.E. Industrial Instruments and Regulations Division Committe on Technology.

Set point: Desired value or target

Deviation: Error

Controller: A device, which operates automatically to regulate a controlled variable.

Feedback: Control in which a measured variable is compared to its desired value to produce an actuating error 'signal' that is acted upon in such a way as to reduce the magnitude of the error; Signal is a physical variable, one or more 'parameters' of which carry information about another variable (which the signal represents). Parameter is a quantity or property treated as a constant but which may sometimes vary or be adjusted.

Feed forward control: It is relevant information concerning one or more conditions that can disturb the controlled variable, which is converted outside of any feedback loop, into corrective action to minimize deviations of the controlled variable.

"A control system, in general, which operates without human intervention is called an 'Automatic Control System' (ACS), whilst a control system is a system in which deliberate guidance or manipulation is used to achieve a prescribed value of a variable".

There are exceptions to a pure (100 per cent) automatic control system in that some form of human intervention is at least necessary to re-start or re-energise the system up and running.

'Adaptive control' is control in which automatic means is used to change the type or influence of control parameters in such a way as to improve the performance of the control system.

A 'device' is an apparatus for performing a prescribed function. The action 'calibrate' is intended to ascertain outputs of a device corresponding to a series of values of the quantity which the device is to measure, receive, or transmit data.

Data obtained in such a manner are used to

(i) Determine the locations at which scale graduations are to be placed,
(ii) Adjust the output, to bring it to the desired value, within a specified limit or tolerance, and
(iii) Ascertain the 'error', (explained subsequently), by comparing the device output reading against a standard.

'Deviation' is another name for error.

A 'signal' is a physical variable, one or more parameters of which carry information about another variable, which the signal represents.

'Ideal value' is the value of the indication, output or ultimately controlled variable of an idealized device or system.

'Error' is the algebraic difference between the indication and the ideal value of the measured signal.

Error is the quantity, which algebraically subtracted from the indication gives the ideal value.

In this context, 'parameter' is a quantity or property that is treated as constant but which may sometimes vary or that can be adjusted.

A 'summing point' is a junction or node point at which algebraically addition of signals is performed.

A 'feedback' or 'closed-loop' is a signal path, which includes a forward path, a feedback path, and a summing point and forms a closed circuit.

'Loop gain' is the ratio of the change in return signal to the change in its corresponding error signal at a specified frequency.

'Closed-loop gain' arises in a closed-loop system, and it is expressed as the ratio of the output change to the input change.

'Compensation' is the provision of a special construction, a supplemental device, circuit, or special materials to counteract sources of error due to variations in specified operating conditions.

'Compensator' is a device, which converts a signal into some function, which, either alone or in combination with other signals, directs the final controlling element to reduce deviations in the directly controlled variable.

It is a value associated with the variable, which is sensed to originate a feedback signal.

'Control action' is a device, which operates automatically to regulate a controlled variable of a controlling system, to minimize the change of the output affected by the input.

The output may be a signal or a value of a manipulated variable.

Similarly, the input may be control loop feedback signal when the 'set point', (desired value or target) is constant, an actuating error signal or the output of another controller.

A 'manipulated variable' is a quantity or condition, which is varied as a function of the actuating error signal, so as to change the value of the directly controlled variable.

An 'error signal' is the signal from its corresponding input signal in a closed-loop, whereas an input signal is a signal applied to a device, element, or a system.

Set Point – An input variable, which sets the desired value of the controlled variable, where the desired value is the preferred value of the controlled variable.

'Derivative' (D) control action is the control action in which the output is proportional to the rate of change of the input.

'Control action', (of a controller), or a controlling system, is the nature of the change of the output affected by the input. The output may be a signal or a value of a manipulated variable. The input may be the control loop feedback signal when the 'set point' is constant, an actuating error signal, or the output of another controller.

5 AUTOMATION

Before concluding this Chapter on Introduction, a brief idea and definition of Automation is given in order to enable the reader to understand the principles of operation of control systems and automation and to show how closely automation and control systems are closely related and have links with one another.

5.1 Definition

The term automation can be referred to 'the automatic operation or control of equipment, a process, or a system, 'the techniques and equipment used