Industrial Automation and Control
(AEE511)

INTRODUCTION TO INDUSTRIAL AUTOMATION AND CONTROL

by

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UNIT-I
Industrial Automation and Control

UNIT-I

INTRODUCTION TO INDUSTRIAL AUTOMATION AND CONTROL

Industrial Automation

- Automation is encompassing virtually every walk of life.
- Automation solutions are required right from agricultural to space technology.
- Plant Automation is the necessity for the manufacturing industry to survive in today’s globally competitive market.

What is Automation?

Automation is basically the delegation of human control function to technical equipment for

- Increasing productivity
- Increasing Quality
- Reducing Cost
- Increasing safety in working conditions

History of Automation

- Pneumatic Control.
- Hard wired logic Control.
- Electronic Control using Logic Gates.
- Programmable Logic Controller.
- Manual Control.

Manual Control

All the actions related to process control are taken by the operators.

Drawbacks:

- Likely human errors and consequently its effect on quality of final product.

- The production, safety, energy consumption and usage of raw material are all subject to the correctness and accuracy of human action.

Pneumatic Control

Industrial automation, with its machine and process control, had its origin in the 1920s with the advent of "Pneumatic Controllers".

Actions were controlled by a simple manipulation of pneumatic valves, which in turn were controlled by relays and switches.

Drawbacks

- Bulky and Complex System.
- Involves lot of rework to implement control logic.
- Longer project time.

Hard wired logic control

The contactor and Relays together with hardware timers and counters were used in achieving the desired level of automation

Drawbacks

- Bulky panels
- Complex wiring
- Longer project time
- Difficult maintenance and troubleshooting

Electronic Control using Logic Gates

In 1960s with the advent of electronics, the logic gates started replacing the relays and auxiliary contactors in the control circuits.

The hardware timers & counters were replaced by electronic timers.

Drawbacks.

- Reduced space requirements.
- Energy saving.
- Less maintenance & greater reliability.
- Changes in control logic not possible.
- More project time.

Programmable Logic Controllers

In 1970s with the coming of microprocessors and associated peripheral chips, the whole process of control and automation underwent a radical change.

- Instead of achieving the desired control or automation through physical wiring of control devices, in PLC it is achieved through a program or say software.
- The programmable controllers have in recent years experienced an unprecedented growth as universal element in Industrial Automation.
- It can be effectively used in applications ranging from simple control like replacing small number of relays to complex automation problems

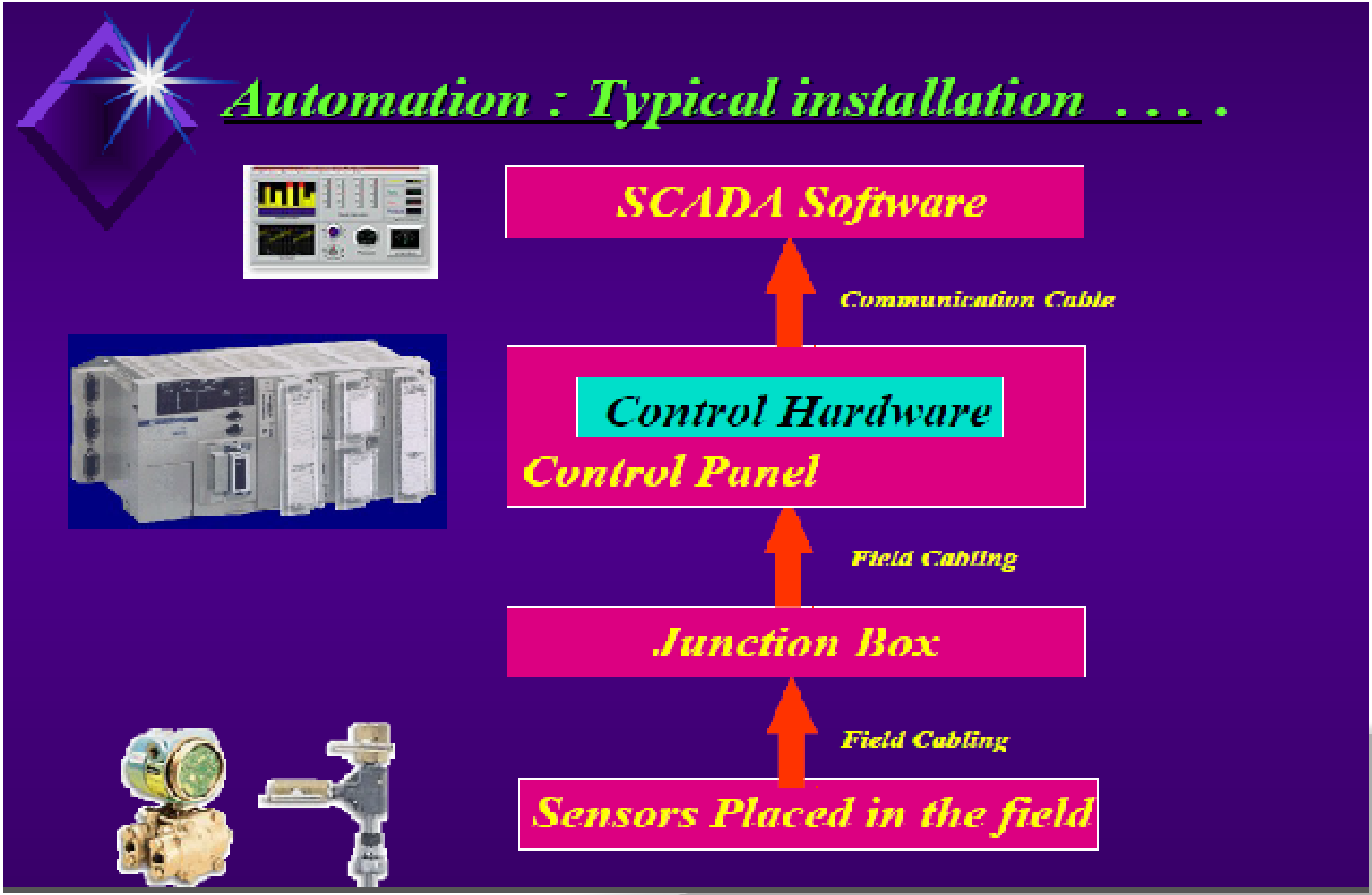
Advantages of PLCs

- Reduced space
- Energy saving
- Ease of maintenance
- Economical
- Greater life & reliability
- Tremendous flexibility
- Shorter project time
- Easier storage, archiving and documentation

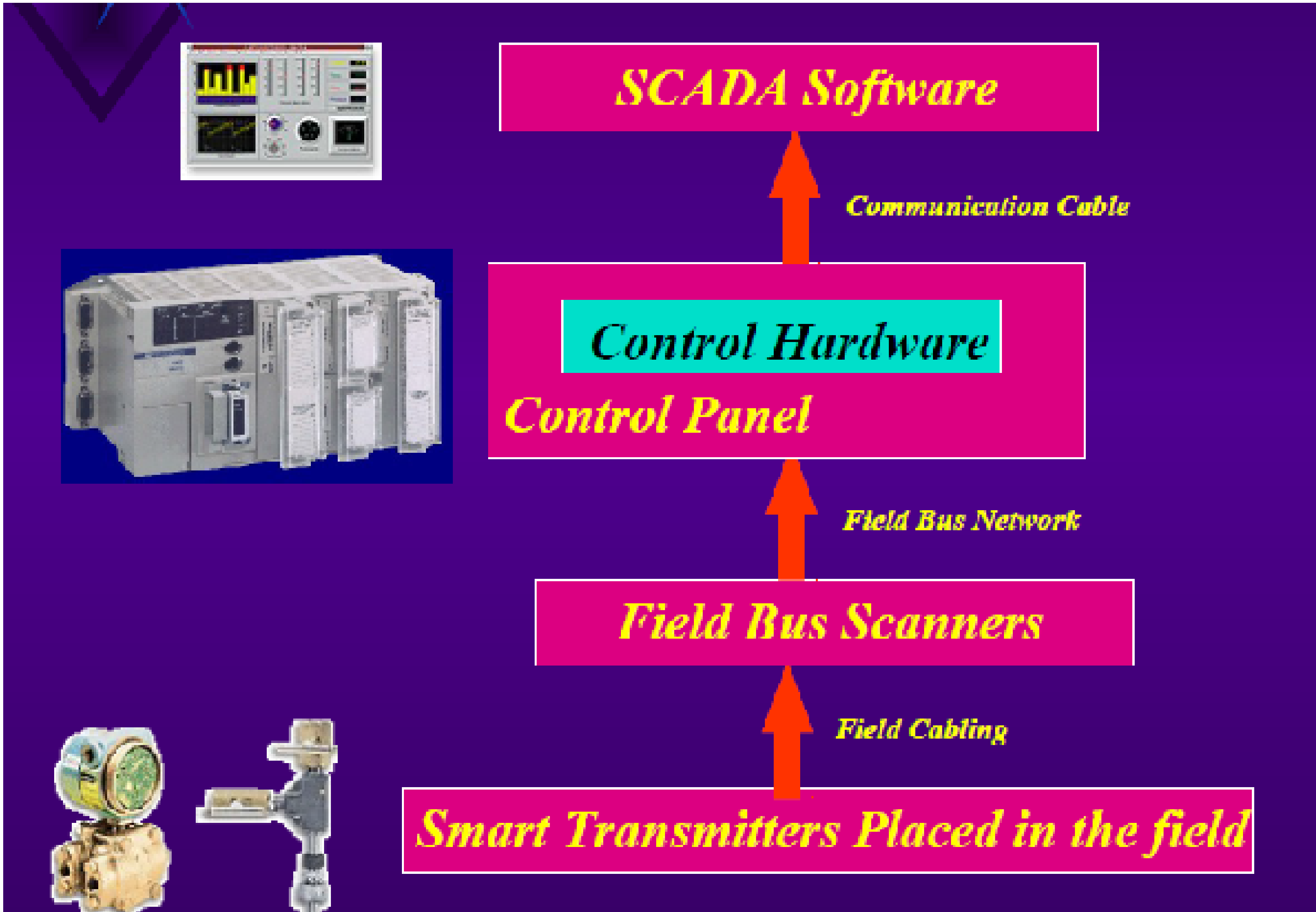
Industrial Automation Components

- Field Instruments.
- Control Hardware.
- Control Software.

Automation : Typical installation



Automation : Advanced Technology



Sensors (Field Instruments)

- Sensors with transmitters are the field devices placed in the field who actually sense the parameter and send the analog signal to the control hardware.
- The analog signals used are Ohm (RTD), mV(Thermocouple), 4-20 mA, +/-10 V, etc

Widely used Sensors (Field Instruments)

RTD : Output in Ohms (Temperature)

Thermocouples : Output in mV (Temperature)

Pressure Transmitters : 4-20mA, 0-10 V .....

Flow Transmitter : 4-20mA, 0-10 V .....

Level Transmitter : 4-20mA, 0-10 V .....

Conductivity meter : 4-20mA, 0-10 V .....

Density meter : 4-20mA, 0-10 V .....

pH transmitter : 4-20mA, 0-10 V .....

Leading Manufacturers in Sensors (Field Instruments)

- Fisher Rosemount.
- Yokogawa.
- Anderson & Housers.
- Radix.
- ToshBro.

Control hardware

Standalone PID Controllers

Programmable logic controllers (PLC)

Distributed Control System

Standalone PID Controllers

- These are the independent small hardware units which caters requirement of closed loop controls in the process.
- These hardware can be installed in field or in control room.
- These hardware can be connected on the network.
- Currently the controllers are available with 100s of segment and programming patterns.

Leading Manufacturers in PID Controllers

- Yokogawa.
- ABB.
- Moore.
- Eurotherm.
- ASCON.
- Chino.
- Bells.
- Fuji.

Programmable Logic Controllers

- **Now a days PLCs are the most widely used control hardware in control applications. The applications ranges from standalone system for CNC machines to Hot swappable Redundant System for Critical Process Control.**

What Constitutes A PLC ?

- The PLC is programmed interface between the field I/p element like limit switches, sensors, push button and the final control elements like actuator, solenoid/control valves, drives, hooters etc

PLC consist of

- Input Module
- CPU with Processor and Program memory
- Output module
- Bus System
- Power Supply

Role of Engineers In Industrial Automation

- Designing of the Automation system.
- Erection and Commissioning.
- Maintenance and Troubleshooting of existing system.

Job Prospect for Fresher

- Today management of almost all manufacturing units are going for industrial automation to survive in globally competitive market. Most of these industrial units are looking forward for trained engineers in the field of industrial automation.
- Since they are thinking about more accuracy, productivity in less time & with minimum manpower , It’s a golden opportunity to prepare yourself to take on this task.

Job prospects for Engineers In Industrial Automation

- Manufacturing Industries like Reliance, Ceat, Godrej,Colgate ....

- Automation Solution Products manufacturer/developer like Rockwell, Siemens, Grouppe Schneider, Yokogawa, ABB.

- System Integrators for Grouppe Schneider Rockwell, Siemens, Etc.
- Consultants for Automation.

Current Situation

- Automation is a high growth sector globally hence it is essential to all professionals and students to have practical knowledge about the hardware and software used in Industrial Automation.

Architecture of industrial automation system

- An Industrial Automation System consists of numerous elements that perform a variety of functions related to Instrumentation, Control, Supervision and Operations Management related to the industrial process.
- These elements may also communicate with one another to exchange information necessary for overall coordination and optimized operation of the plant/factory/process. Below, we classify the major functional elements typically found in IA systems and also describe the nature of technologies that are employed to realize the functions.

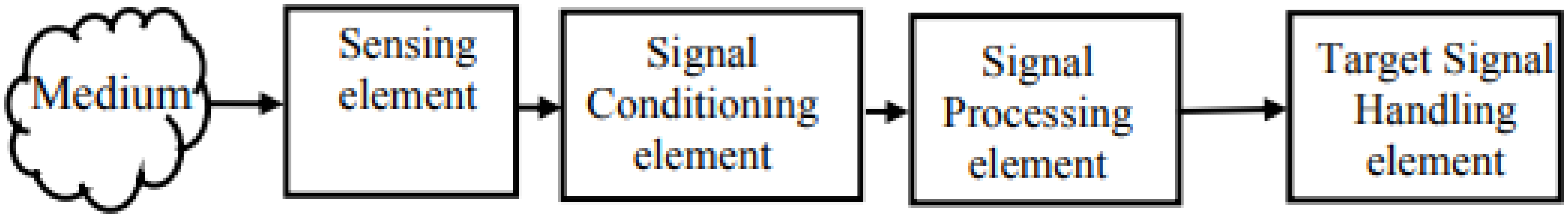


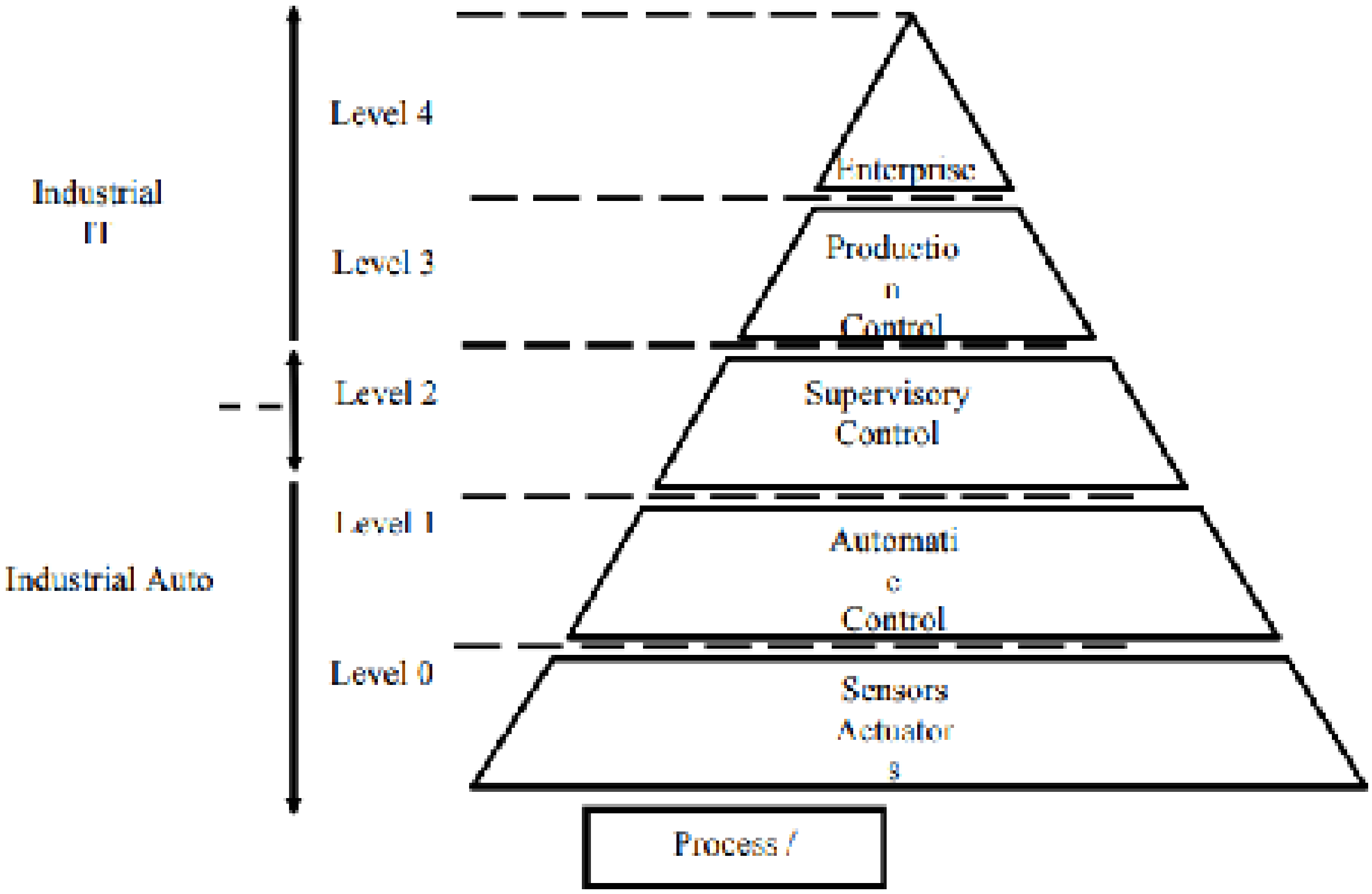
Fig. Functional configuration of a typical sensor system

The physical medium refers to the object where a physical phenomenon is taking place and we are interested in the measurement of some physical variable associated with the phenomenon.

- The sensing element is affected by the phenomenon in the physical medium either through direct or physical contact or through indirect interaction of the phenomenon in the medium with some component of the sensing element.
- The signal-conditioning element serves the function of altering the nature of the signal generated by the sensing element

- The signal processing element is used to process the signal generated by the first stage for a variety of purposes such as, filtering (to remove noise), diagnostics (to assess the health of the sensor), linearisation (to obtain an output which is linearly related with the physical measurand etc.
- The target signal-handling element may perform a variety of functions depending on the target application. It may therefore contain data/signal display modules, recording or/storage modules, or simply a feedback to a process control system.

The Architecture of Elements: The Automation Pyramid



Measurement Systems Specifications

Measurement system specifications can be classified into three categories:

(i) Static characteristics.

(ii) Dynamic characteristics.

(iii) Random characteristics.

Static characteristics

- Static characteristics refer to the characteristics of the system when the input is either held constant or varying very slowly. The items that can be classified under the heading static characteristics are mainly:
- Range.
- Sensitivity.
- Linearity.
- Hysteresis.
- Resolution.
- Accuracy and precision.

Dynamic Characteristics

- Dynamic characteristics refer to the performance of the instrument when the input variable is changing rapidly with time. For example, human eye cannot detect any event whose duration is more than one-tenth of a second; thus the dynamic performance of human eye cannot be said to be very satisfactory.
- The dynamic performance of an instrument is normally expressed by a differential equation relating the input and output quantities.

Random Characteristics

- If repeated readings of the same quantity of the measurand are taken by the same instrument, under same ambient conditions, they are bound to differ from each other.
- This is often due to some inherent sources of errors of the instrument that vary randomly and at any point of time it is very difficult to exactly say, what would be its value.
- For example, the characteristics of resistance and diode elements of an electronic circuit are random, due to two sources of noises: thermal noise and flicker noise.

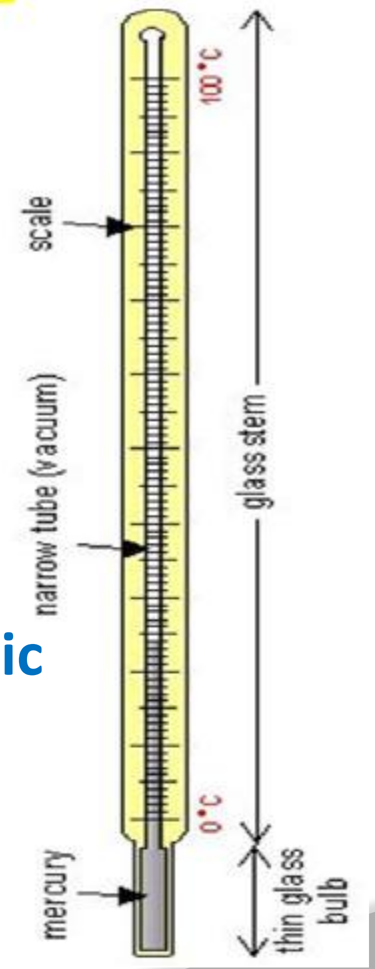
Measurement of Temperature

- The accurate measurement of temperature is vital across abroad spectrum of human activities,
  - > including industrial processes manufacturing.
  - > Health and safety.
- In fact, in almost every sector, temperature is on of the key parameters to be measured.
- Different people will have different perceptions of what is hot and what is cold.

Liquid in Glass- Thermometer

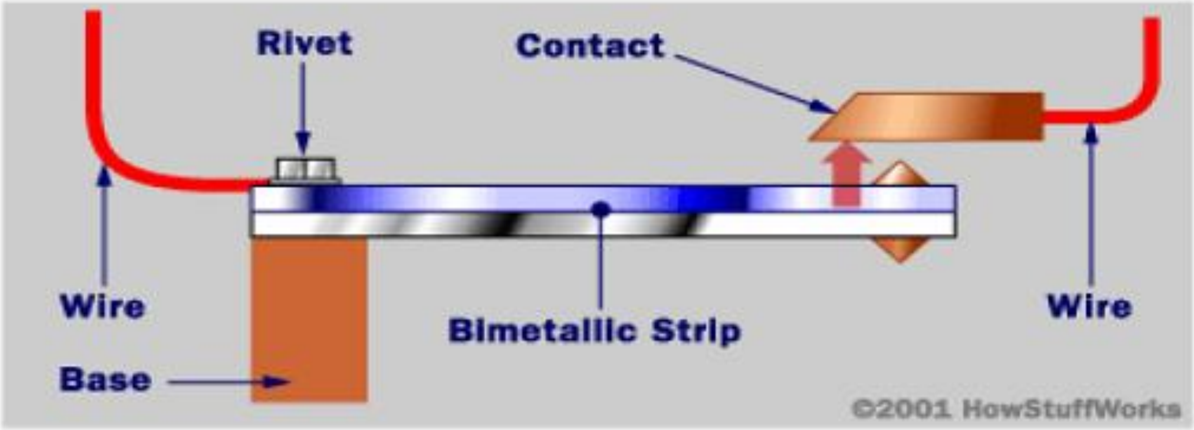
- The volume of mercury changes with slightly with temperature

- The space above the mercury may be filled with nitrogen or it may be less than atmospheric pressure, a partial vacuum



Bimetallic Thermometer

- Temperature indicators or temperature gauges



Principles:

- expansion/ Contractions – change in temperature
- different metals – different coefficient of temperatures
- the rate of volumetric change depends on this coefficient of temperature

Resistance temperature detector (RTD)

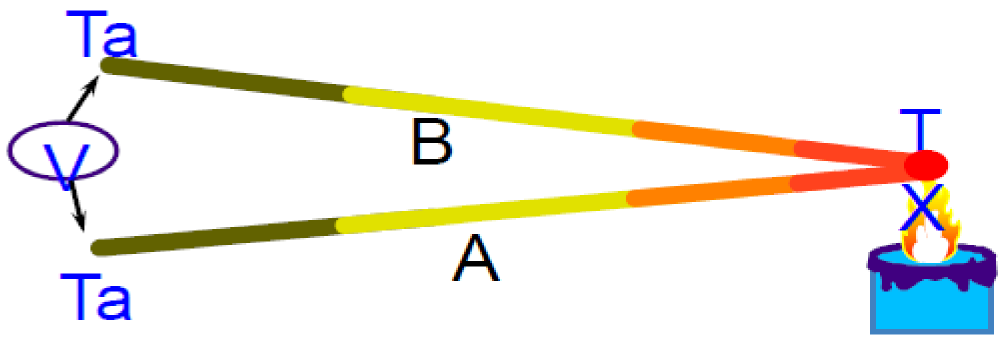
- Resistance Thermometer

- Principle
  Temperature raises resistance also raises and vice-versa

- Positive temperature coefficient

$$R = R_0(1 + AT + BT^2) \quad T > 0\ C$$

Thermocouples



The Seebeck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductors or \semiconductors produces a voltage difference between the two substances.

When heat is applied to one of the two conductors or semiconductors , heated electrons flow toward the cooler one. If the pair is connected through an electrical circuit, direct current (DC) flows through that circuit.

Measurement of Force

- **The unknown force may be measured by following methods:**

1. **Balancing the unknown force against known gravitational force due to standard mass. Scales and balances works based on this principle.**

2. **Applying unknown force to an elastic member and measuring the deflection on calibrated force scale or the deflection may be measured by using a secondary transducer. i.e spring scale, cantilever beam, providing ring, strain gauge Load cell**

Methods:

- Manometer
- Elastic Transducers
- Measuring Vacuum
- Balancing force or known area
- Electrical pressure transducers

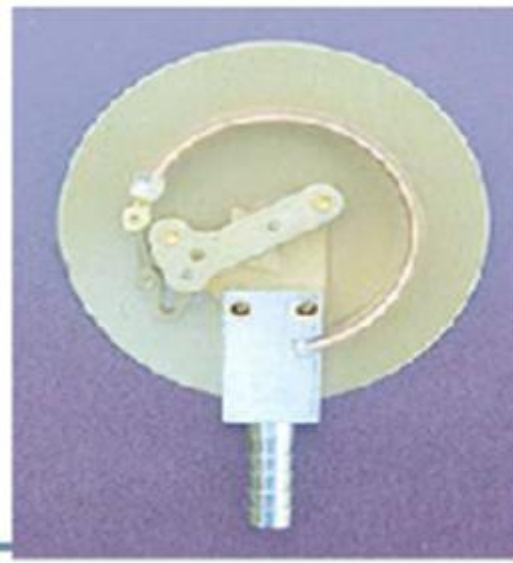
Manometers

- Manometers measure a pressure difference by balancing the weight of a fluid column between the two pressures of interest.

- Large pressure difference are measured with heavy fluids, such as Mercury.
- Small pressure differences, such as those experienced in experimental wind tunnels or venture flow meters, are measured by lighter fluids such as water

Bourdon Gauge

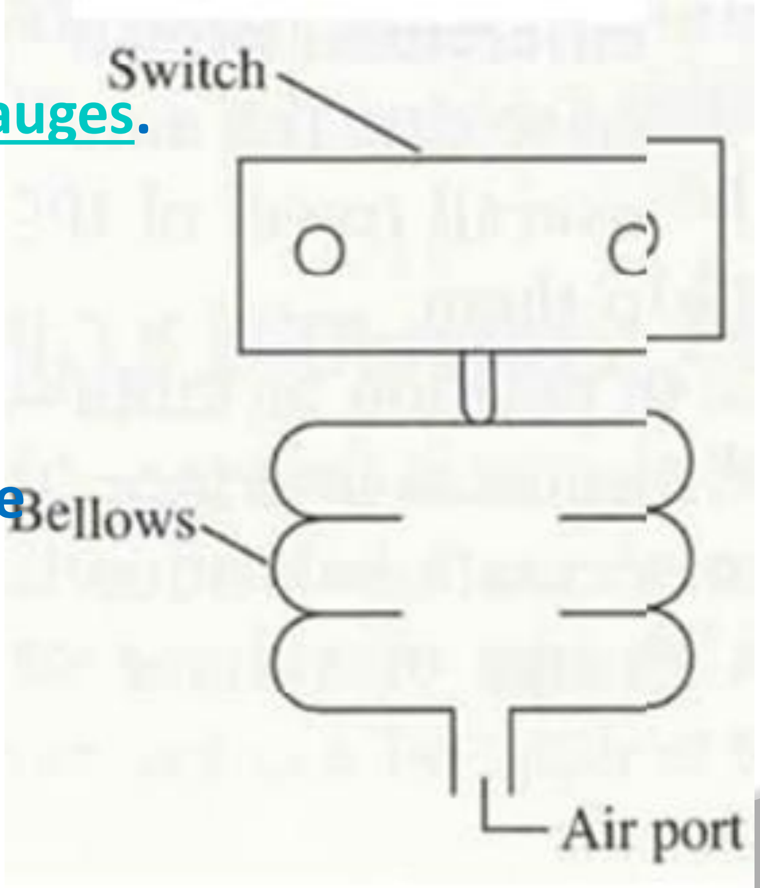
- **A Bourdon gauge uses a coiled tube, which as it expands due to pressure increase causes a rotation of an arm connected to the tube. In 1849 the bourdon tube pressure gauge was patented by France by Eugene bourdon.**


Bellows

The bellow type gauges are used for the measurement of absolute pressure.
They are more sensitive than bourdon gauges.
It may be used for measuring pressures up to 40 mm Hg.

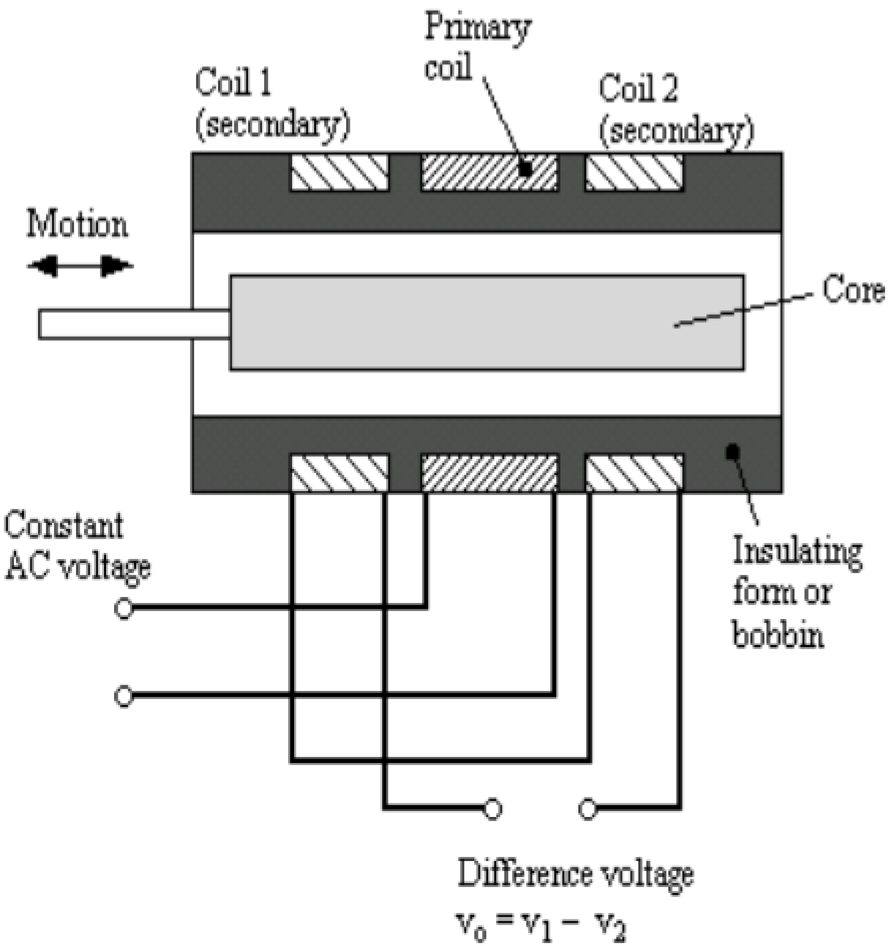
he bellows are made up of an alloy with high strength and ductility. It should have very little hysteresis effect. Commonly brass or phosphor bronze is used for making bellows.

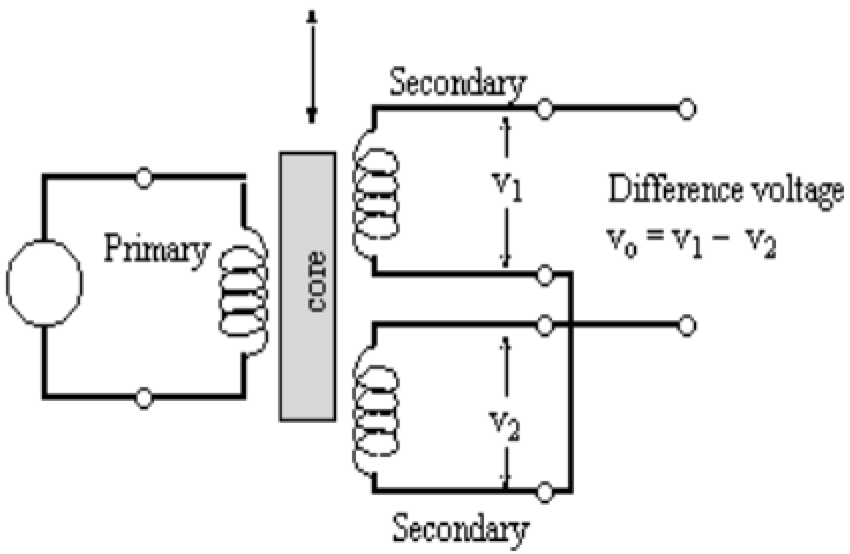


Linear Variable Displacement Transducer (LVDT)

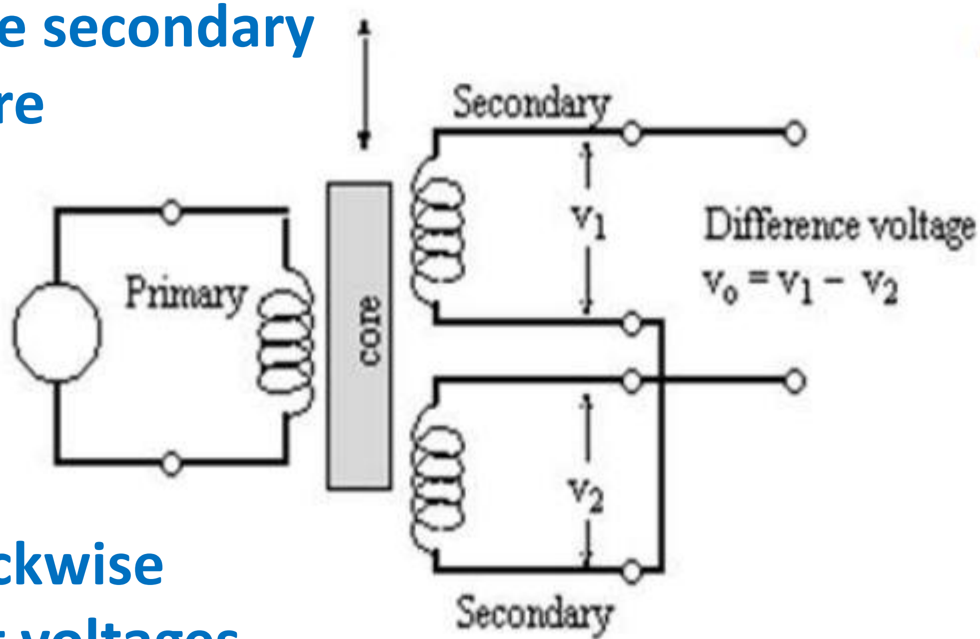
A very basic transducer which is always useful in the field of instrumentation Principle of LVDT: LVDT works under the principle of mutual induction, and the displacement which is a non-electrical energy is converted into an electrical energy. And the way how the energy is getting converted is described in working of LVDT in a detailed manner

Linear Variable Displacement Transducer (LVDT)





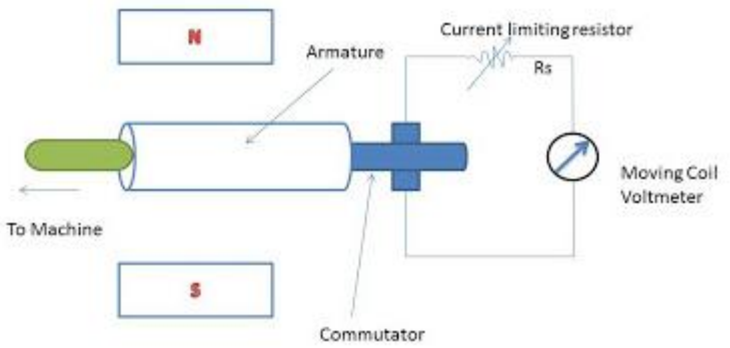
The number of turns in both the secondary windings are equal, but they are opposite to each other.



i.e., if the left secondary windings is in the clockwise direction, the right secondary windings will be in the anti-clockwise direction, hence the net output voltages will be the difference in voltages between the two secondary coil.

DC Tachogenerator

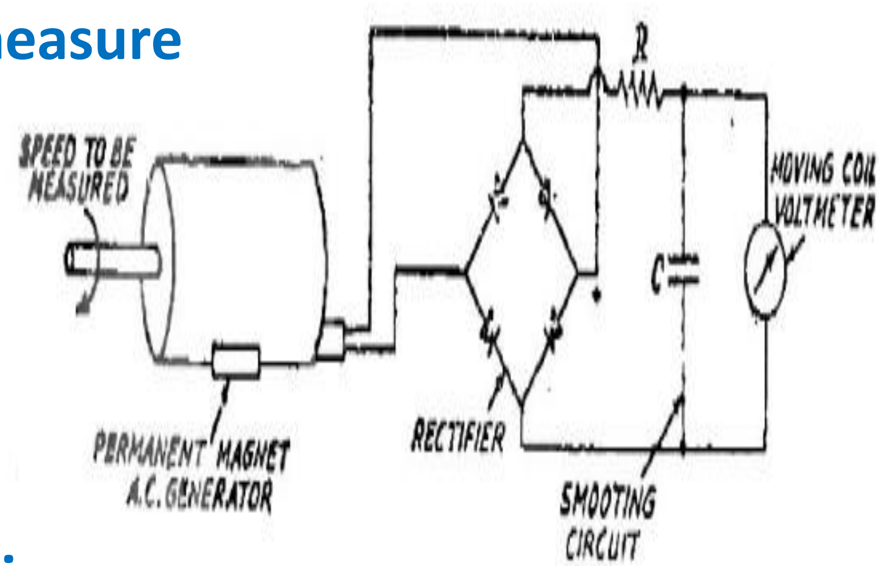
The D.C Tachogenerators is a type of electrical type's tachogenerators which can also be used for speed Measurement.



The armature of the D.C Tachogenerator is kept in the permanent magnetic field.
The armature of the tachogenerator is coupled to the machine whose speed is to be measured.
When the shaft of the machine revolves, the armature of the tachogenerator revolves in the magnetic field producing e.m.f. which is proportional to the product of the flux and speed to be measured.

AC Tachogenerator

The AC tachogenerator is used to measure the speed only in one direction.
In AC tachogenerator the armature is provided with an AC winding, either single phase or three phase windings.



A.C. Tachometer Generator.

When the rotor is stationary and primary winding excited by an AC input voltage, the induced voltage in secondary is zero. Due to relative position of two winding being placed at 90^0 to each other. As the rotor rotates, a voltage is induced in the secondary winding whose magnitude is propertional to the rotor speed.

Signal Conditioning

- Amplification.
- Isolation.
- Filtering.
- Linearization.

Isolation

Isolation circuits are required to differentiate signals from unwanted common mode voltages.

Linearization

There are many sensors which produces non linear output such as thermocouple, thermistor, etc. linearization circuits are used to convert non linear signal into linear one. It can be achieved by varying the gain of an amplifier as a function of input signal.

Errors

Basically Three types of errors are studied:-

1. Gross Errors .

2. Systematic Errors.

3. Random Errors.

Gross Errors

Gross Errors mainly covers the human mistakes in reading instruments and recording and calculating measurement results.

Example:- Due to oversight, The read of Temperature as 31.5 deg while the actual reading may be 21.5 deg.

Systematic Errors

Systematic Errors classified into three categories :-

1.Instrumental Errors.

2.Environmental Errors.

3. Observational Errors.

Random Errors

- The quantity being measured is affected by many happenings in the universe. We are aware for some of the factors influencing the measurement, but about the rest we are unaware.
- The errors caused by happening or disturbances about which we are unaware are Random Errors. Its also known as residual Errors.

Calibration

- In measurement technology and metrology, calibration is the comparison of measurement values delivered by a device under test with those of a calibration standard of known accuracy.

- Such a standard could be another measurement device of known accuracy, a device generating the quantity to be measured such as a voltage, a sound tone, or a physical artefact, such as a metre ruler.

- The outcome of the comparison can result in one of the following:
  No significant error being noted on the device under test
  a significant error being noted but no adjustment made
  an adjustment made to correct the error to an acceptable level

UNIT-II
Process Control

Introduction

- In any industrial plant the aim is to produce standard and high quality products and sell them at prices which make profit.

- These purposes can be achieved in a successfully designed and controlled processes.

Important Characteristics of Process Control Syste

1. **The focus of the engineer must be on the process.**
2. **The dynamic behavior of the individual units and the process as a whole is to be understood.**
3. **It is always the best to utilize the simplest control system that will achieve the desired objectives.**
4. **The design of a process determines how it will respond dynamically and how it can be controlled**

Control Terminology

- controlled variables - these are the variables which quantify the performance or quality of the final product, which are also called output variables.

- manipulated variables - these input variables are adjusted dynamically to keep the controlled variables at their set-points.

- disturbance variables - these are also called "load" variables and represent input variables that can cause the controlled variables to deviate from their respective set points.

Control Terminology

- set-point change - implementing a change in the operating conditions. The set-point signal is changed and the manipulated variable is adjusted appropriately to achieve the new operating conditions. Also called servomechanism (or "servo") control.

- disturbance change - the process transient behavior when a disturbance enters, also called regulatory control or load change. A control system should be able to return each controlled variable back to its set-point.

PID Controller

PID controllers are found in a wide range of applications for industrial process control. Approximately 95% of the closed loop operations of industrial automation sector use PID controllers.

PID stands for Proportional-Integral-Derivative. These three controllers are combined in such a way that it produces a control signal

Working of PID Controller

- Proportional or P- controller gives output which is proportional to current error e (t).

- It compares desired or set point with actual value or feedback process value. The resulting error is multiplied with proportional constant to get the output. If the error value is zero, then this controller output is zero.

- Integral controller integrates the error over a period of time until error value reaches to zero. It holds the value to final control device at which error becomes zero.

- D-Controller: I-controller doesn't have the capability to predict the future behavior of error. So it reacts normally once the set point is changed.

- D-controller overcomes this problem by anticipating future behavior of the error. Its output depends on rate of change of error with respect to time, multiplied by derivative constant.

- It gives the kick start for the output thereby increasing system response.

Tuning methods of PID Controller

Trial and Error Method:

- It is a simple method of PID controller tuning. While system or controller is working, we can tune the controller.
- In this method, first we have to set Ki and Kd values to zero and increase proportional term (Kp) until system reaches to oscillating behavior.
- Once it is oscillating, adjust Ki (Integral term) so that oscillations stops and finally adjust D to get fast response.

Process reaction curve technique:

It is an open loop tuning technique. It produces response when a step input is applied to the system. Initially, we have to apply some control output to the system manually and have to record response curve.

Zeigler-Nichols method:

Zeigler-Nichols proposed closed loop methods for tuning the PID controller. Those are continuous cycling method and damped oscillation method.

Feedback Control

- The advantage of feedback control is that it is a very simple technique that compensates for all disturbances.

- Any disturbance affects the controlled variable and once this variable deviates from set point , the controller changes its input in such a way as to return the temperature to the set point.

- The feedback loop does not know, nor does it care, which disturbance enters the process.

- It tries only to maintain the controlled variable at set point and in so doing compensates for all disturbances.

- The feedback controller works with minimum knowledge of the process. In fact, the only information it needs is in which direction to move.

- How much to move is usually adjusted by trial and error.

- Feedback control is the most common control strategy in the process industries.

- Its simplicity accounts for its popularity.

Feed forward Control

- **The objective of feed forward control is to measure the disturbances and compensate for them before the controlled variable deviates from set point.**

- **If applied correctly, the controlled variable deviation would be minimum.**

- **Suppose that in heat exchanger example the major disturbance is the inlet temperature.**

- **To implement feed forward control the disturbance first must be measured and then a decision is be made how to manipulate the steam to compensate for this change.**

Model Predictive Control

- Model Predictive Control (MPC) – regulatory controls that use an explicit dynamic model of the response of process variables to changes in manipulated variables to calculate control “moves”.

- Control moves are intended to force the process variables to follow a pre-specified trajectory from the current operating point to the target.

When Should Predictive Control be Used?

1. Processes are difficult to control with standard PID algorithm – long time constants, substantial time delays, inverse response, etc.

2. There is substantial dynamic interaction among controls, i.e., more than one manipulated variable has a significant effect on an important process variable.

3. Constraints (limits) on process variables and manipulated variables are important for normal control.

Model Predictive Control: Basic Concepts

1. Future values of output variables are predicted using a dynamic model of the process and current measurements.Unlike time delay compensation methods, the predictions are made for more than one time delay ahead.
2. The control calculations are based on both future predictions and current measurements.
3. The manipulated variables, $\boldsymbol{u}(k)$, at the k-th sampling instant are calculated so that they minimize an objective function, J.
4. Inequality & equality constraints, and measured disturbances are included in the control calculations.
5. The calculated manipulated variables are implemented as set point for lower level control loops. (cf. cascade control).

Model Predictive Control: Calculations

1. At the *k*-th sampling instant, the values of the manipulated variables, *u,* at the next *M* sampling instants, {*u*(k), *u*(k+1), …, *u*(*k*+*M* -1)} are calculated.

- This set of *M* "control moves" is calculated so as to minimize the predicted deviations from the reference trajectory over the next *P* sampling instants while satisfying the constraints.
- Typically, an LP or QP problem is solved at each sampling instant.
- Terminology: *M* = control horizon, *P* = prediction horizon

1. Then the first “control move”, $u(k)$, is implemented.

2. At the next sampling instant, $k+1$, the M-step control policy is re-calculated for the next M sampling instants, $k+1$ to $k+M$, and implement **the first control move, $u(k+1)$.**

3. Then Steps 1 and 2 are repeated for subsequent sampling instants.

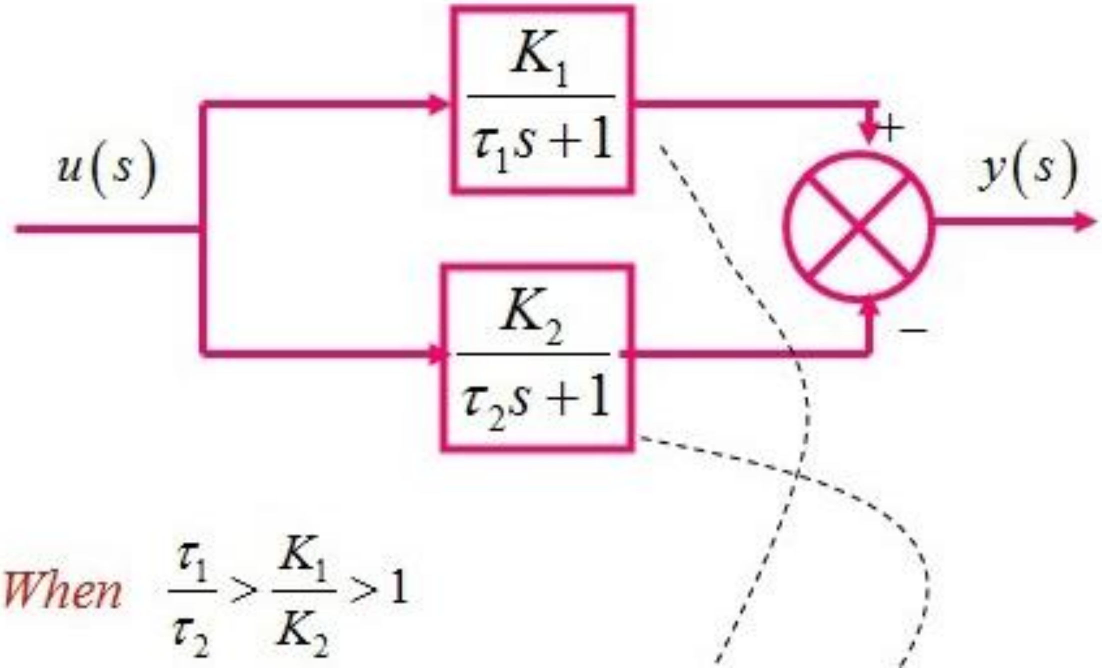
General Characteristics

Targets (set points) selected by real-time optimization software based on current operating and economic conditions.

- Minimize square of deviations between predicted future outputs and specific reference trajectory to new targets.
- Discrete step response model.
- Framework handles multiple input, multiple output (MIMO) control problem.

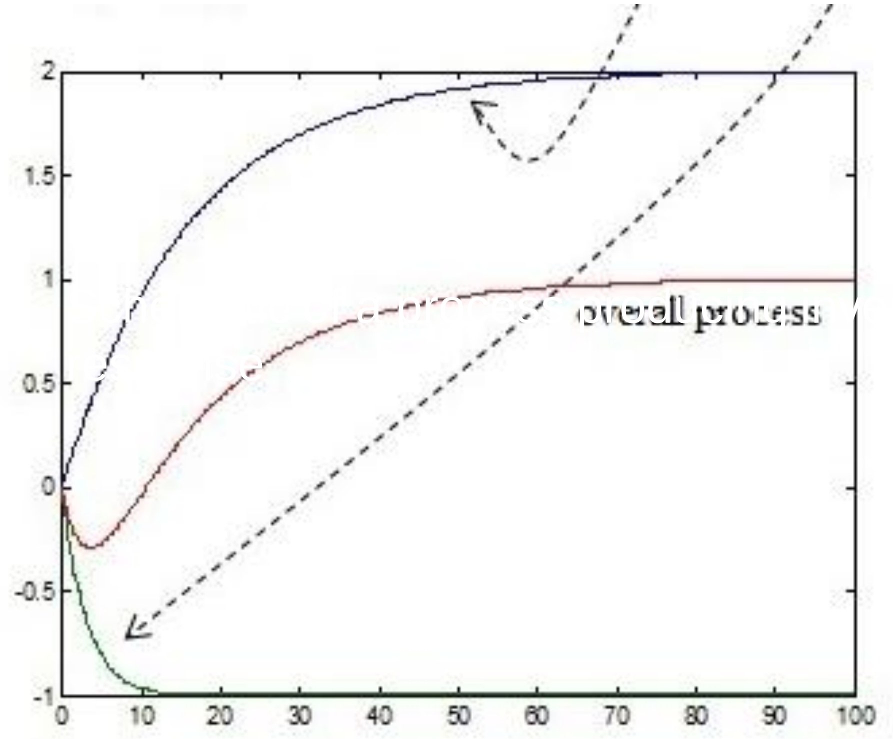
Processes with inverse response

Let us assume two first order processes $\frac{K_1}{\tau_1+1}$ and $\frac{K_2}{\tau_2+1}$, where $\frac{\tau_1}{\tau_2} > \frac{K_1}{K_2} > 1$, are arranged in the following manner



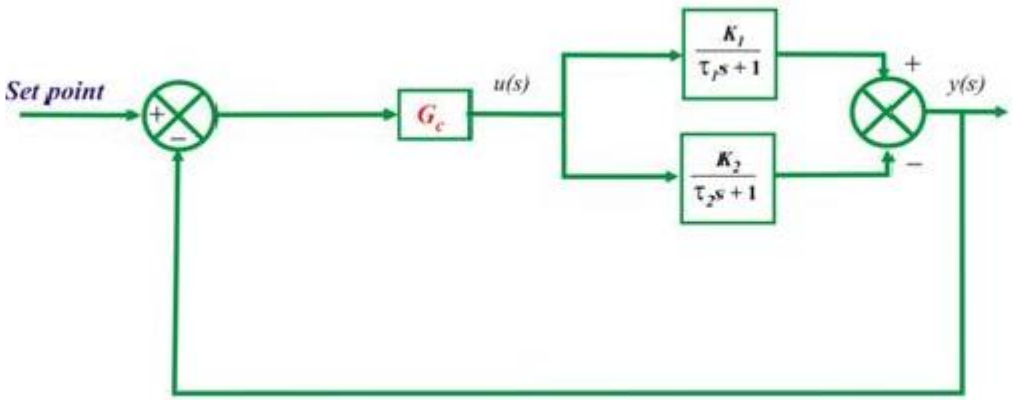
When $\frac{\tau_1}{\tau_2} > \frac{K_1}{K_2} > 1$

Schematic of a process producing inverse response

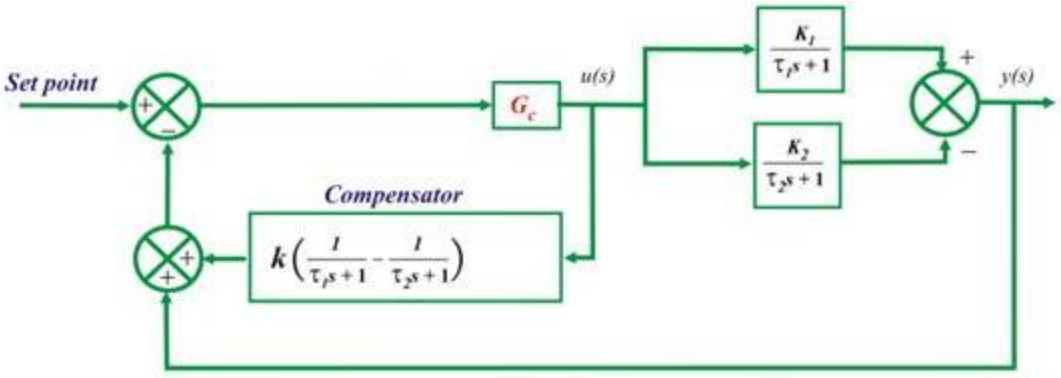


- As the Process 2 will be faster than Process 1.
- Hence, the initial direction of the overall process response will be guided by the Process 2 in the negative direction.
- On the other hand, indicates that Process 1 will guide the ultimate steady state in the positive direction by virtue of its higher gain than the Process 2.
- As a result the overall process response curve will initially transit towards in the opposite direction of its final steady state.
- However, the transition will change its direction after some time and finally settle at the steady state value.
- This type of response is termed as inverse response.

Compensation for inverse response



(a) Conventional



(b) With compensator

UNIT-III
Programmable logic control systems

Objectives

- To define the basic components of a PLC.
- To apply PLC based control to a manufacturing system.
- To be identify instrumentation required to implement a PLC control system.
- To program a PLC.
- To implement a PLC control program and hardware.

PURPOSE OF Programmable Logic Controllers (PLCs)

•Initially designed to replace relay logic boards

Sequence device actuation

Coordinate activities

•Accepts input from a series of switches

Sends output to devices or relays

FUNCTIONS OF CONTROLLERS

1) on-off control,
2) sequential control,
3) feedback control, and
4) motion control.

CONTROL DEVICES

1) mechanical control - cam, governor, etc.,

2) pneumatic control - compressed air, valves, etc.

3) electromechanical control - switches, relays, a timer, counters, etc,

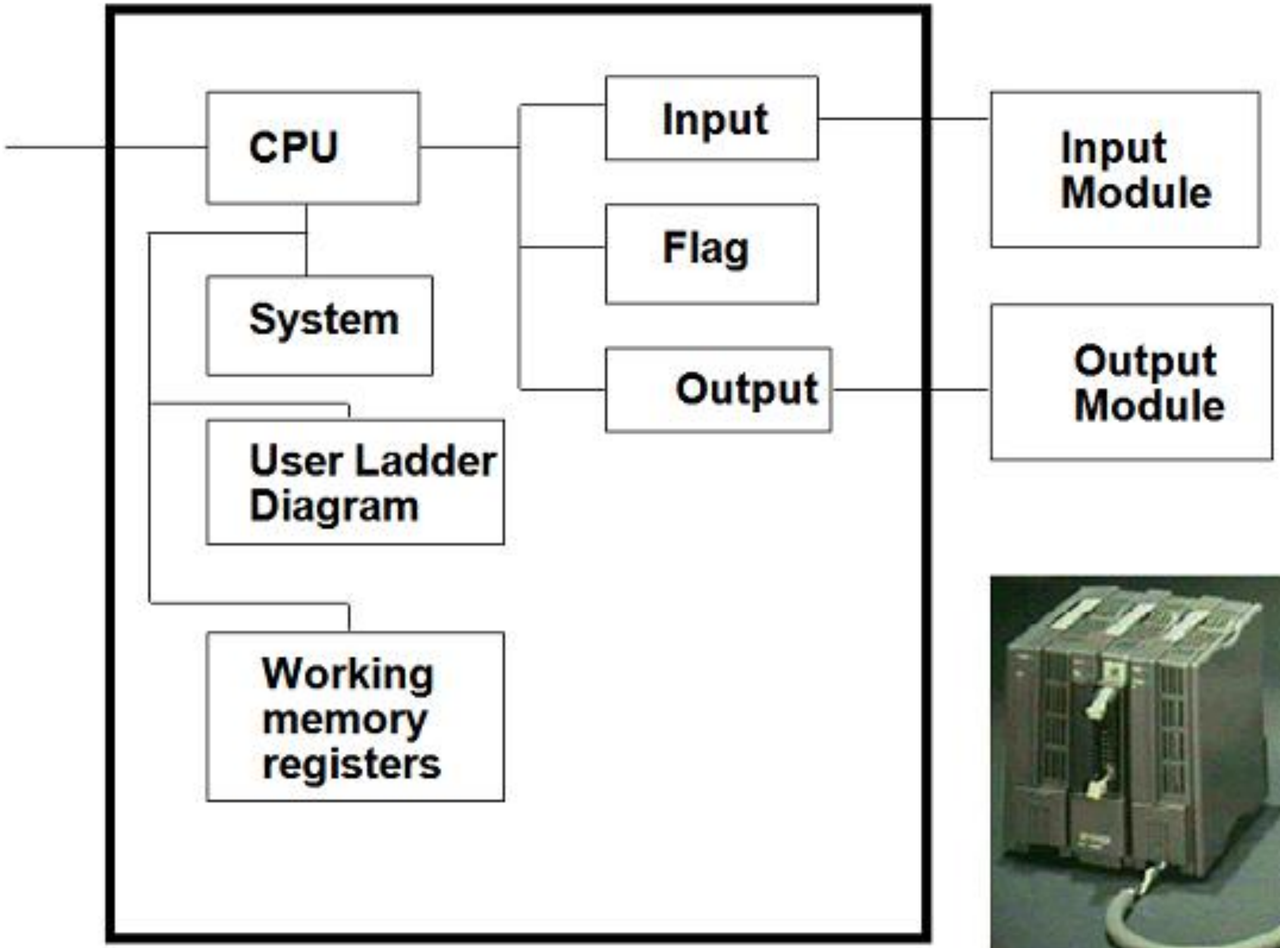
4) electronics control - similar to electromechanical control, except uses electronic switches.

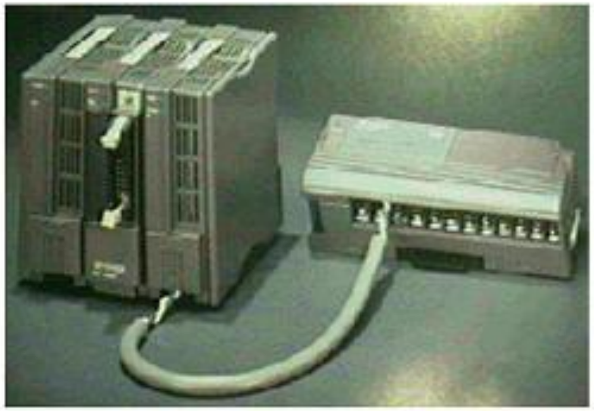
5) computer control.

PROGRAMMABLE LOGIC CONTROLLER

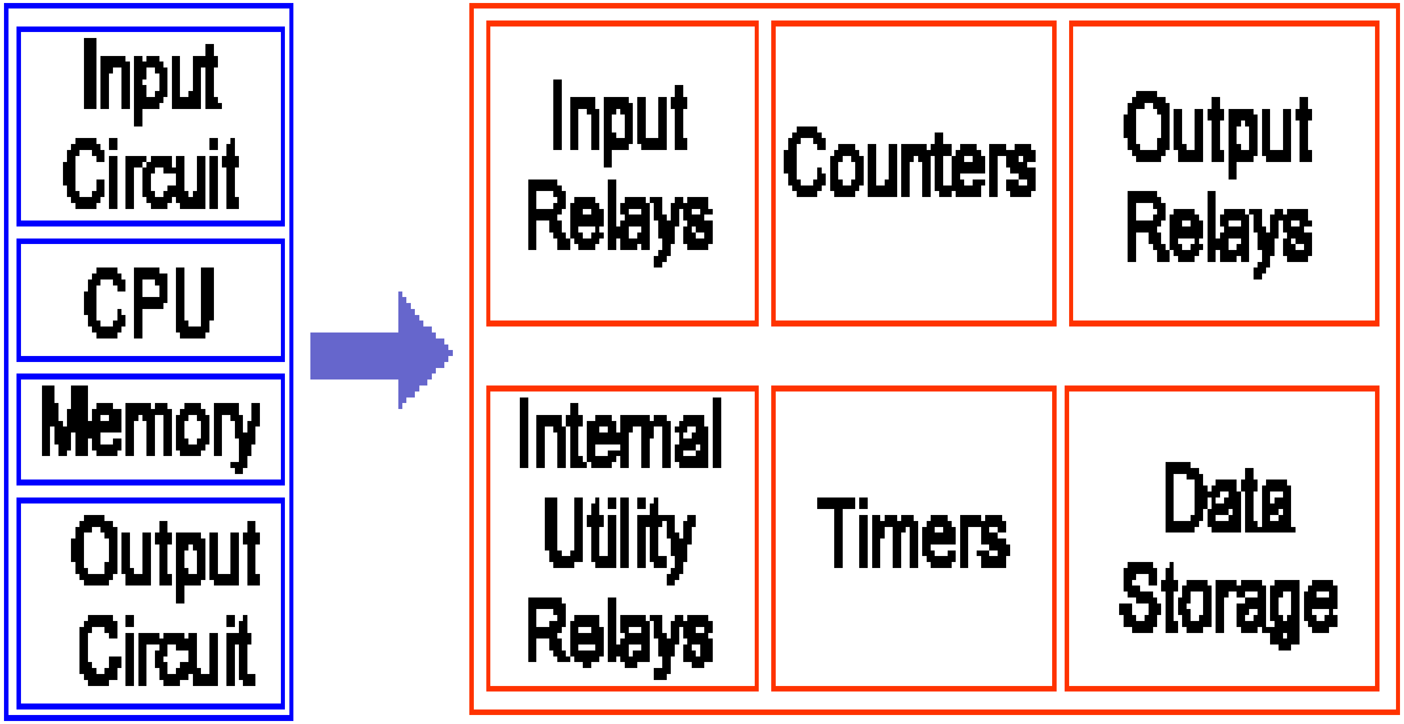
"A digitally operating electronic apparatus which uses a programmable memory for the internal storage of instructions by implementing specific functions such as logic sequencing, timing, counting, and arithmetic to control, through digital or analog input/output modules, various types of machines or processes. The digital computer which is used to perform the functions of a programmable controller is considered to be within this scope. Excluded are drum and other similar mechanical sequencing controllers."

PLC


CPU
Input
Flag
Output
System
User Ladder Diagram
Working memory registers
Input Module
Output Module



PLC Configuration



What devices does a PLC interact with?

INPUT RELAYS-(contacts)These are connected to the outside world. They physically exist and receive signals from switches, sensors, etc. Typically they are not relayas but rather they are transistors.

INTERNAL UTILITY RELAYS-(contacts) These do not receive signals from the outside world nor do they physically exist. They are simulated relays and are what enables a PLC to eliminate external relays. There are also some special relays that are dedicated to performing only one task. Some are always on while some are always off. Some are on only once during power-on and are typically used for initializing data that was stored.

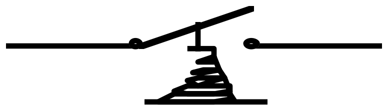
COUNTERS-These again do not physically exist. They are simulated counters and they can be programmed to count pulses. Typically these counters can count up, down or both up and down. Since they are simulated they are limited in their counting speed. Some manufacturers also include high-speed counters that are hardware based. We can think of these as physically existing. Most times these counters can count up, down or up and down. a

TIMERS-These also do not physically exist. They come in many varieties and increments. The most common type is an on-delay type. Others include off-delay and both retentive and non-retentive types. Increments vary from 1ms through 1s.

OUTPUT RELAYS-(coils)These are connected to the outside world. They physically exist and send on/off signals to solenoids, lights, etc. They can be transistors, relays, or triacs depending upon the model chosen.

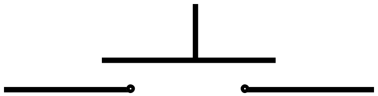
DATA STORAGE-Typically there are registers assigned to simply store data. They are usually used as temporary storage for math or data manipulation. They can also typically be used to store data when power is removed from the PLC. Upon power-up they will still have the same contents as before power was removed. Very convenient and necessary!!

SWITCHES

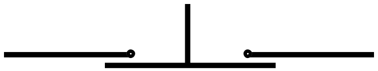


Non-locking

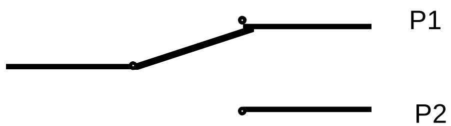
Locking



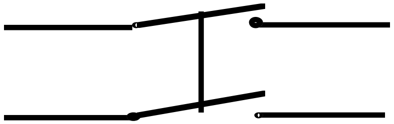
Normally Open



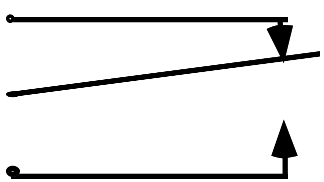
Normally Closed



Multiple Throw



Multiple Pole



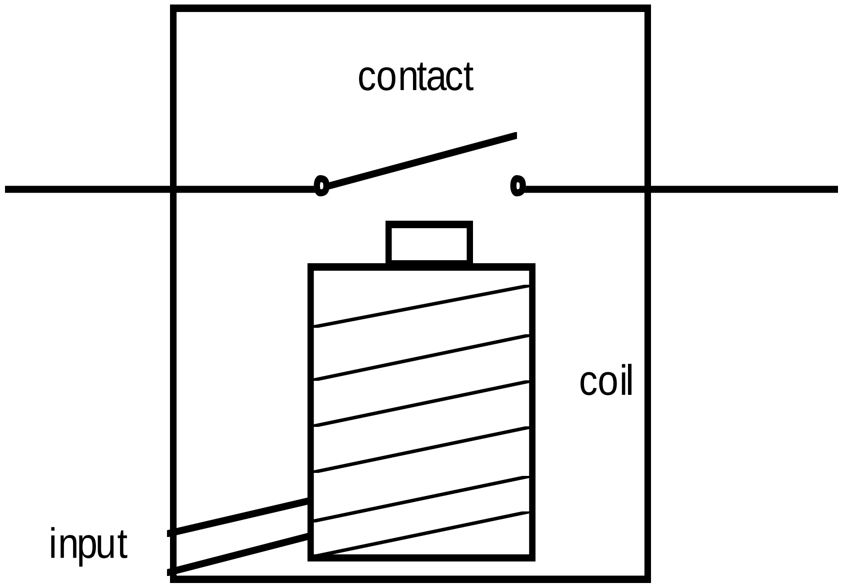
Break-before-make

Make-before-break

TYPES OF SWITCHES

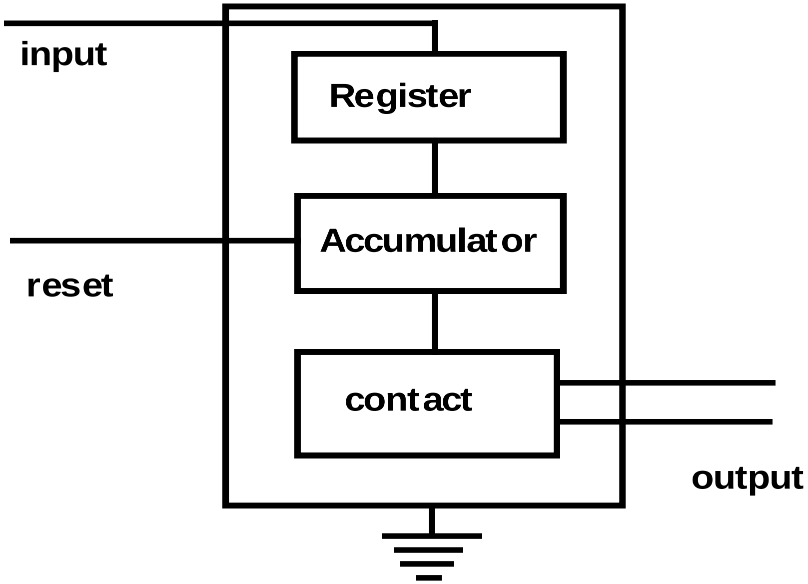
1. Basic switch, operated by a mechanical level
2. Push-button switch,
3. Slide switch,
4. Thumbwheel switch,
5. Limit switch,
6. Proximity switch, and
7. Photoelectric switch.

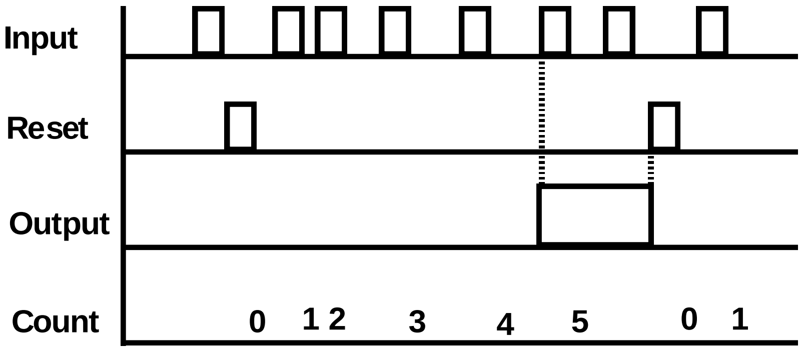
A switch whose operation is activated by an electromagnet is called a "relay"



COUNTER

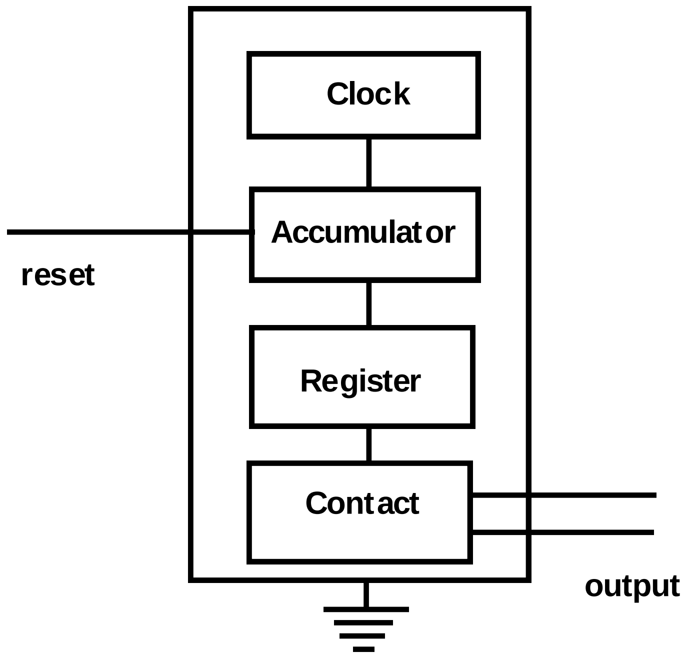
Digital counters output in the form of a relay contact when a pre assigned count value is reached.

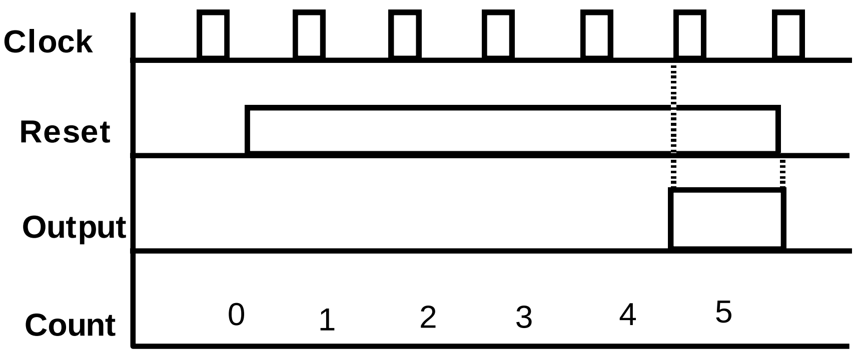




TIMER

A timer consists of an internal clock, a count value register, and an accumulator. It is used for or some timing purpose.

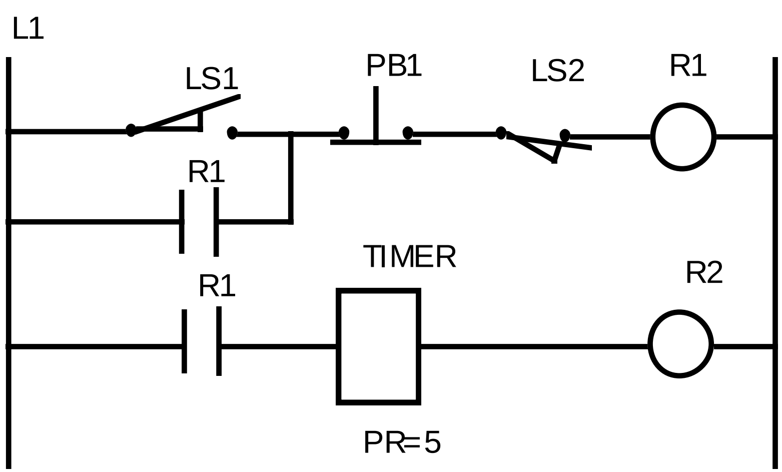


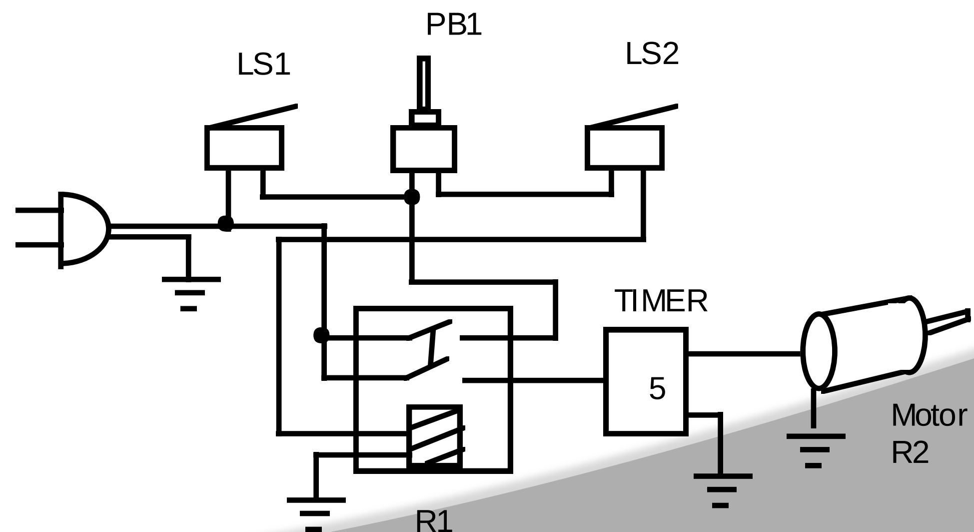


Time 5 seconds.

AN EXAMPLE OF RELAY LOGIC

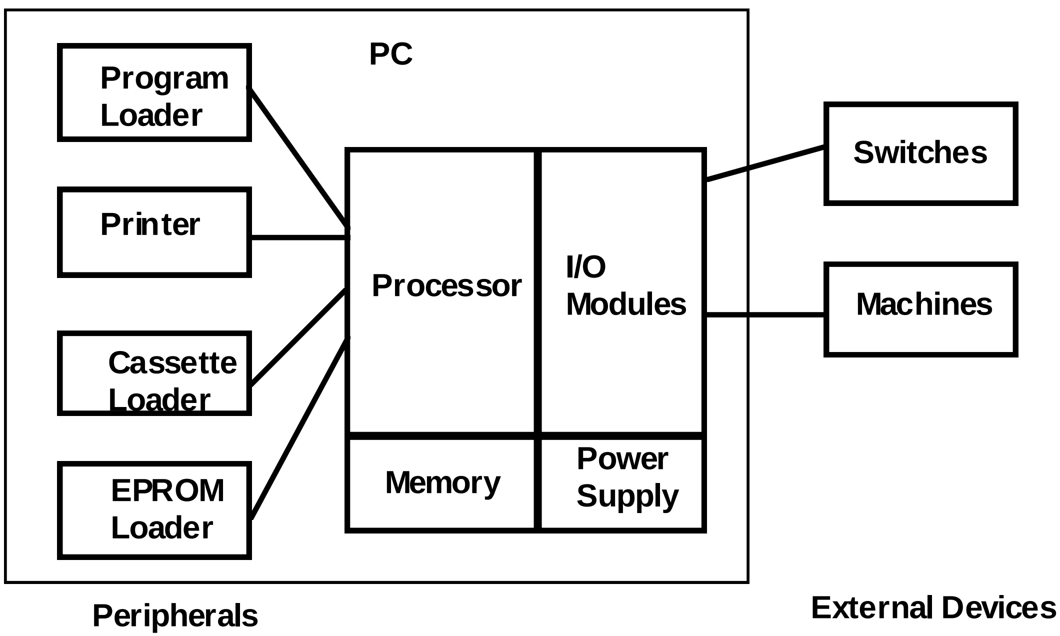
For process control, it is desired to have the process start (by turning on a motor) five seconds after a part touches a limit switch. The process is terminated automatically when the finished part touches a second limit switch. An emergency switch will stop the process any time when it is pushed.





PLC ARCHITECTURE

Programmable controllers replace most of the relay panel wiring by software programming.



PLC COMPONENTS

1. Processor Microprocessor based, may allow arithmetic operations, logic operators, block memory moves, computer interface, local area network, functions
2. 2. Memory Measured in words.

ROM (Read Only Memory),

RAM (Random Access Memory),

PROM (Programmable Read Only Memory),

EEPROM (Electronically Erasable Programmable ROM),

EPROM (Erasable Programmable Read Only Memory),

EAPROM (Electronically Alterable Programmable Read Only Memory), and

Bubble Memory.

3. I/O Modular plug-in periphery

AC voltage input and output,

DC voltage input and output,

Low level analog input,

High level analog input and output,

Special purpose modules, e.g.., high speed timers,

Stepping motor controllers, etc. PID, Motion

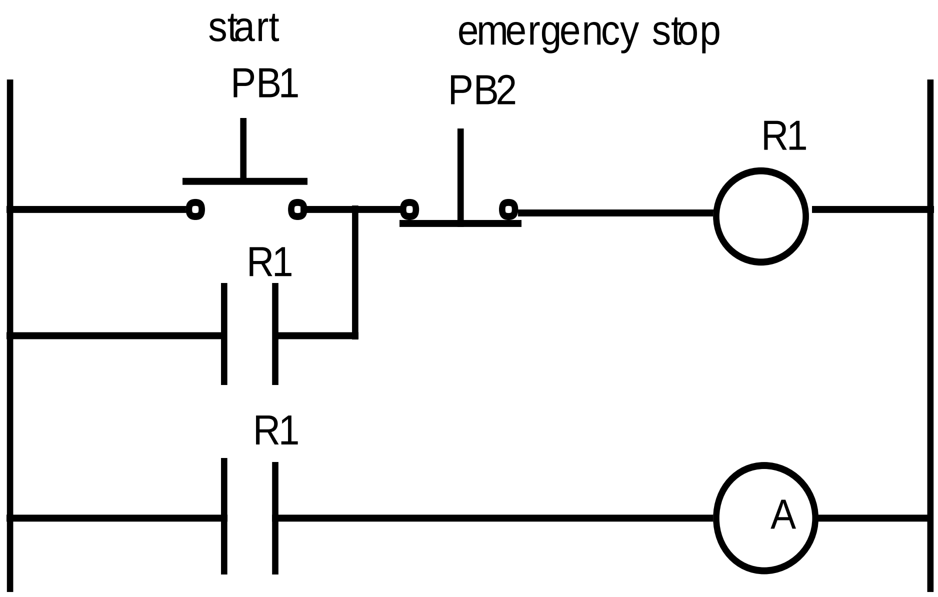
4. Power supply AC power

5. Peripheral Hand held programmer (loader),

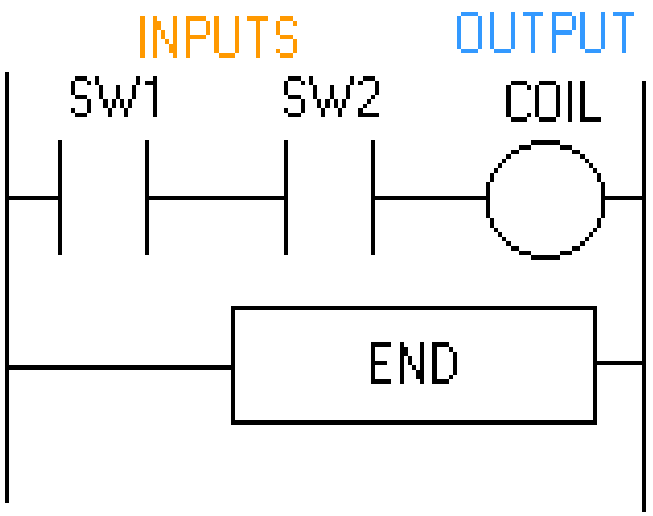
CRT programmer, Operator console, Printer, Simulator, EPROM loader, Cassette loader, Graphics processor, and Network communication interface. MAP, LAN

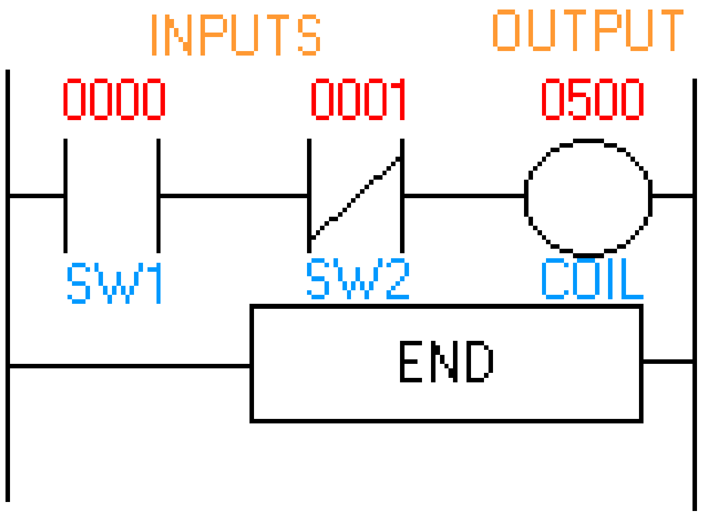
LADDER DIAGRAM

A ladder diagram (also called contact symbology) is a means of graphically representing the logic required in a relay logic system.

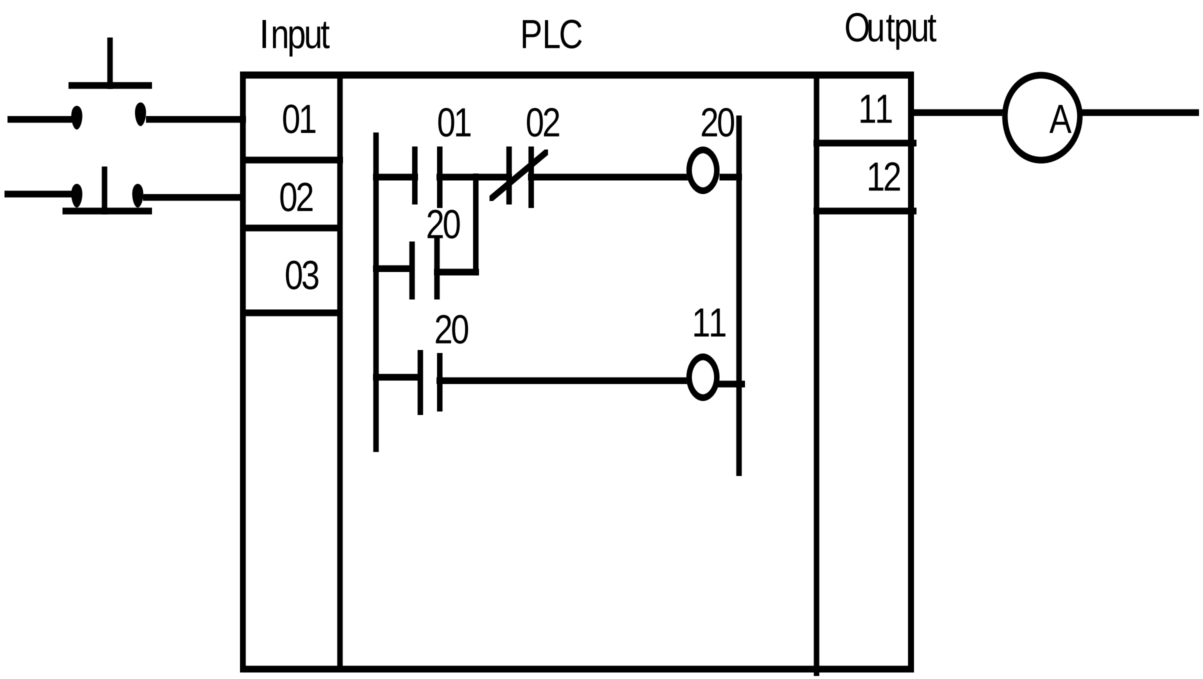


Ladder Representation





PLC WIRING DIAGRAM



SCAN

A PLC resolves the logic of a ladder diagram (program) rung by rung, from the top to the bottom. Usually, all the outputs are updated based on the status of the internal registers. Then the input states are checked and the corresponding input registers are updated. Only after the I/Os have been resolved, is the program then executed. This process is run in a endless cycle. The time it takes to finish one cycle is called the scan time.

PLC INSTRUCTIONS

1) Relay,

2) Timer and counter,

3) Program control,

4) Arithmetic,

5) Data manipulation,

6) Data transfer, and

7) Others, such as sequencers.

LOGIC STATES

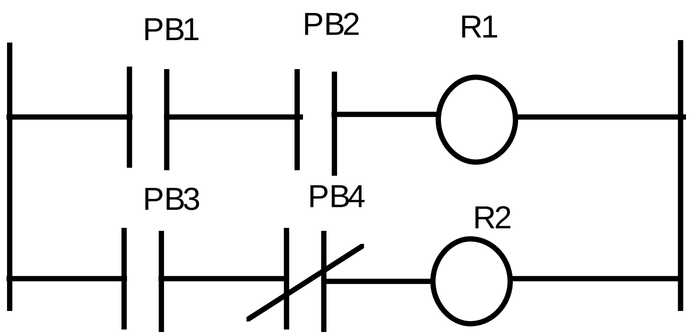
ON : TRUE, contact closure, energize, etc.

OFF: FALSE, contact open , de-energize, etc.

Do not confuse the internal relay and program with the external switch and relay. Internal symbols are used for programming. External devices provide actual interface.

AND and OR LOGIC

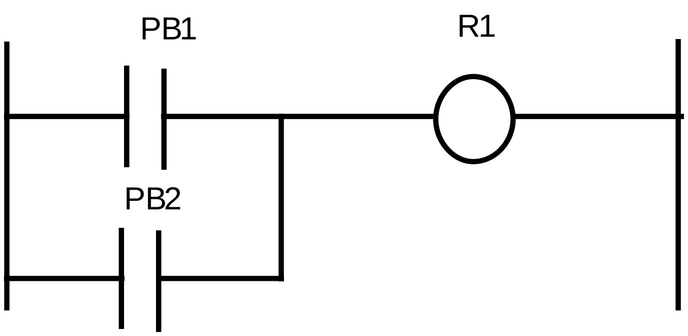
AND



R1 = PB1.AND.PB2

R2 = PB2.AND.~PB4

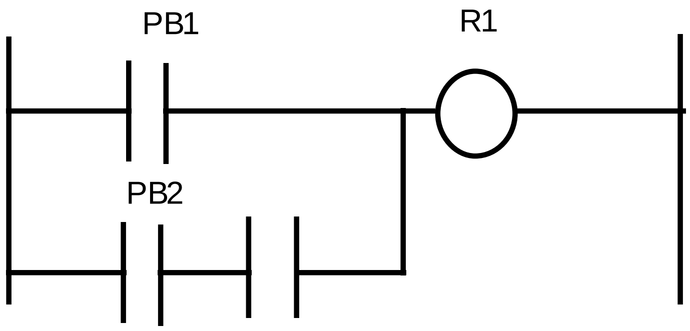
OR



R1 = PB1 .OR. PB2

COMBINED AND & OR

R1 = PB1 .OR. (PB2 .AND. PB3)



RELAY

Contacts

a. Normally open -| |-

b. Normally closed -|/|-

c. Off-on transitional -|?|-

d. On-off transitional -|? |-

Coil:

a. Energize Coil -( )-

b. De-energize -(/)-

c. Latch -(L)-

d. Unlatch -(U)-

TIMERS AND COUNTERS

Timers:

a. Retentive on delay -(RTO)-

b. Retentive off delay -(RTF)-

c. Reset -(RST)-

Counter:

a. Counter up -(CTU)-

b. Counter down -(CTD)-

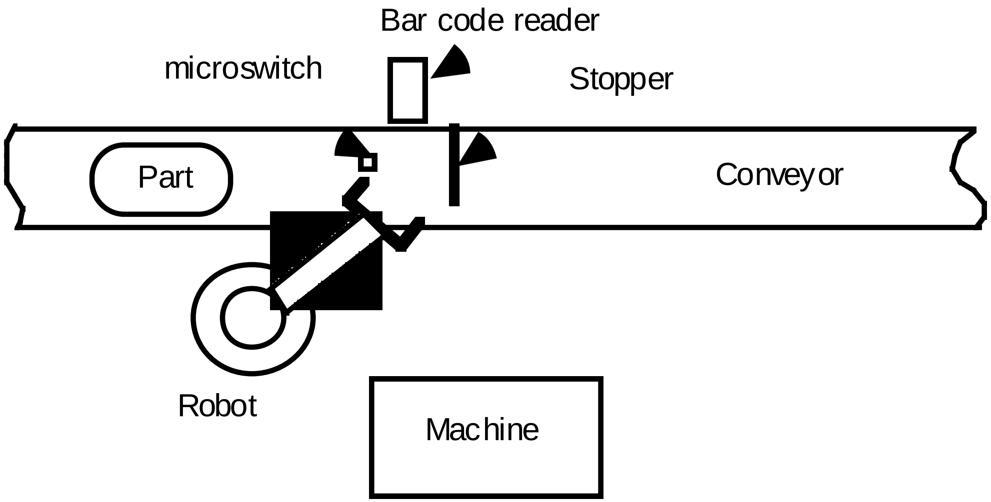
c. Counter reset

SEQUENCER

Sequencers are used with machines or processes involving repeating operating cycles which can be segmented into steps.

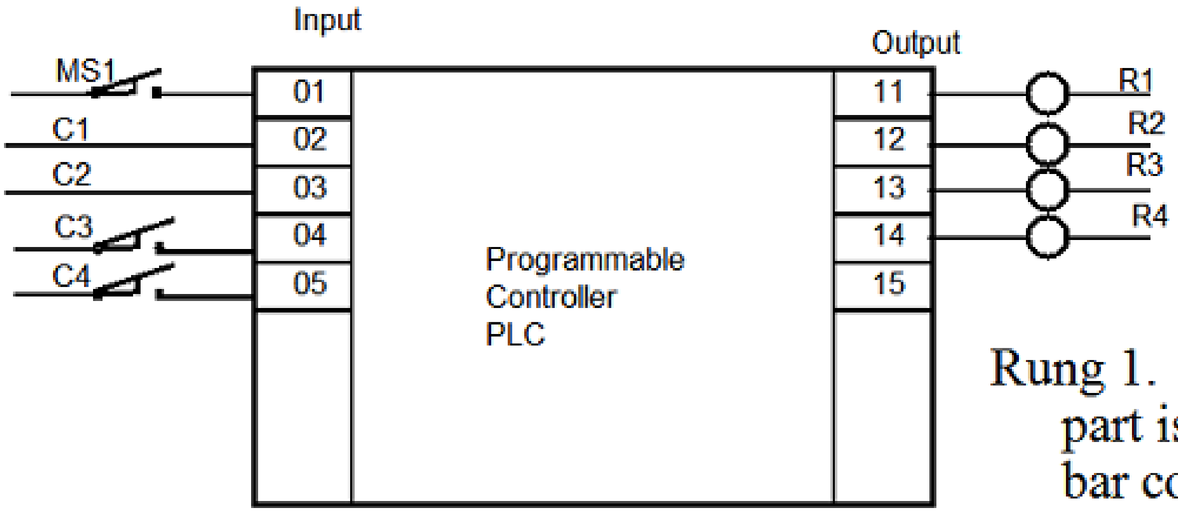
	Output			
Step	A	B	C	Dwell time
1	ON	OFF	OFF	5 sec.
2	ON	ON	OFF	10 sec.
3	OFF	OFF	ON	3 sec.
4	OFF	ON	OFF	9 sec.

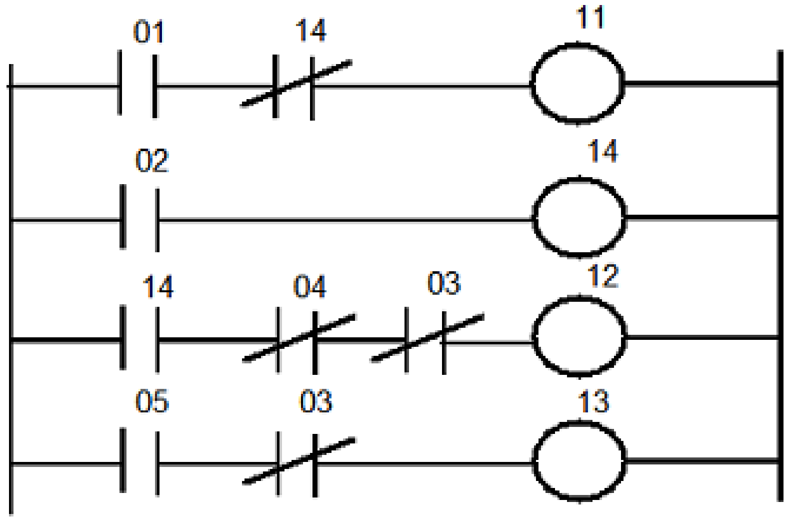
PROGRAMMING EXAMPLE 1



id	description	state	explanation
MSI	microswitch	1	part arrive
R1	output to bar code reader	1	scan the part
C1	input from bar code reader	1	right part
R2	output robot	1	loading cycle
R3	output robot	1	unloading cycle
C2	input from robot	1	robot busy
R4	output to stopper	1	stopper up
C3	input from machine	1	machine busy
C4	input from machine	1	task complete

SOLUTION





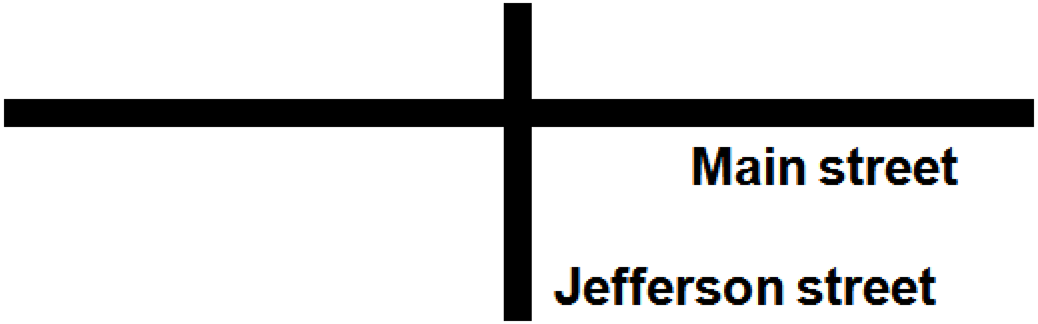
Rung 1. If part arrives and no part is stopped, trigger the bar code reader.

Rung 2. If it is a right part, activate the stopper.

Rung 3. If the stopper is up, the machine is not busy and the robot is not busy, load the part onto the machine.

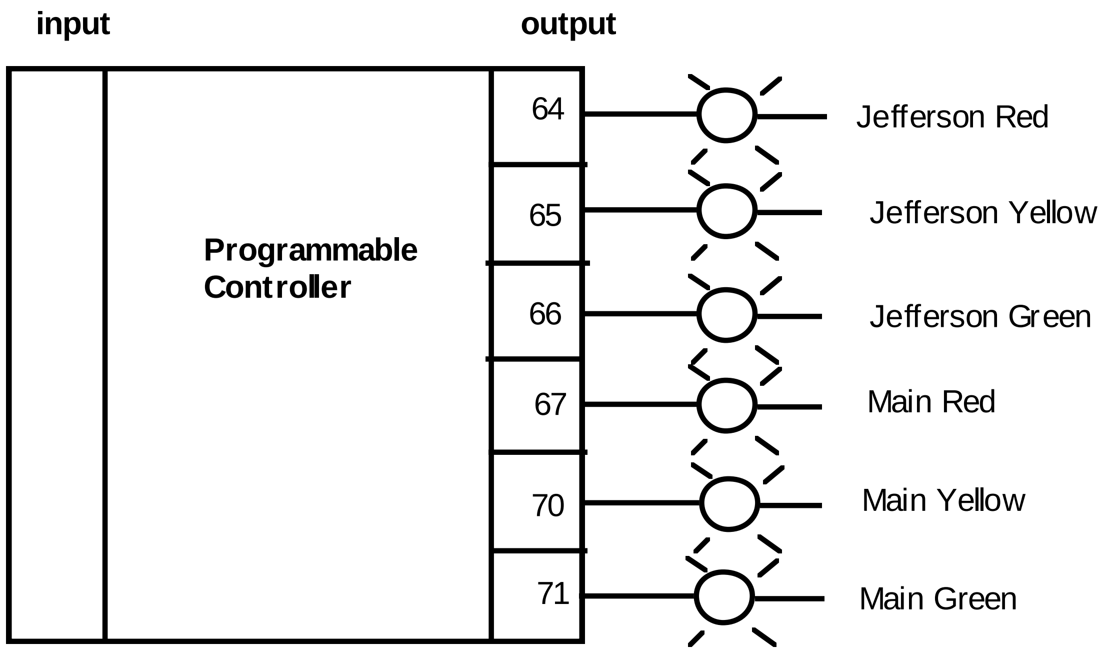
Rung 4. If the task is completed and the robot is not busy, unload the machine.

EXAMPLE 2 TRAFFIC LIGHTS

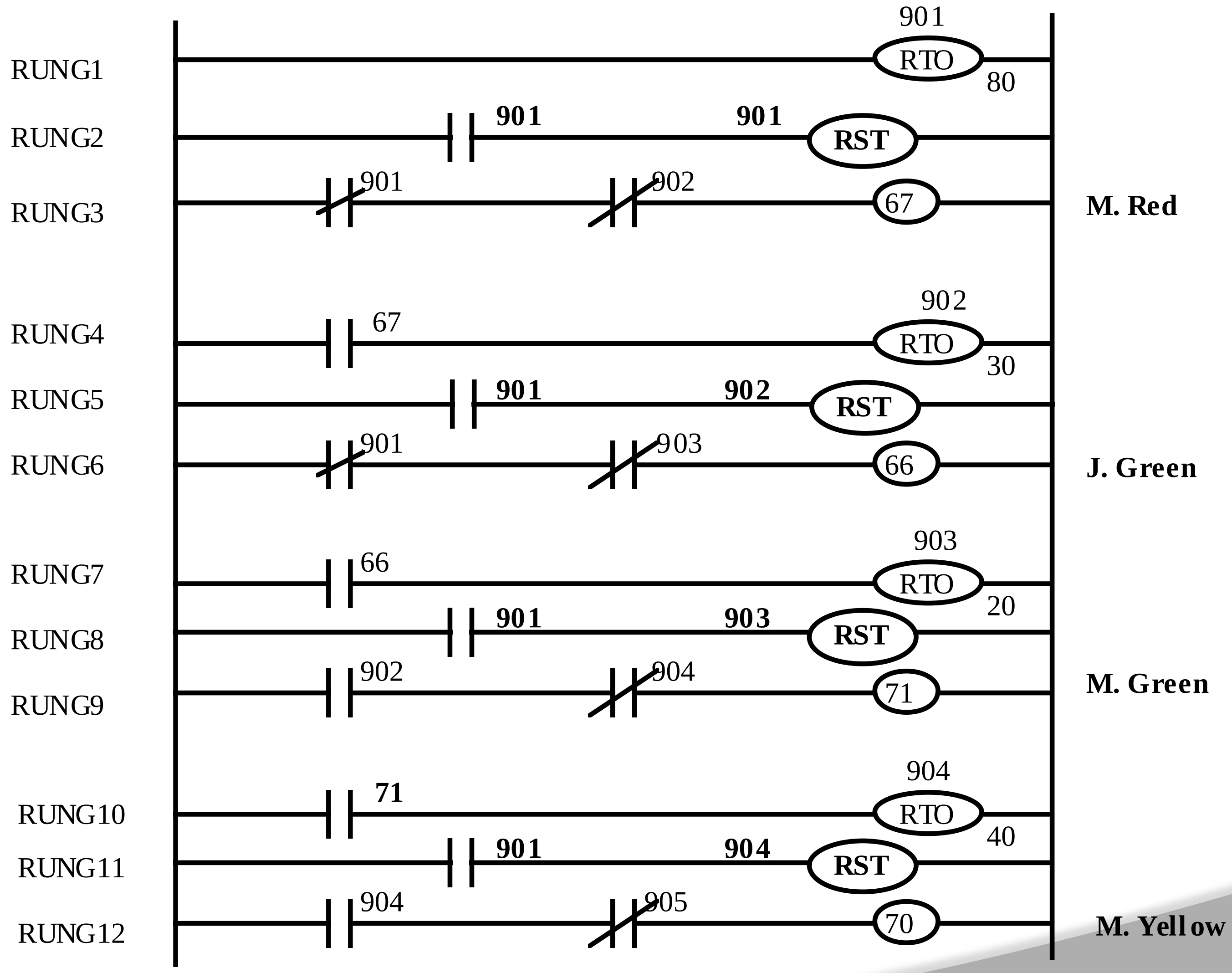


Cycle time			
Street	Red	Yellow	Green
Main	3	1	4
Jefferson	5	1	2

WIRING DIAGRAM

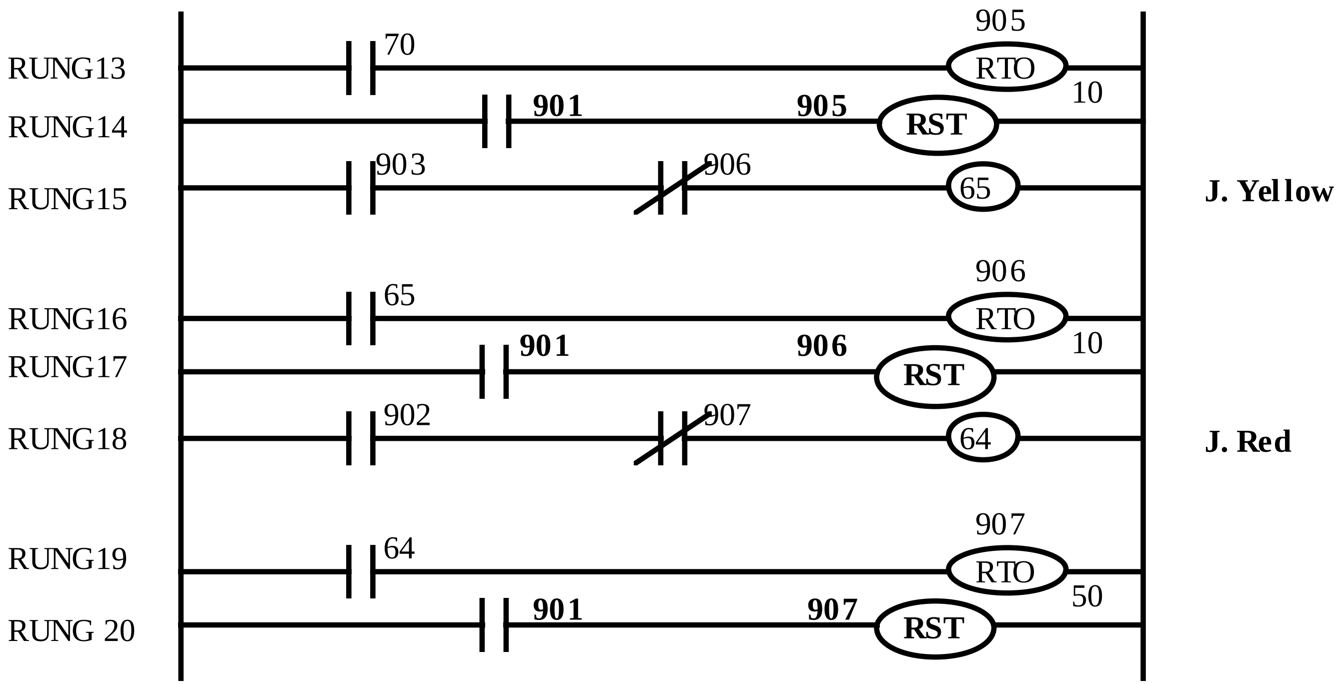


PROGRAM (1)



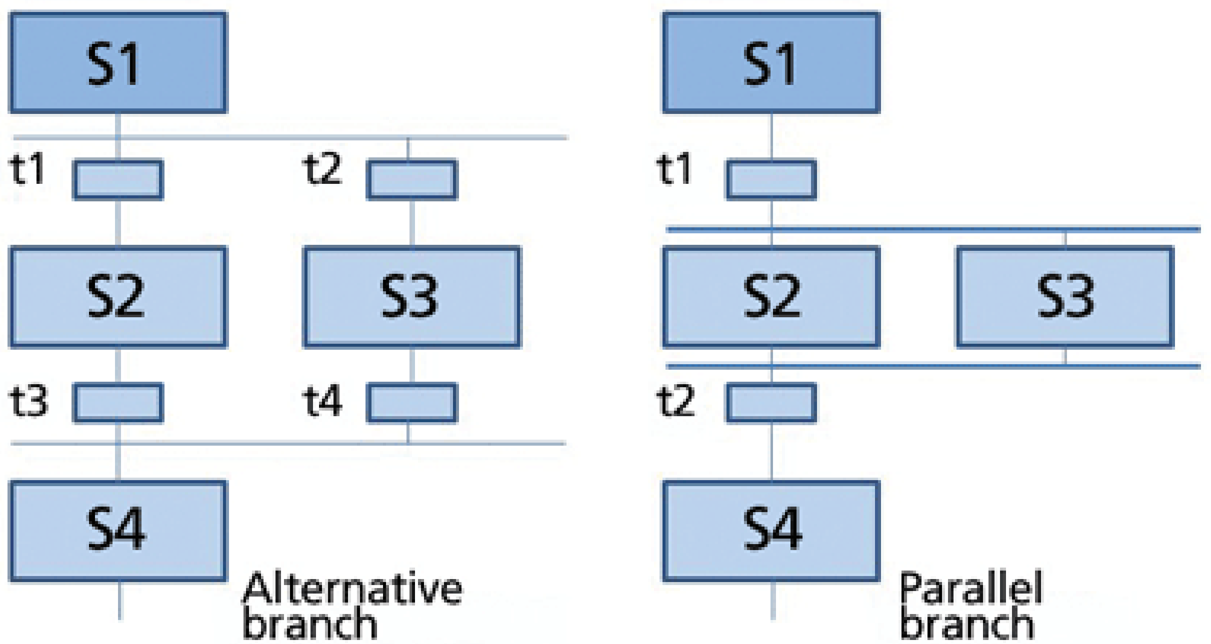
RUNG1
RUNG2
RUNG3
RUNG4
RUNG5
RUNG6
RUNG7
RUNG8
RUNG9
RUNG10
RUNG11
RUNG12
901
RTO
80
901
901
RST
901
902
67
M. Red
67
902
RTO
30
901
902
RST
901
903
66
J. Green
66
903
RTO
20
901
903
RST
902
904
71
M. Green
71
904
RTO
40
901
904
RST
904
905
70
M. Yell ow

PROGRAM (2)


RUNG13
70
905
RTO
10
RUNG14
901
905
RST
RUNG15
903
906
65
J. Yellow
RUNG16
65
906
RTO
10
RUNG17
901
906
RST
RUNG18
902
907
64
J. Red
RUNG19
64
907
RTO
50
RUNG 20
901
907
RST

Sequential function charts

Sequential function charts (or SFCs) are one of the five PLC programming languages defined by the IEC 61131-3 standard. (The others being ladder logic diagrams, function block diagrams, structured text and instruction lists.) SFCs are a graphical programming language, not text-based. Being a visual programming language means that it's well suited to the task of breaking down a large and complex process into smaller pieces that are easier to see and understand than with solely text-based programming environments.



A typical SFC diagram with steps labeled S and transitions T, showing different branch structures. (Image via ISA)

The key concepts underlying SFCs are steps and transitions. A step is basically some function within the overall system, like an individual machine process. A transition is just that, the change from one step to another step or state. Beyond the basics, SFC programs can also include standard logical programming techniques such as feedback loops and branching (either parallel or alternative branches.) SFCs can also be designed with the aide of state diagrams.

Because SFCs are graphical programming environments, it makes other tasks surrounding PLC programming that much easier and even more intuitive. For instance, tasks such as initial design, debug, and troubleshooting the program itself.

PLC manufacturers typically offer more detailed information about SFCs, including programming instructions for their specific product offerings.

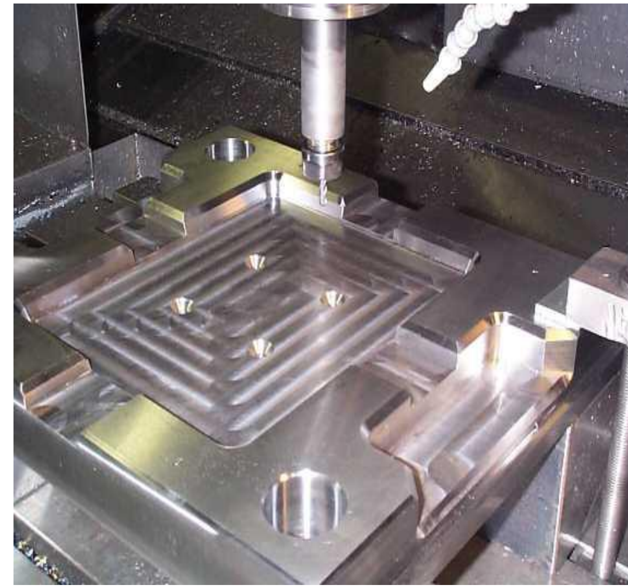
UNIT-IV
CNC Machines and Actuators

Introduction to CNC

- Numerical control (NC) is the automation of machine tools that are operated by precisely programmed commands encoded on a storage medium, as opposed to controlled manually.
- Most NC today is computer numerical control (CNC), in which computers play an integral part of the control.
- In modern CNC systems, end-to-end component design is highly automated using computer-aided design (CAD) and computer-aided manufacturing (CAM) programs.

Operations in CNC

CNC Plasma Cutter



CNC Milling

CNC Electric Discharge Machining


5-Tailstock Quill
4-Tailstock
3-Chuck
7-CNC Control Panel
8-Tool Turret
ROMI
C 620
1-Headstock
2-Bed
6-Foot Switches or Pedals

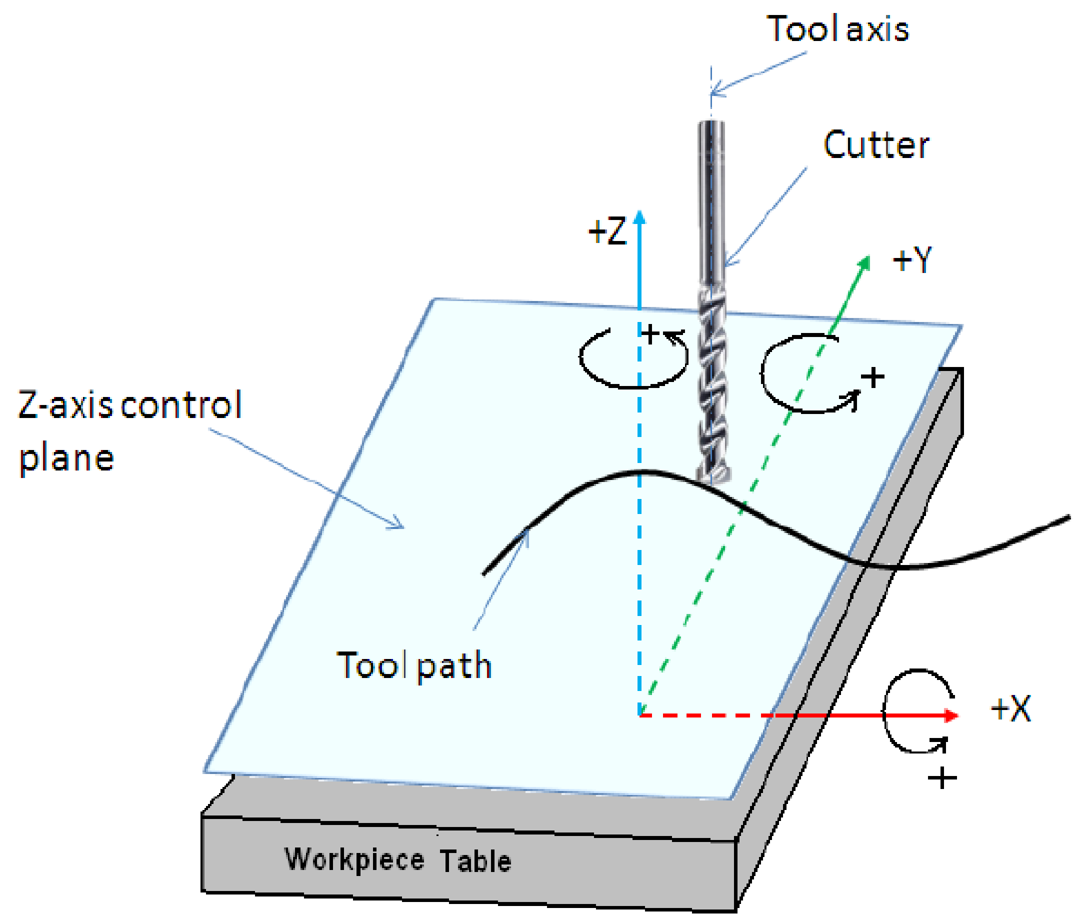
Other CNC Operations are:-

- CNC Water Jet Cutter
- Drilling
- Sheet metal works (Turret punch)
- Wire bending machines
- Surface grinders
- Cylindrical grinders

Advantages of CNC

- CNC machines can be used continuously
- Batch production with high accuracy
- can be updated by improving the software
- Training in the use of CNCs is available through the use of ‘virtual software’.
- Intricate detail machining
- no need to make a prototype or a model
- One person can supervise many CNC machines simultaneously
- saves time

Axes of CNC Machine Tool

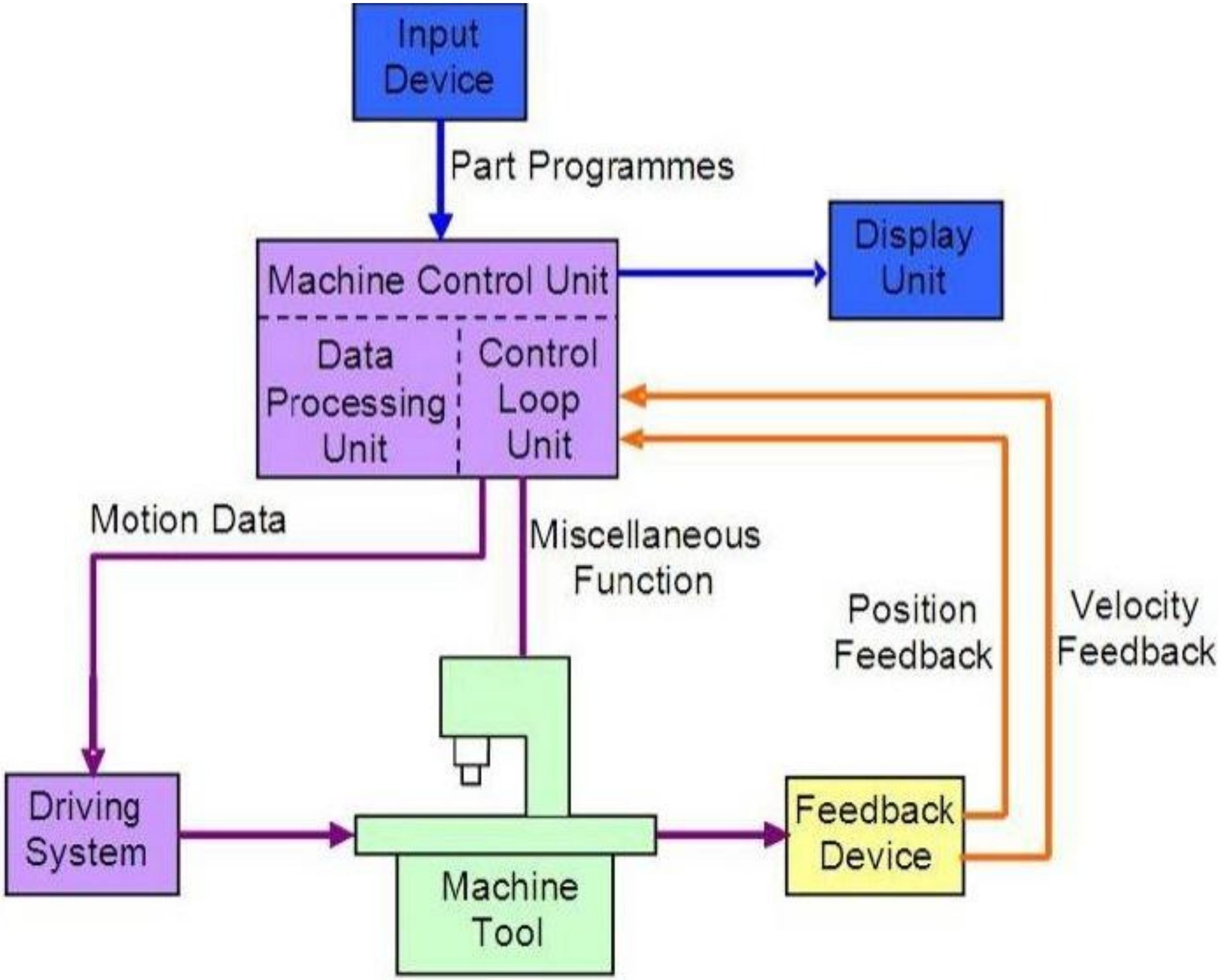


Elements of CNC Machine

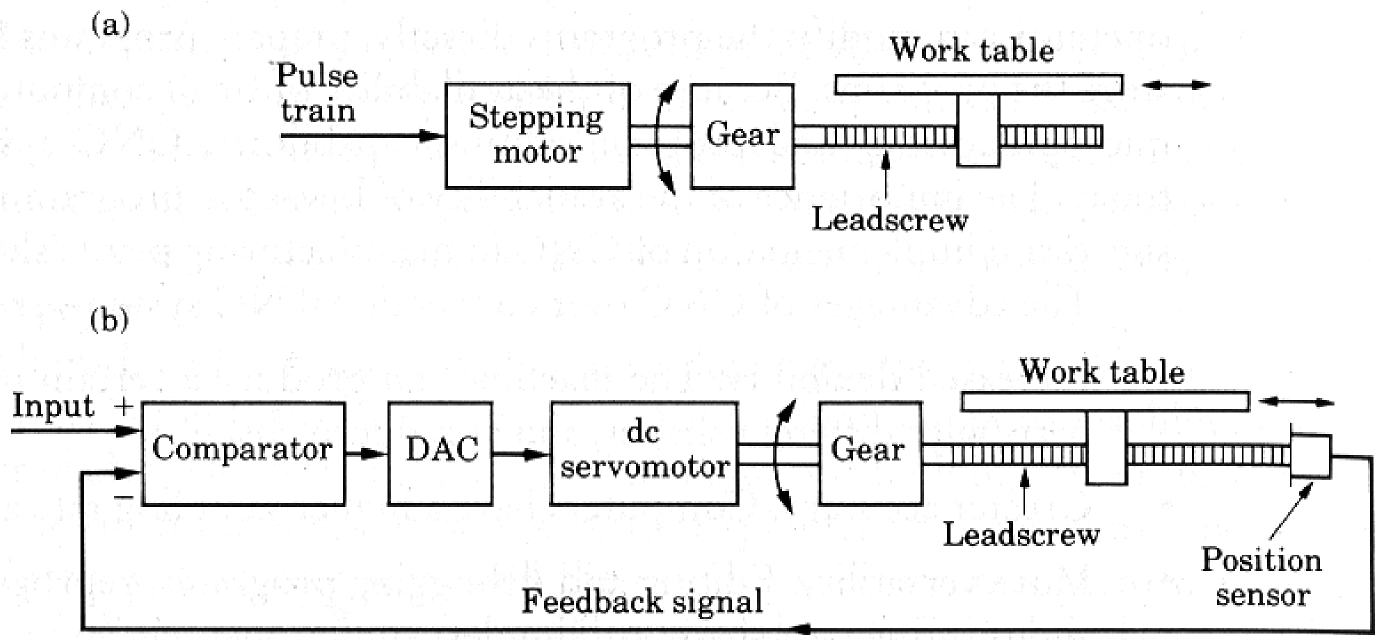
A CNC machine consist of following 6 major elements:

i. Input Device
ii. Machine Control Unit
iii. Machine Tool
iv. Driving System
v. Feedback Devices
vi. Display Unit

Block diagram of CNC Machine



Open loop and Closed loop controls



How CNC Works

- Controlled by G and M codes.
- These are number values and co-ordinates.
- Each number or code is assigned to a particular operation.
- Typed in manually to CAD by machine operators.
- G & M codes are automatically generated by the computer software.

Features of CNC Machinery

- The tool or material moves automatically.
- Tools can operate in 1-5 axes.
- Larger machines have a machine control unit (MCU) which manages operations.
- Movement is controlled by motors (actuators).
- Feedback is provided by sensors (transducers)
- Tool magazines are used to change tools automatically.

What Is A Control Valve?

- The most common final control element in the process control industries is the control valve. The control valve manipulates a flowing fluid, such as gas, steam, water, or chemical compounds, to compensate for the load disturbance and keep the regulated process variable as close as possible to the desired set point.

- The control valve assembly typically consists of the valve body, the internal trim parts, an actuator to provide the motive power to operate the valve, and a variety of additional valve accessories, which can include positioners, transducers, supply pressure regulators, manual operators, snubbers, or limit switches.

Actuator: A pneumatic, hydraulic, or electrically powered device that supplies force and motion to open or close a valve.

Accessory: A device that is mounted on the actuator to complement the actuator's function and make it a complete operating unit. Examples include positioners, supply pressure regulators, solenoids, and limit switches.

Capacity (Valve): The rate of flow through a valve under stated conditions. n I/P: Shorthand for current-to-pres-sure (I-to-P). Typically applied to input transducer modules.

Positioner: A position controller (servomechanism) that is mechanically connected to a moving part of a final control element or its actuator and that automatically adjusts its output to the actuator to maintain a desired position in proportion to the input signal.

Travel: The movement of the closure member from the closed position to an intermediate or rated full open position. n Trim: The internal components of a valve that modulate the flow of the controlled fluid.

Bonnet: The portion of the valve that contains the packing box and stem seal and can guide the stem. It provides the principal opening to the body cavity for assembly of internal parts or it can be an integral part of the valve body. It can also provide for the attachment of the actuator to the valve body. Typical bonnets are bolted, threaded, welded, pressure-seals, or integral with the body. (This term is often used in referring to the bonnet and its included packing parts. More properly, this group of component parts should be called the bonnet assembly.)

Seat: The area of contact between the closure member and its mating surface that establishes valve shut-off.

Types of control valves

Globe Valves

Ball *Valves*

Butterfly Valves

Eccentric Disk

Globe valves

- Size Limitation
- Lower Capacity than Ball or Butterfly
- Overall expensive specially in large sizes
- Tight shutoff in small sizes

Butterfly Valves

Most Economical valve on a cost per flow capacity basis

Fully lined valves bore can provide tight shutoff

Low cost body material for corrosive fluid due to lined body bore

Handling of high inlet pressure and pressure drop

Eccentric Disk Valves

ECCENTRIC DISK VALVE

Balance plug Style Valve Bodies

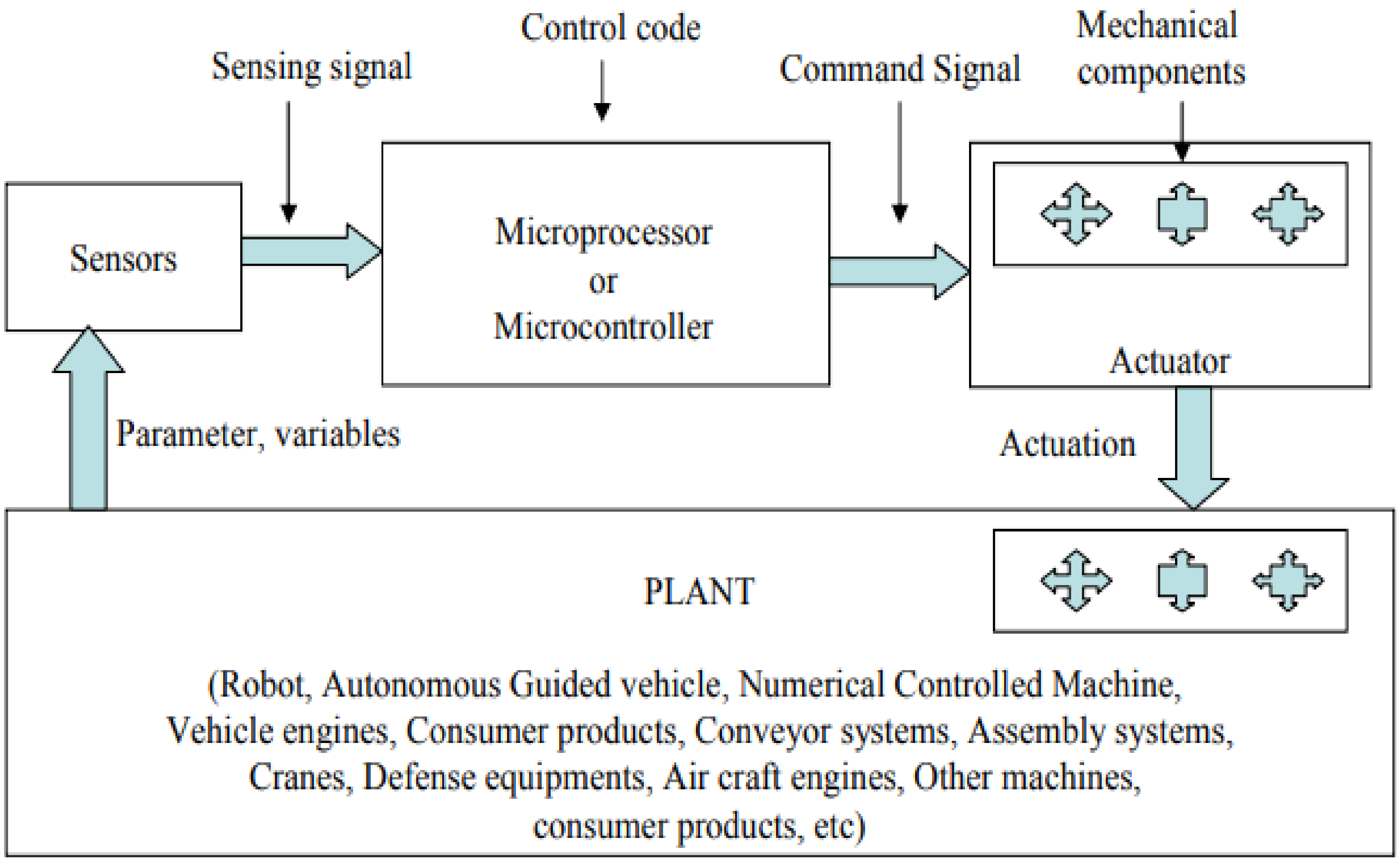
- Single ported that only one seat ring is used
- High capacity
- High capacity
- Large sizes
- Smaller actuator sizes
- Cage style allows ease of reducing trim, characteristic change
- Unbalance is double ported

Data needed for Control Valve Selection

- Type of fluid
- Temperature of fluid
- Flow rate of fluid
- Viscosity of fluid
- Specific Gravity of fluid
- Inlet pressure (Upstream)
- Outlet pressure (Downstream)
- Delta P shutoff for actuator sizing
- Pipe size/Schedule

Actuation systems

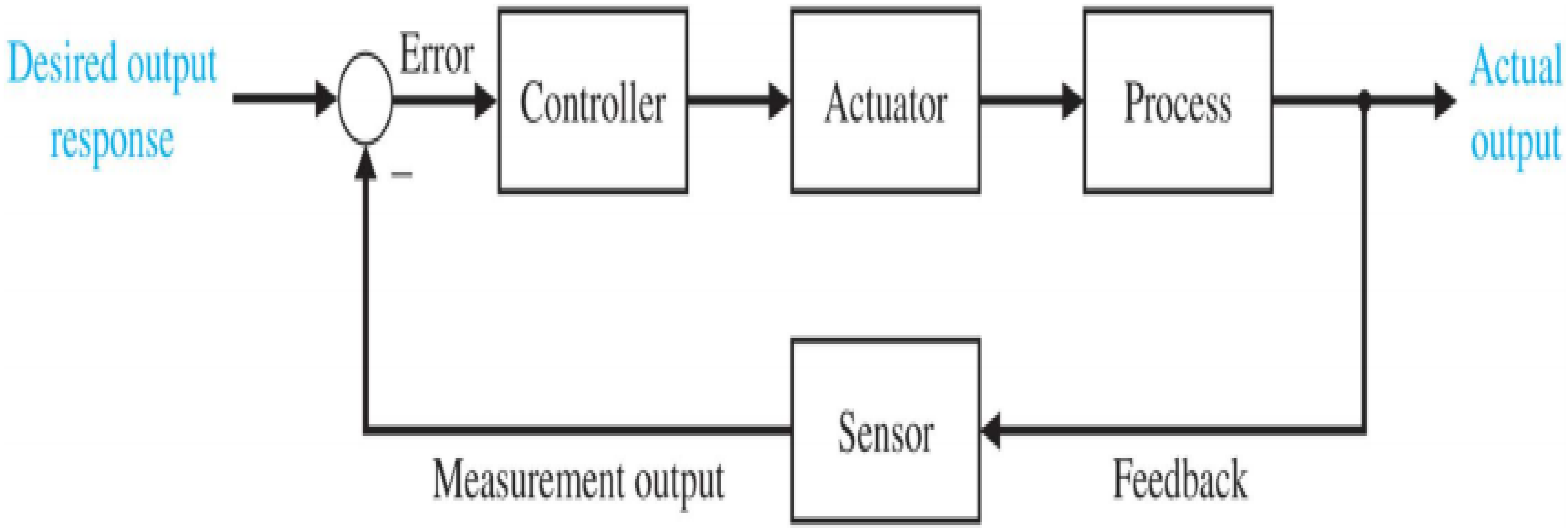
Actuation systems are the elements of control systems which are responsible for transforming the output of a microcontrollers or microprocessor or control system into a controlling action on machine or device


Control code
Sensing signal
Command Signal
Mechanical components
Sensors
Microprocessor or Microcontroller
Actuator
Parameter, variables
Actuation
PLANT
(Robot, Autonomous Guided vehicle, Numerical Controlled Machine, Vehicle engines, Consumer products, Conveyor systems, Assembly systems, Cranes, Defense equipments, Air craft engines, Other machines, consumer products, etc)

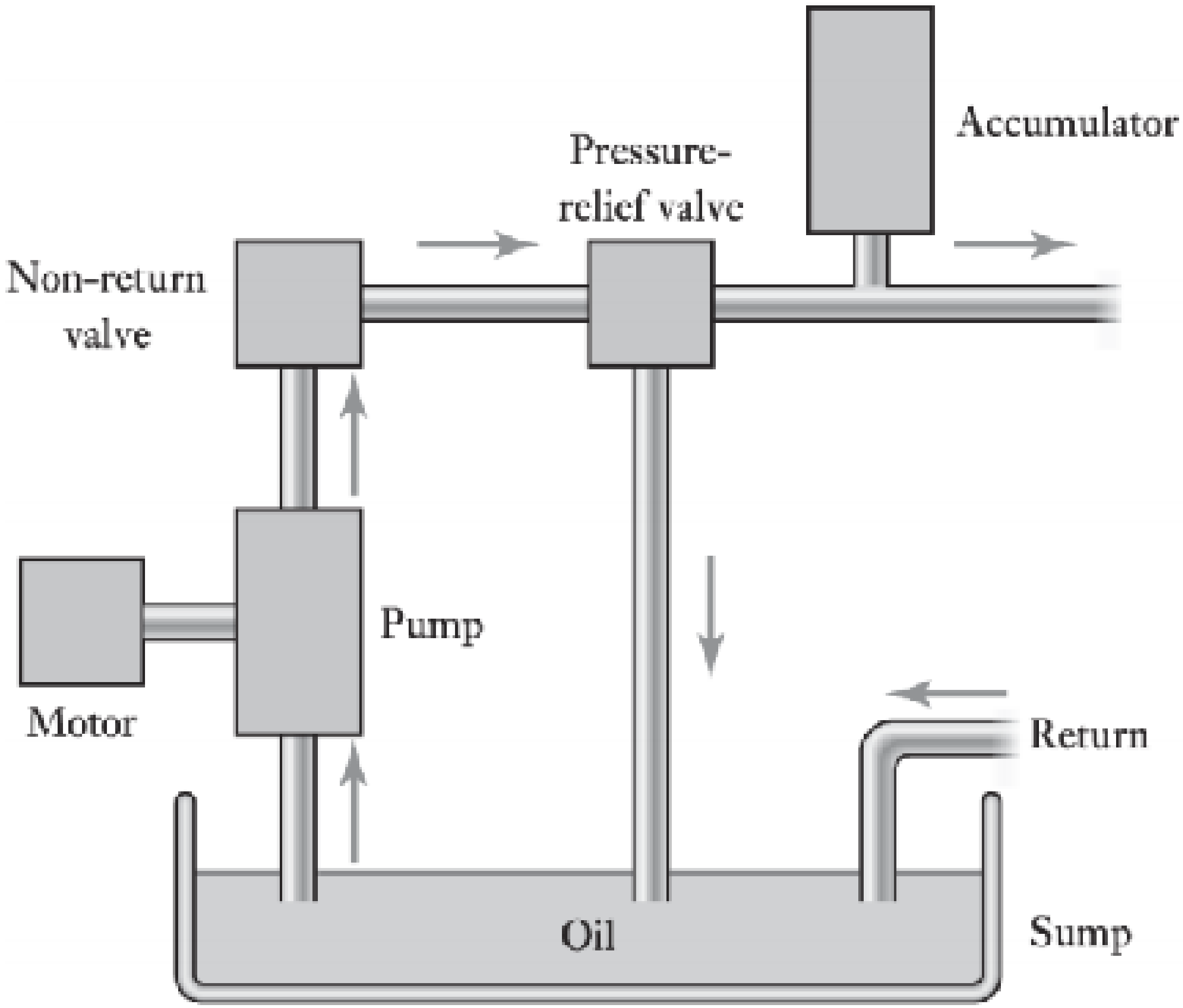
Pneumatic & hydraulic actuation systems

Pneumatic deals with air pressure

- **Hydraulic deals with fluid motion and pressure**

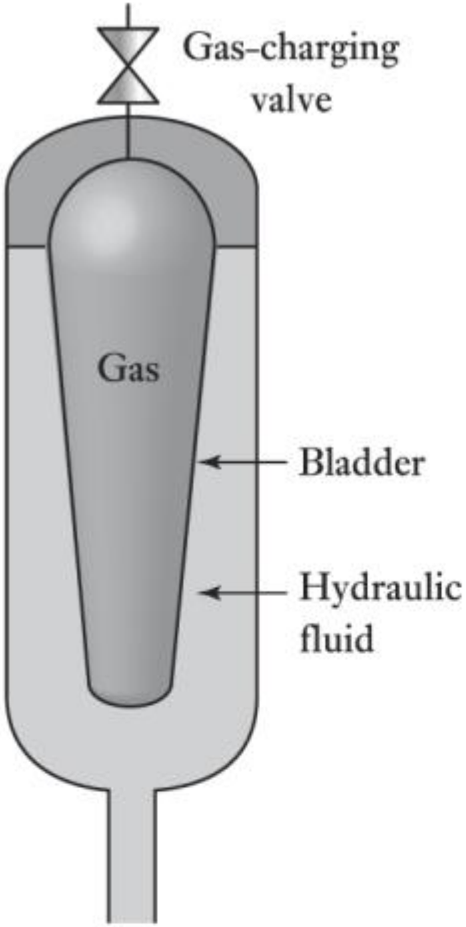


Typical Hydraulic Power System



- The pump pumps oil from a sump through a non return valve and an accumulator to the system, from which it return to the sump.
- The pressure relief valve is to release the pressure if it rises above a safe level
- The accumulator is to smooth out any short term fluctuations in the output oil pressure

Accumulator is a container in which the oil is held under pressure against an external force, which involves gas within a bladder in the chamber containing the hydraulic fluid



Accumulator

UNIT-V
Electrical Machine Drives

WHAT IS A VARIABLE-SPEED DRIVE?

A way to control and adjust the work performed by a motor to meet changing demands and energy requirements

It is a technology that today is found in many applications

- Fans and Air Compressors
- Conveyor belts
- Municipal water systems
- Solar pumps

This technology has several different names:

- Variable-Speed Drive (VSD)
- Adjustable-Speed Drive (ASD)
- Variable-Frequency Drive (VFD)
- Adjustable-Frequency Drive (AFD)
- Frequency Converter
- Inverter (a term used by manufacturers)
- etc.

These names all represent the same technology.

HOW DOES THIS SAVE ENERGY?

- Pumps driven by electric motors typically operate at full speed even when the loads they are serving are less than the motor capacity.
- To match the output of the pump to the load needed, some sort of part-load control is necessary – ie. variable speeds.
- The laws of physics dictate that:
- The flow will vary proportionally with the speedThe pressure, or head, will vary with the square of the speedThe energy consumed will vary with the cube of the speed

HOW DO VARIABLE-SPEED DRIVES WORK?

- The most common method is to use a pressure sensor at a key point in the irrigation system

The information from the sensor is sent to the variable-speed control system, which adjusts accordingly

  This can be done with direct wiring, or

  By radio transmitter (more on this later)

- These drives can be used to control more than one pump at a time – very important for situations where there is more than one pump supplying water

Measurement of Actual Power Savings is Being Done

In June of this year, Paul White of Whitewater farms installed the first VSD control in the area

A data logger was also installed that records pressure, speed, and kilowatts. The information is time- and date-stamped.

Preliminary information suggests that when the pivot end is at the lowest point on the field the actual power used is as low as 50% of the power used without the control

Power used during one revolution of the pivot is being reduced by 20-25%.

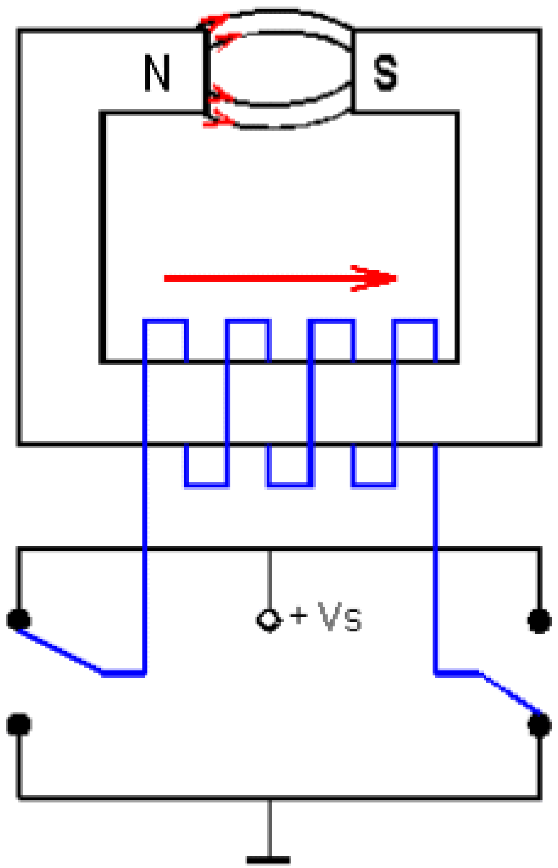
Other Benefits of Variable-Speed Drives

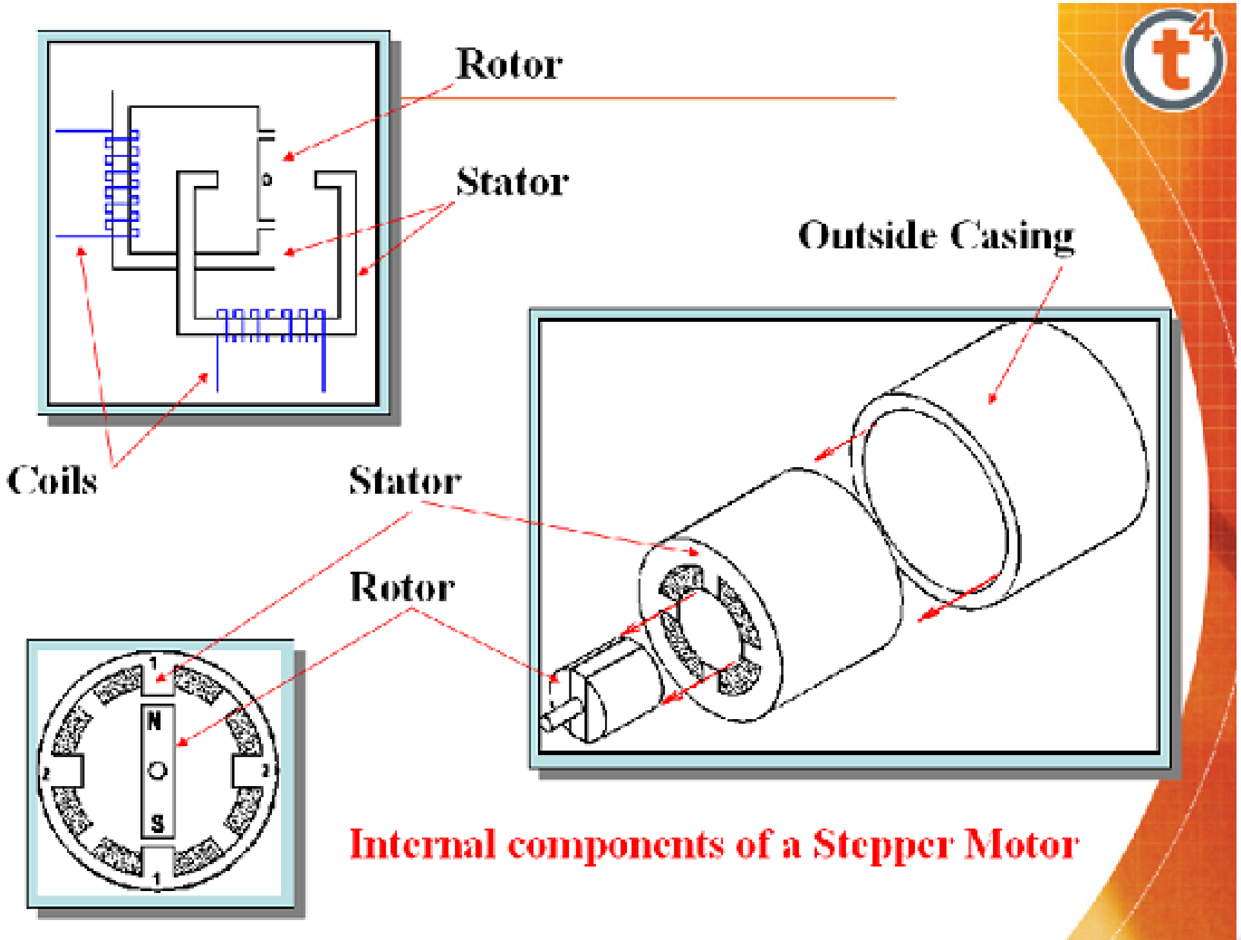
Allows high-efficiency irrigation systems to operate at their potential

1. Better system operation
2. Higher motor and pump efficiencies
3. Longer pump life
4. Longer motor life

The enemy of electric motors is current fluctuations; transmission lines can vary 10-12%. VSD technology reduces that to less than 1%

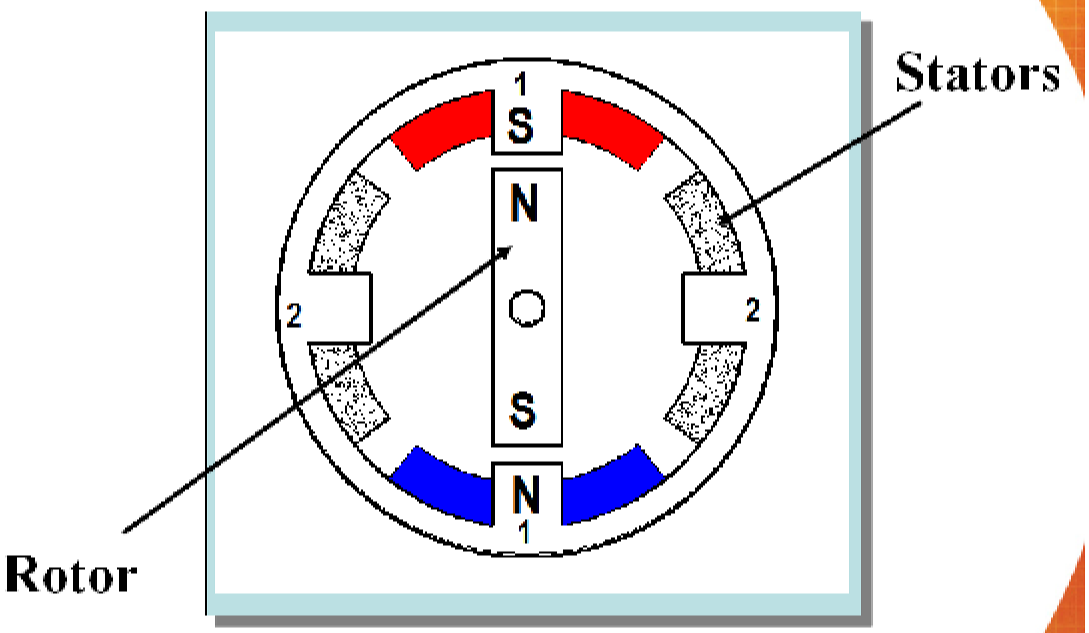
Stepper Motor / Electro magnet



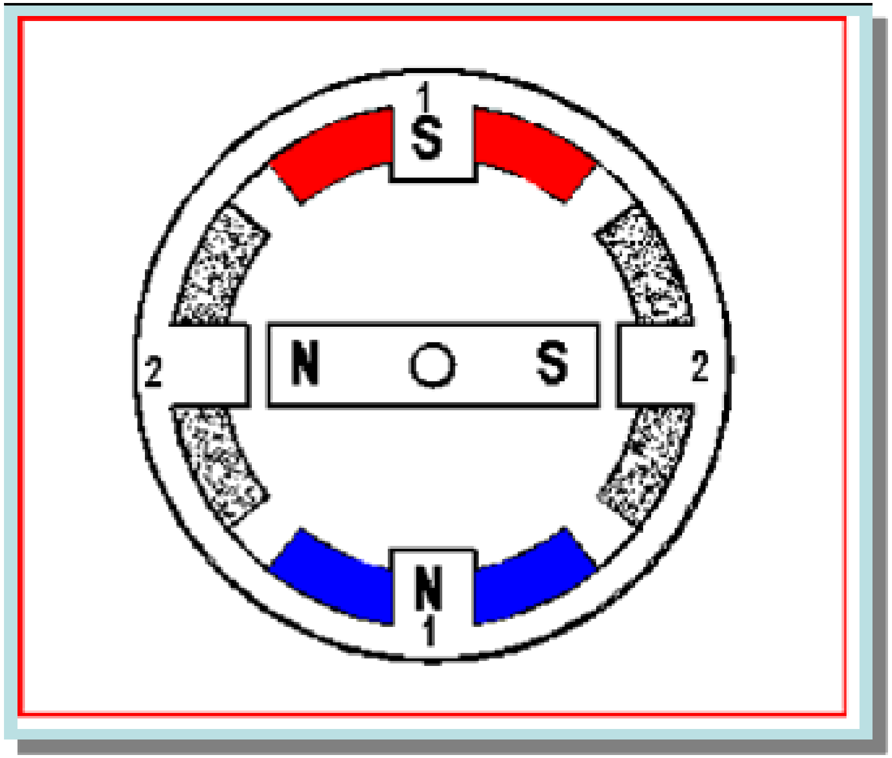


Internal components of a Stepper Motor

Cross Section of a Stepper Motor

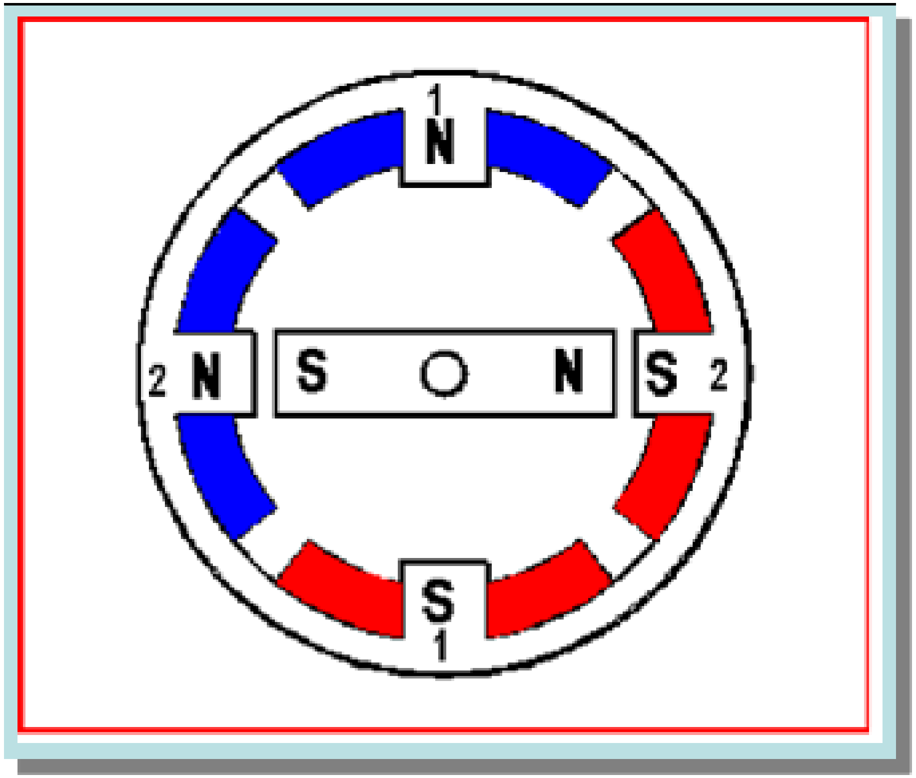


Full Step Operation



Four Steps per revolution i.e. 90 deg. steps.

Half Step Operation

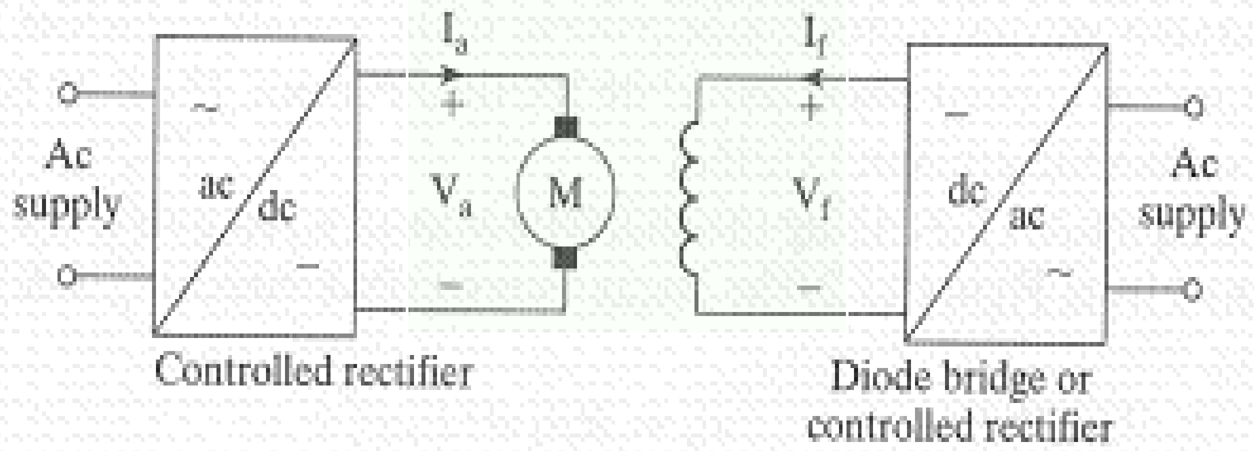


Eight steps per. revolution i.e. 45 deg. steps.

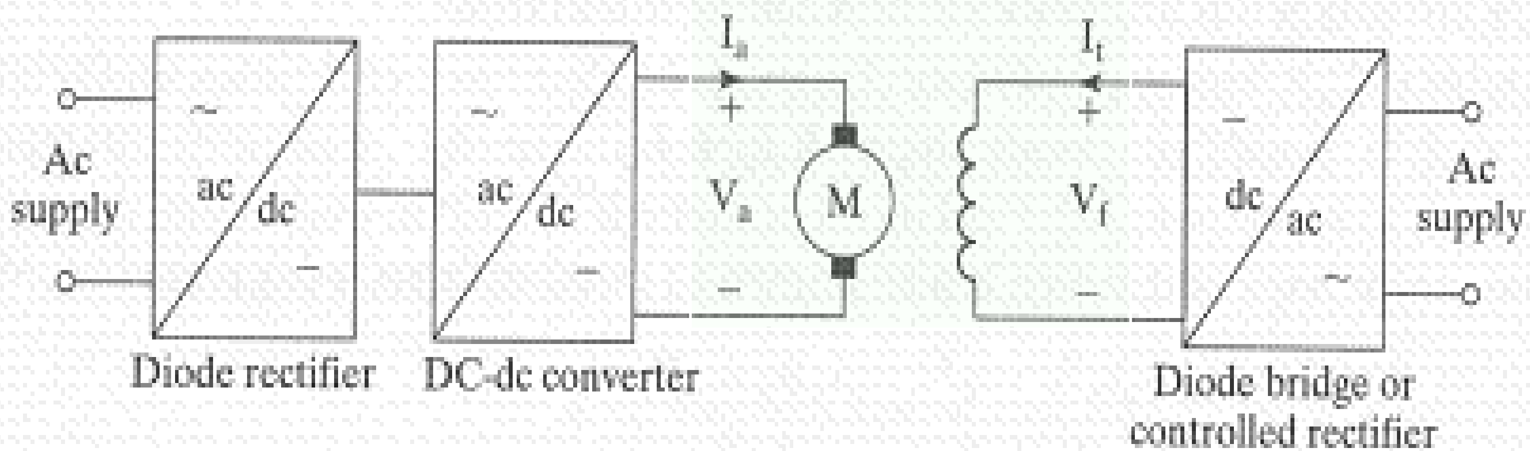
Introduction: DC Motor Drives

- Direct current (dc) motors have variable characteristics and are used extensively in variable-speed drives.
- DC motors can provide a high starting torque and iDirect current (dc) motors have variable characteristics and are used extensively in variable-speed drives.
- DC motors can provide a high starting torque and it is also possible to obtain speed control over a wide range.

Controlled Rectifier- and DC-DC Converter-Fed Drive

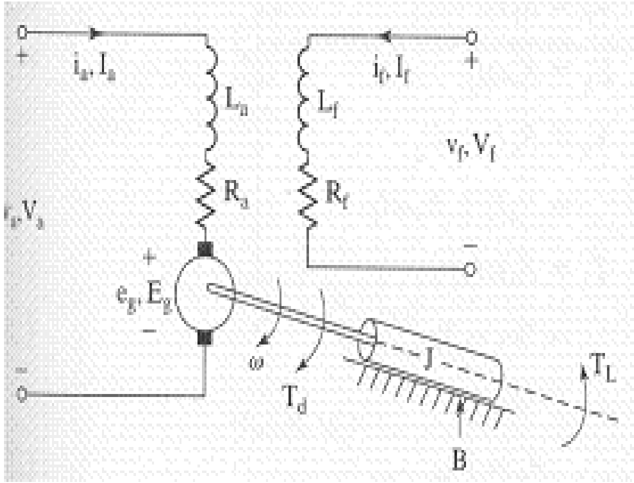


(a) Controlled rectifier-fed drive



(b) Chopper-fed drive

Basic Characteristics of Shunt DC Motors



The motor speed can bevaried

- controlling the armature voltage
- controlling the field current I_f, known as field control; or
- torque demand, which corresponds to an armature current I_a, for a fixed field current I_f.

- The speed, which corresponds to the rated armature voltage, rated field current and rated armature current, is known as the rated (or base) speed

Basic Characteristics of Shunt DC Motors

- In practice, for a speed less than the base speed, the armature current and field currents are maintained constant to meet the torque demand, and the armature voltage V_a is varied to control the speed.
- For speed higher than the base speed, the armature voltage is maintained at the rated value and the field current is varied to control the speed.
- However, the power developed by the motor (= torque X speed) remains constant.
- Figure below shows the characteristics of torque, power, armature current, and field current against the speed.

Single-Phase Dual-Converter Drives

- Two single-phase full-wave converters are connected.
- Either converter 1 operates to supply a positive armature voltage, V_a, or converter 2 operates to supply a negative armature voltage, $-V_a$.
- Converter 1 provides operation in the first and fourth quadrants, and converter 2, in the second and third quadrants.
- It is a four-quadrant drive and permits four modes of operation: forward powering, forward braking (regeneration), reverse powering, and reverse braking (regeneration).
- It is limited to applications up to 15 kW. The field converter could be a full-wave or a dual converter.

Three-Phase Drives

- The armature circuit is connected to the output of a three-phase controlled rectifier.
- Three-phase drives are used for high-power applications up to megawatt power levels.
- The ripple frequency of the armature voltage is higher than that of single-phase drives and it requires less inductance in the armature circuit to reduce the armature ripple current.

Three-Phase Drives

- The armature current is mostly continuous, and therefore the motor performance is better compared with that of single-phase drives.
- Similar to the single-phase drives, three-phase drives may also be subdivided into:

  – Three-phase half-wave-converter drives.
  – Three-phase semiconverter drives.
  – Three-phase full-converter drives.
  – Three-phase dual-converter drives.

Induction Motor Drives: Frequency Control

- The torque and speed of induction motors can be controlled by changing the supply frequency.
- If the voltage is maintained fixed at its rated value while the frequency is reduced below its rated value, the flux increases.
- This would cause saturation of the air-gap flux, and the motor parameters would not be valid in determining the torque-speed characteristics.
- At low frequency, the reactances decrease and the motor current may be too high. This type of frequency control is not normally used.

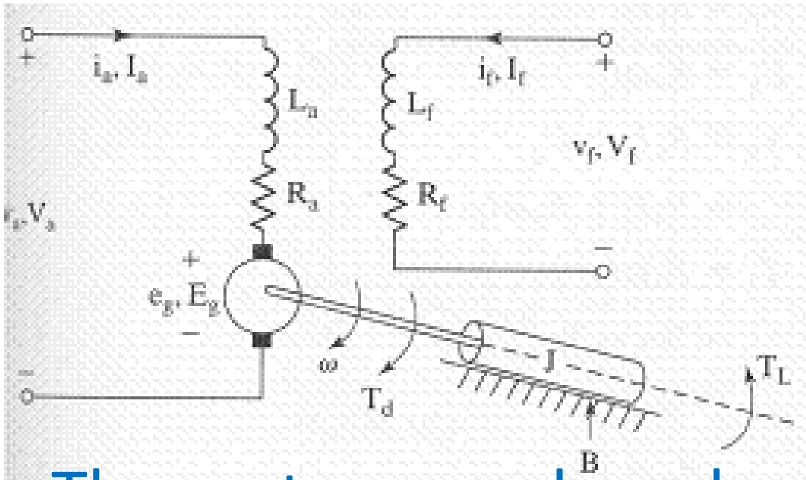
DC and AC Motor Drives

- Direct current (dc) motors have variable characteristics and are used extensively in variable-speed drives.
- DC motors can provide a high starting torque and it is also possible to obtain speed control over a wide range.
- The methods of speed control are normally simpler and less expensive than those of AC drives.
- DC motors play a significant role in modern industrial drives.
- Both series and separately excited DC motors are normally used in variable-speed drives, but series motors are traditionally employed for traction applications.
- Due to commutators, DC motors are not suitable for very high speed applications and require more maintenance than do AC motors.

Introduction: DC Motor Drives

- Controlled rectifiers provide a variable dc output voltage from a fixed ac voltage, whereas a dc-dc converter can provide a variable dc voltage from a fixed dc voltage.
- Due to their ability to supply a continuously variable dc voltage, controlled rectifiers and dc-dc converters made a revolution in modern industrial control equipment and variable-speed drives, with power levels ranging from fractional horsepower to several megawatts.
- Controlled rectifiers are generally used for the speed control of dc motors.
- The alternative form would be a diode rectifier followed by dc-dc converter.

Basic Characteristics of Shunt DC Motors



$$\omega = \frac{V_a - R_a I_a}{K_v I_f} = \frac{V_a - R_a I_a}{K_v V_f / R_f}$$

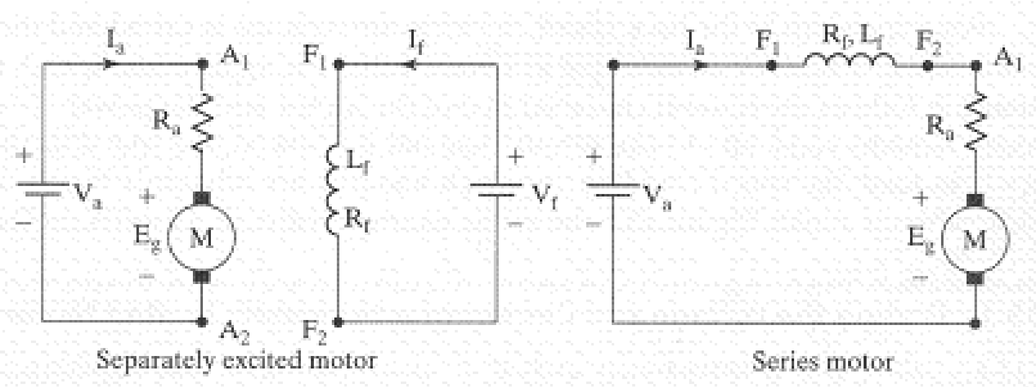
- The motor speed can be varied by
  - controlling the armature voltage V_a, known as voltage control;
  - controlling the field current I_f, known as field control; or
  - torque demand, which corresponds to an armature current I_a, for a fixed field current I_f.

Basic Characteristics of Series DC Motors

- For a speed up to the base speed, the armature voltage is varied and the torque is maintained constant.
- Once the rated armature voltage is applied, the speed-torque relationship follows the natural characteristic of the motor and the power (= torque X speed) remains constant.
- As the torque demand is reduced, the speed increases.
- At a very light load, the speed could be very high and it is not advisable to run a dc series motor without a load.

- In variable-speed applications, a dc motor may be operating in one or more modes:
  - motoring, regenerative braking, dynamic braking,
  - plugging, and four quadrants.

Motoring: The arrangements for motoring are shown in Figure 15.7a. Back emf Eg is less than supply voltage Vy. Both armature and field currents are positive. The motor develops torque to meet the load demand.



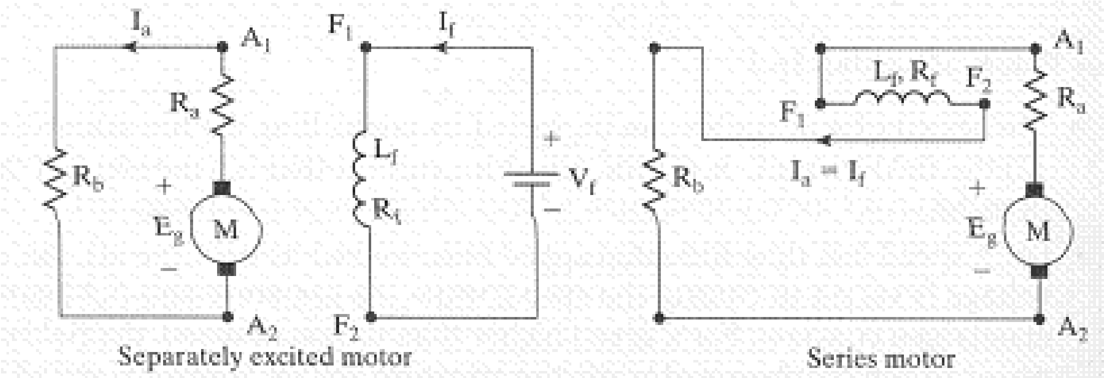
(a) Motoring

Regenerative braking

- The arrangements for regenerative braking are shown in Figure 15.7b.
- The motor acts as a generator and develops an induced voltage E_g. E_g must be greater than supply voltage V_a.
- The armature current is negative, but the field current is positive.
- The kinetic energy of the motor is returned to the supply.
- A series motor is usually connected as a self-excited generator.
- For self-excitation, it is necessary that the field current aids the residual flux. This is normally accomplished by reversing the armature terminals or the field terminals.

Dynamic braking

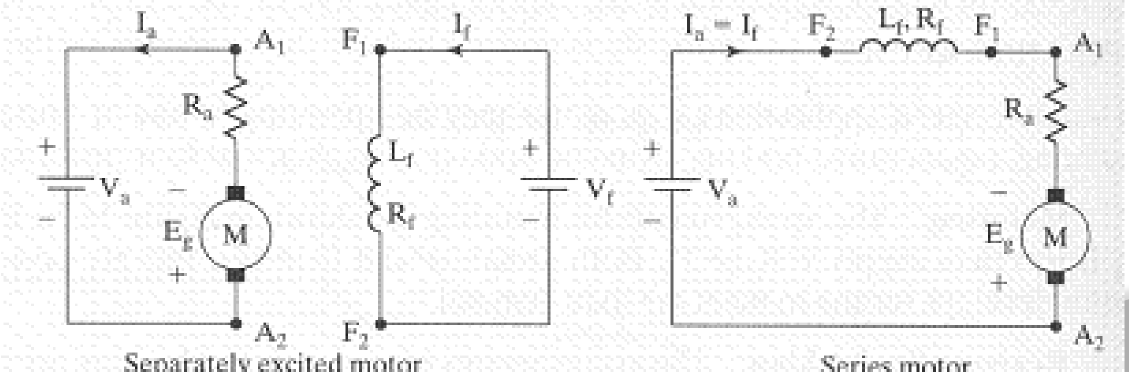
- The arrangements shown in Figure 15.7c are similar to those of regenerative braking, except the supply voltage V_a is replaced by a braking resistance R_b,.
- The kinetic energy of the motor is dissipated in R_b.



(c) Dynamic braking

Plugging

- Plugging is a type of braking. The connections for plugging are shown in Figure 15.7d.
- The armature terminals are reversed while running. The supply voltage V_a and the induced voltage E_g act in the same direction.
- The armature current is reversed, thereby producing a braking torque. The field current is positive.
- For a series motor, either the armature terminals or field terminals should be reversed, but not both.

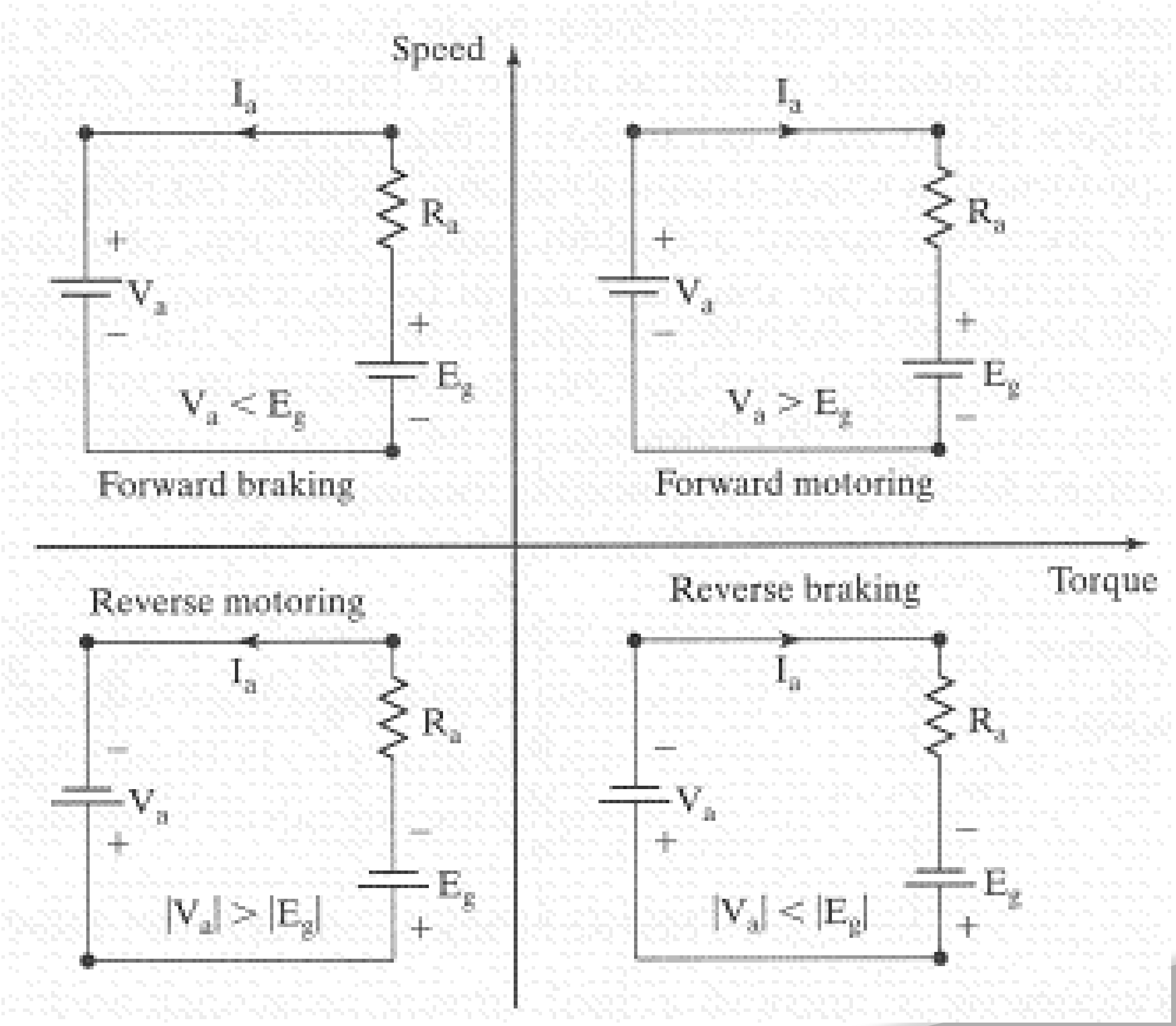


(d) Plugging

Four Quadrants

- In forward motoring (quadrant I), V_a, E_g, and I_a are all positive. The torque and speed are also positive in this quadrant.
- During forward braking (quadrant II), the motor runs in the forward direction and the induced emf E_g continues to be positive. For the torque to be negative and the direction of energy flow to reverse, the armature current must be negative. The supply voltage V_a should be kept less than E_g.
- In reverse motoring (quadrant III), V_a, E_g, and I_a are all negative. The torque and speed are also negative in this quadrant. To keep the torque negative and the energy flow from the source to the motor, the back emf E_g must satisfy the condition $| V_a | > | E_g |$. The polarity of E_g can be reversed by changing the direction of field current or by reversing the armature terminals.

Four Quadrants



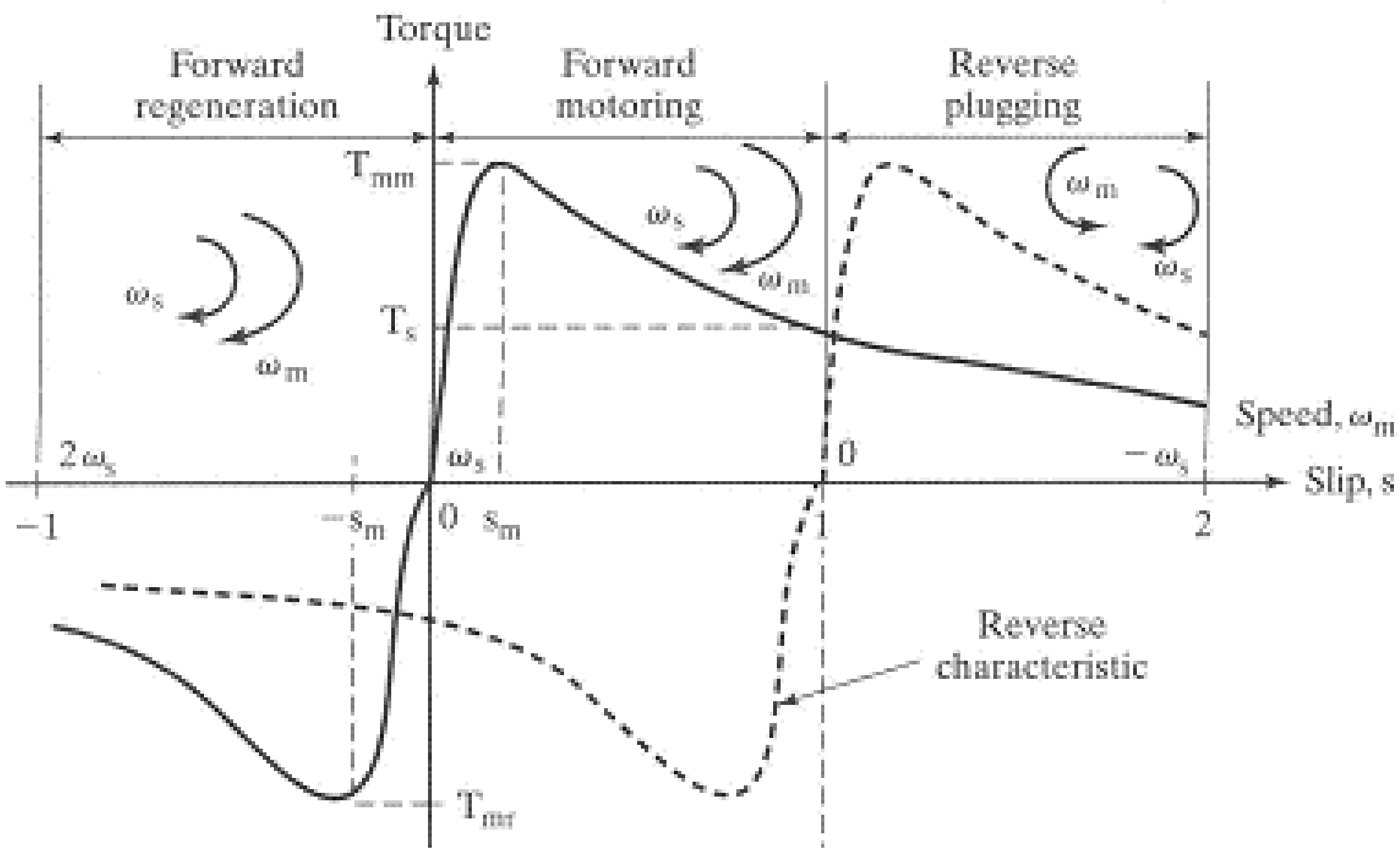
Introduction: AC Motor Drives

- These power controllers, which are relatively complex and more expensive, require advanced feed-back control techniques such as model reference, adaptive control, sliding mode control, and field-oriented control.
- However, the advantages of ac drives outweigh the disadvantages. There are two types of ac drives:

  – Induction motor drives
  – Synchronous motor drives

- Ac drives are replacing dc drives and are used in many industrial and domestic applications.

Induction Motor Drives



- The speed and torque of induction motors can be controlled by
  - Stator voltage control
  - Rotor voltage control
  - Frequency control
  - Stator voltage and frequency control
  - Stator current control
- To meet the torque-speed duty cycle of a drive, the voltage, current, and frequency control are normally used.

Induction Motor Drives: Stator Voltage Control

- The stator voltage can be varied by three-phase
  - ac voltage controllers,
  - voltage-fed variable de-link inverters, or
  - pulse-width modulation (PWM) inverters.
- However, due to limited speed range requirements, the ac voltage controllers are normally used to provide the voltage control. The ac voltage controllers are very simple.
- However, the harmonic contents are high and the input PF of the controllers is low.
- They are used mainly in low-power applications, such as fans, blowers, and centrifugal pumps, where the starting torque is low.
- They are also used for starting high-power induction motors to limit the in-rush current.

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- They are used mainly in low-power applications, such as fans, blowers, and centrifugal pumps, where the starting torque is low. They are also used for starting high-power induction motors to limit the in-rush current.

Induction Motor Drives: Rotor Voltage Control

- In a wound-rotor motor, an external three-phase resistor may be connected to its slip rings, as shown in Figure 16.5a.
- The developed torque may be varied by varying the resistance R_x. If R_x is referred to the stator winding and added to R_r, Eq. (16.18) may be applied to determine the developed torque.
- The typical torque-speed characteristics for variations in rotor resistance are shown in Figure 16.5b.

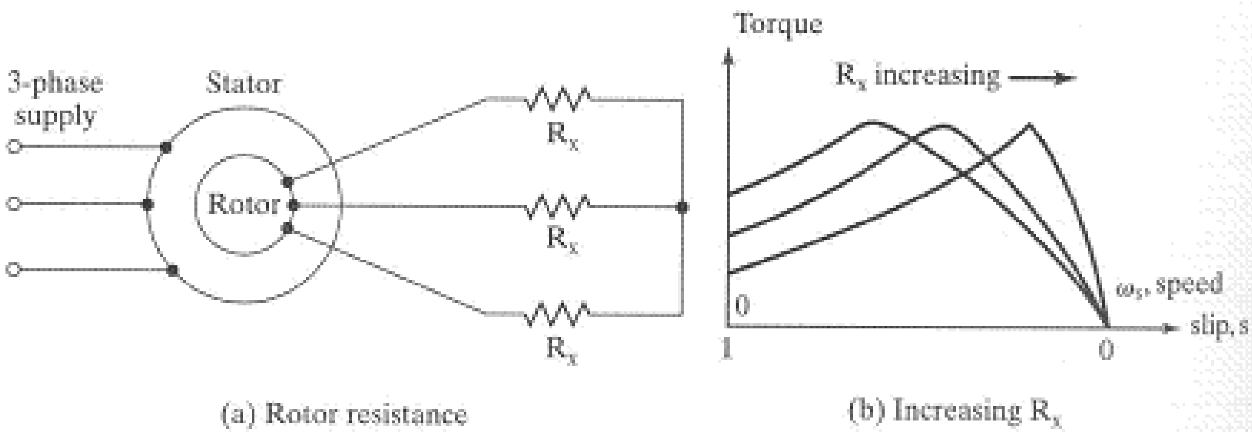

FIGURE 16.5

Speed control by motor resistance.

- In a wound-rotor motor, an external three-phase resistor may be connected to its slip rings, as shown in Figure 16.5a.
- The developed torque may be varied by varying the resistance R_x. If R_x is referred to the stator winding and added to R_r, Eq. (16.18) may be applied to determine the developed torque.
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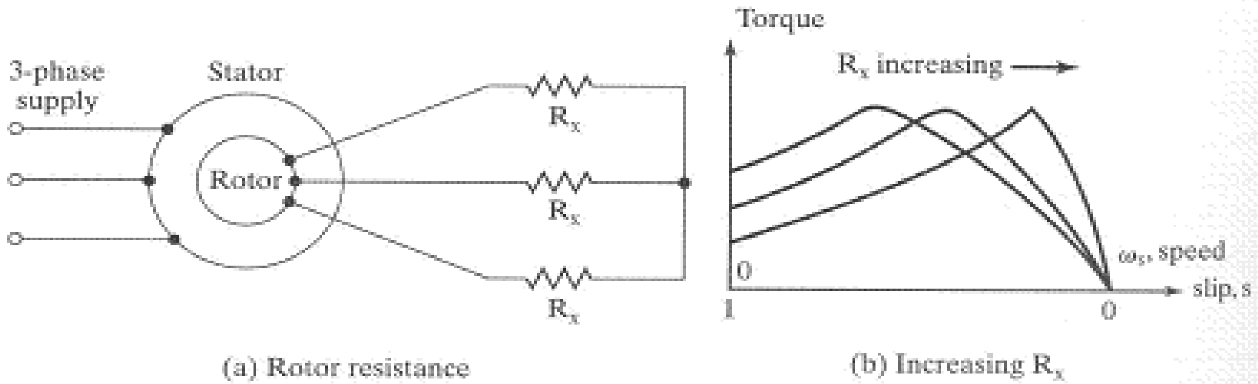


FIGURE 16.5
Speed control by motor resistance.

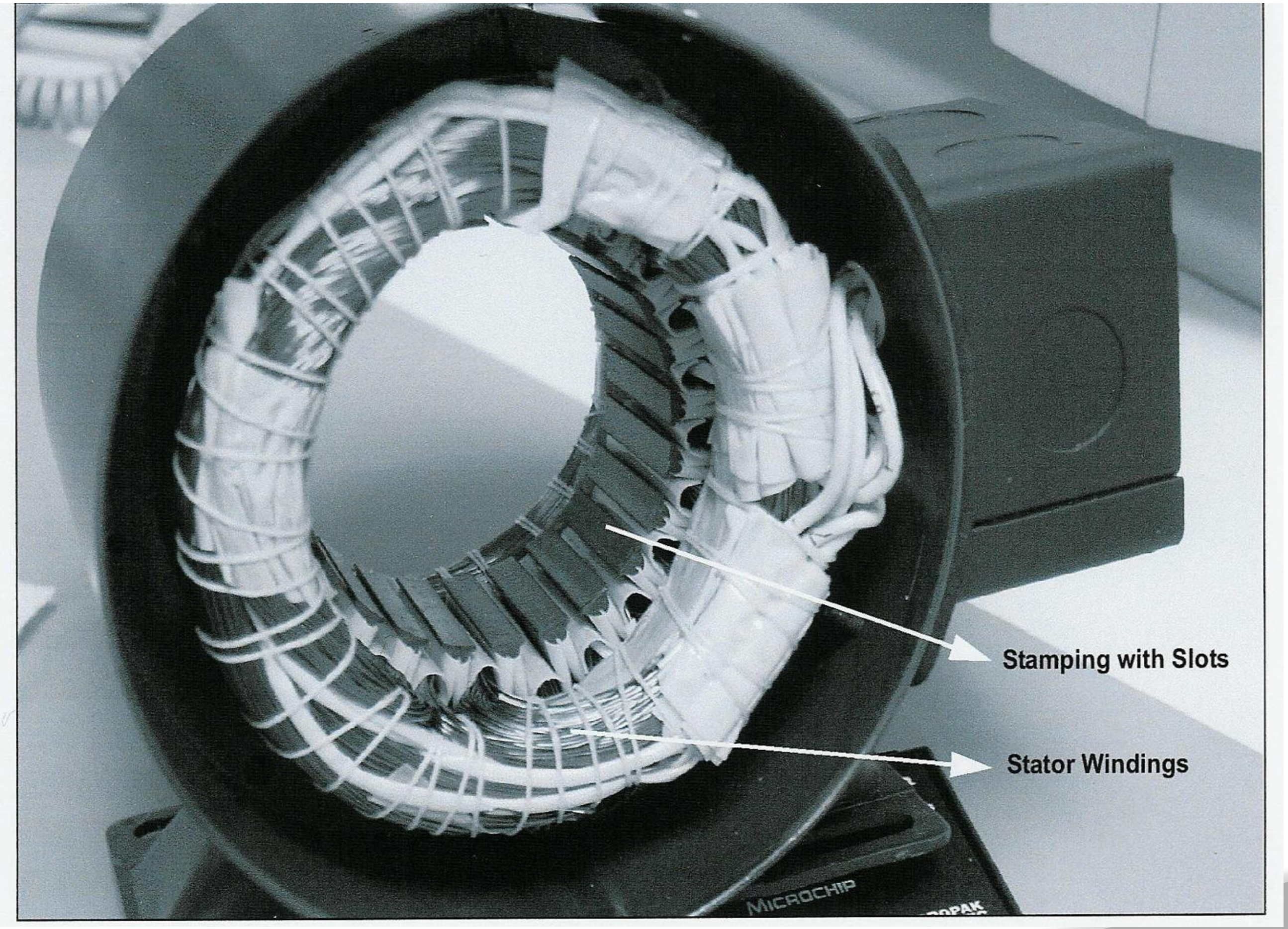
Induction Motor Drives: Frequency Control

- The torque and speed of induction motors can be controlled by changing the supply frequency.
- We can notice from Eq. (16.31) that at the rated voltage and rated frequency, the flux is the rated value.
- If the voltage is maintained fixed at its rated value while the frequency is reduced below its rated value, the flux increases.
- This would cause saturation of the air-gap flux, and the motor parameters would not be valid in determining the torque-speed characteristics.
- At low frequency, the reactances decrease and the motor current may be too high. This type of frequency control is not normally used.

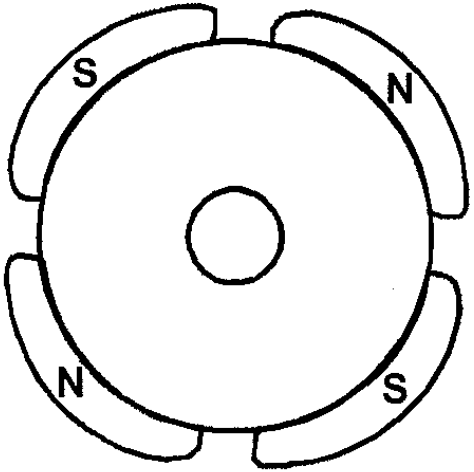
Brushless DC (BLDC) Motors

- Brushless DC Motors are a type of synchronous motor magnetic fields generated by the stator and rotor rotate at the same frequency no slip Available in single-phase, 2-phase, and 3-phase configurations

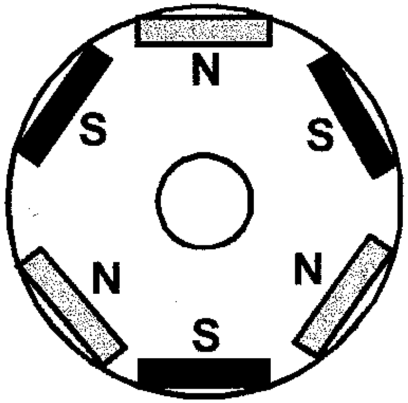
BLDC Motor Stator



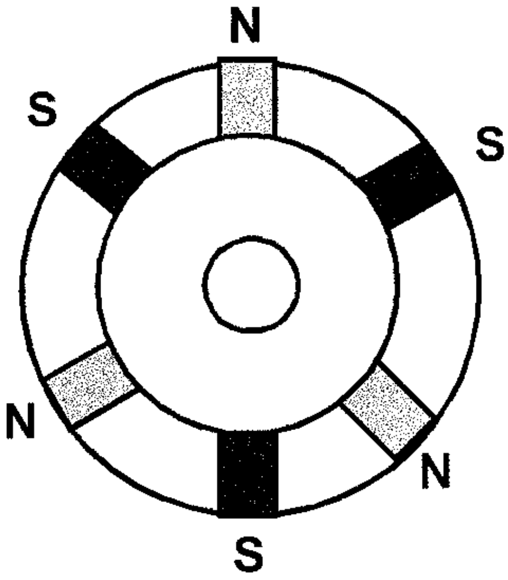
BLDC Motor Rotors



Circular core with magnets
on the periphery



Circular core with rectangular
magnets embedded in the rotor



Circular core with rectangular magnets
inserted into the rotor core

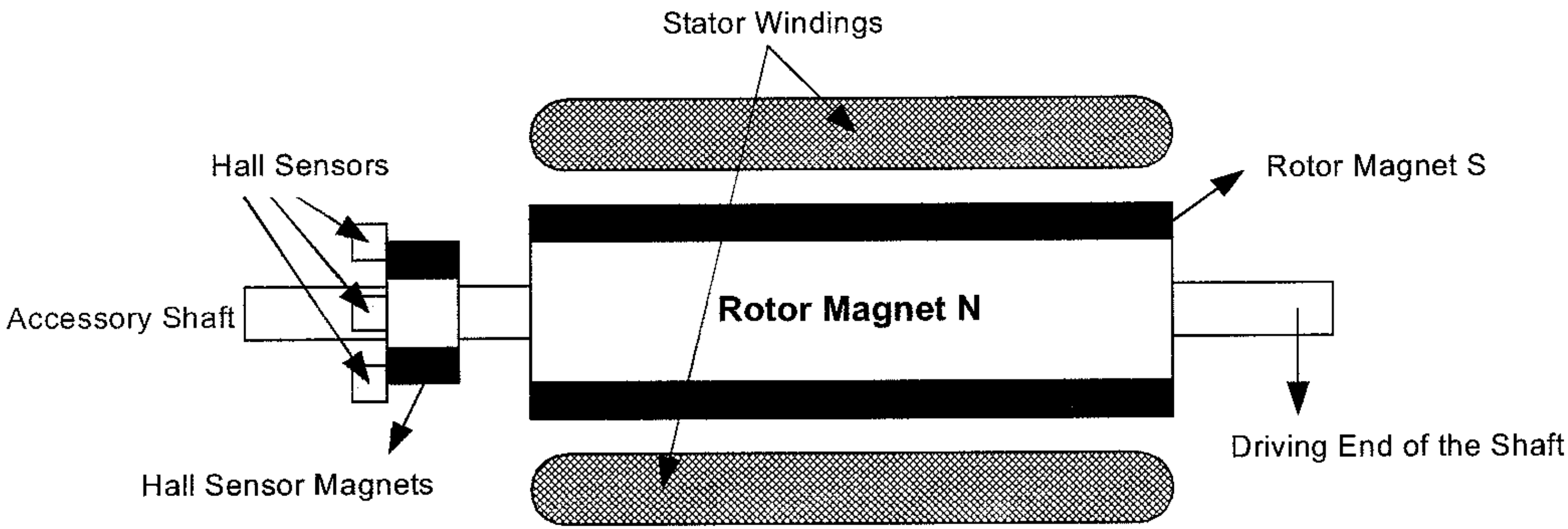
Hall-Effect

If a current-carrying conductor is kept in a magnetic field, the magnetic field exerts a force on the moving charge carriers, tending to push them to one side of the conductor, producing a measurable voltage difference between the two sides of the conductor.

Hall-Effect Sensors:

Need 3 sensors to determine the position of the rotor
When a rotor pole passes a Hall-Effect sensor, get a high or low signal, indicating that a North or South pole

Transverse Sectional View of Rotor



Commutation Sequence

Each sequence has

- one winding energized positive (current into the winding)
- one winding energized negative (current out of the winding)
- one winding non-energized

Torque-Speed Characteristic

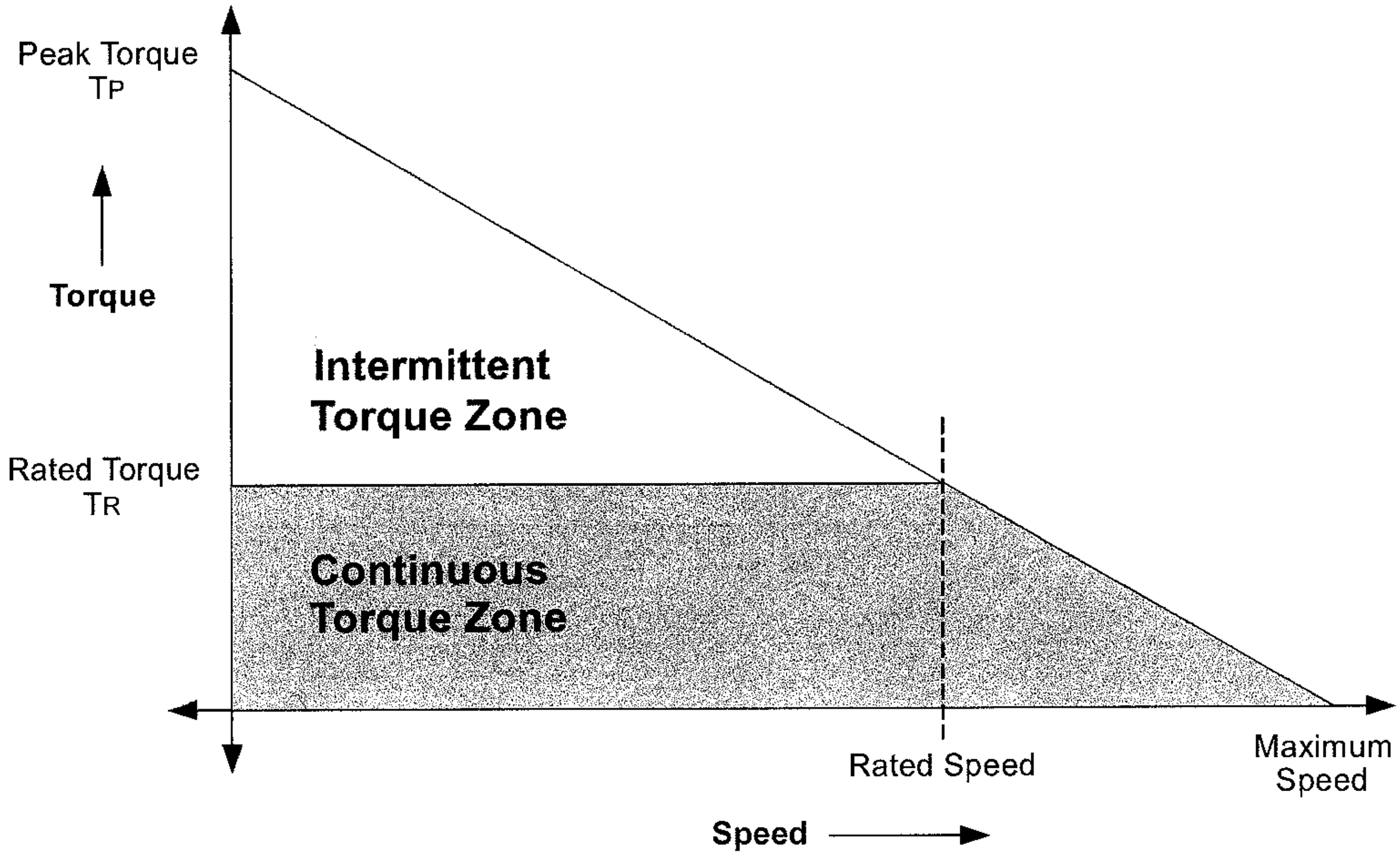


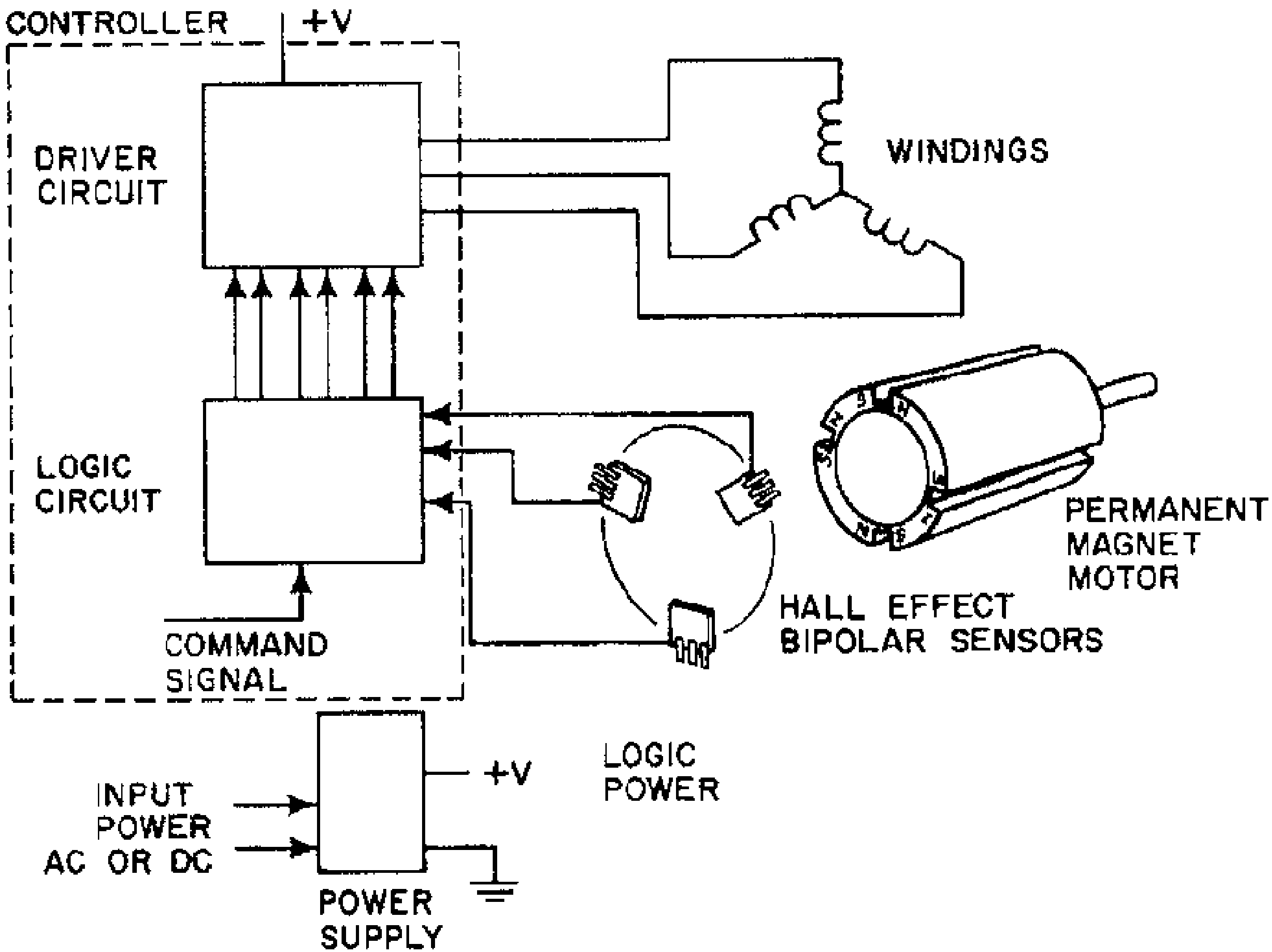
TABLE 1: COMPARING A BLDC MOTOR TO A BRUSHED DC MOTOR

Feature	BLDC Motor	Brushed DC Motor
Commutation	Electronic commutation based on Hall position sensors.	Brushed commutation.
Maintenance	Less required due to absence of brushes.	Periodic maintenance is required.
Life	Longer.	Shorter.
Speed/Torque Characteristics	Flat – Enables operation at all speeds with rated load.	Moderately flat – At higher speeds, brush friction increases, thus reducing useful torque.
Efficiency	High – No voltage drop across brushes.	Moderate.
Output Power/ Frame Size	High – Reduced size due to superior thermal characteristics. Because BLDC has the windings on the stator, which is connected to the case, the heat dissipation is better.	Moderate/Low – The heat produced by the armature is dissipated in the air gap, thus increasing the temperature in the air gap and limiting specs on the output power/frame size.
Rotor Inertia	Low, because it has permanent magnets on the rotor. This improves the dynamic response.	Higher rotor inertia which limits the dynamic characteristics.
Speed Range	Higher – No mechanical limitation imposed by brushes/commutator.	Lower – Mechanical limitations by the brushes.
Electric Noise Generation	Low.	Arcs in the brushes will generate noise causing EMI in the equipment nearby.
Cost of Building	Higher – Since it has permanent magnets, building costs are higher.	Low.
Control	Complex and expensive.	Simple and inexpensive.
Control Requirements	A controller is always required to keep the motor running. The same controller can be used for variable speed control.	No controller is required for fixed speed; a controller is required only if variable speed is desired.

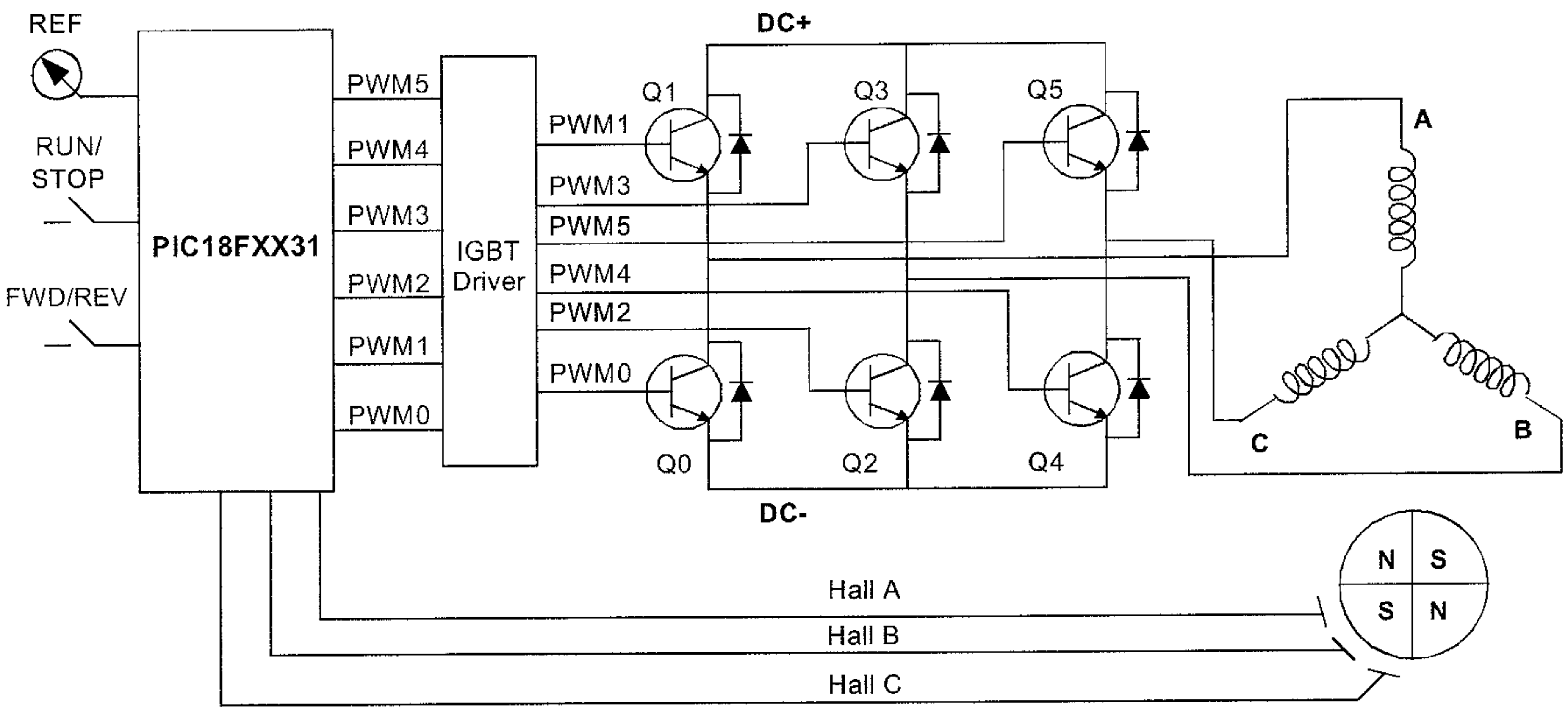
TABLE 2: COMPARING A BLDC MOTOR TO AN INDUCTION MOTOR

Features	BLDC Motors	AC Induction Motors
Speed/Torque Characteristics	Flat – Enables operation at all speeds with rated load.	Nonlinear – Lower torque at lower speeds.
Output Power/ Frame Size	High – Since it has permanent magnets on the rotor, smaller size can be achieved for a given output power.	Moderate – Since both stator and rotor have windings, the output power to size is lower than BLDC.
Rotor Inertia	Low – Better dynamic characteristics.	High – Poor dynamic characteristics.
Starting Current	Rated – No special starter circuit required.	Approximately up to seven times of rated – Starter circuit rating should be carefully selected. Normally uses a Star-Delta starter.
Control Requirements	A controller is always required to keep the motor running. The same controller can be used for variable speed control.	No controller is required for fixed speed; a controller is required only if variable speed is desired.
Slip	No slip is experienced between stator and rotor frequencies.	The rotor runs at a lower frequency than stator by slip frequency and slip increases with load on the motor.

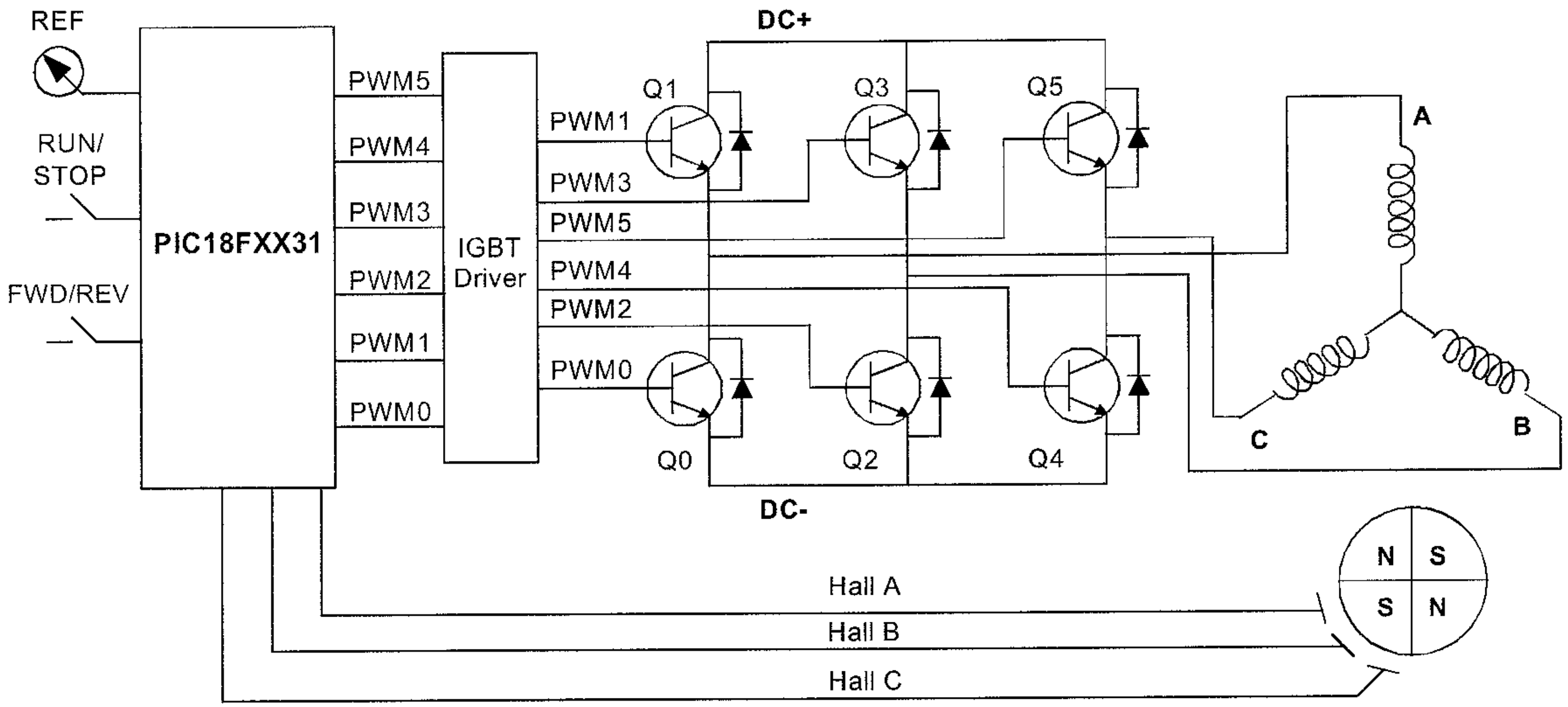
Essential Elements of a Typical BLDC Motor



BLDC Control



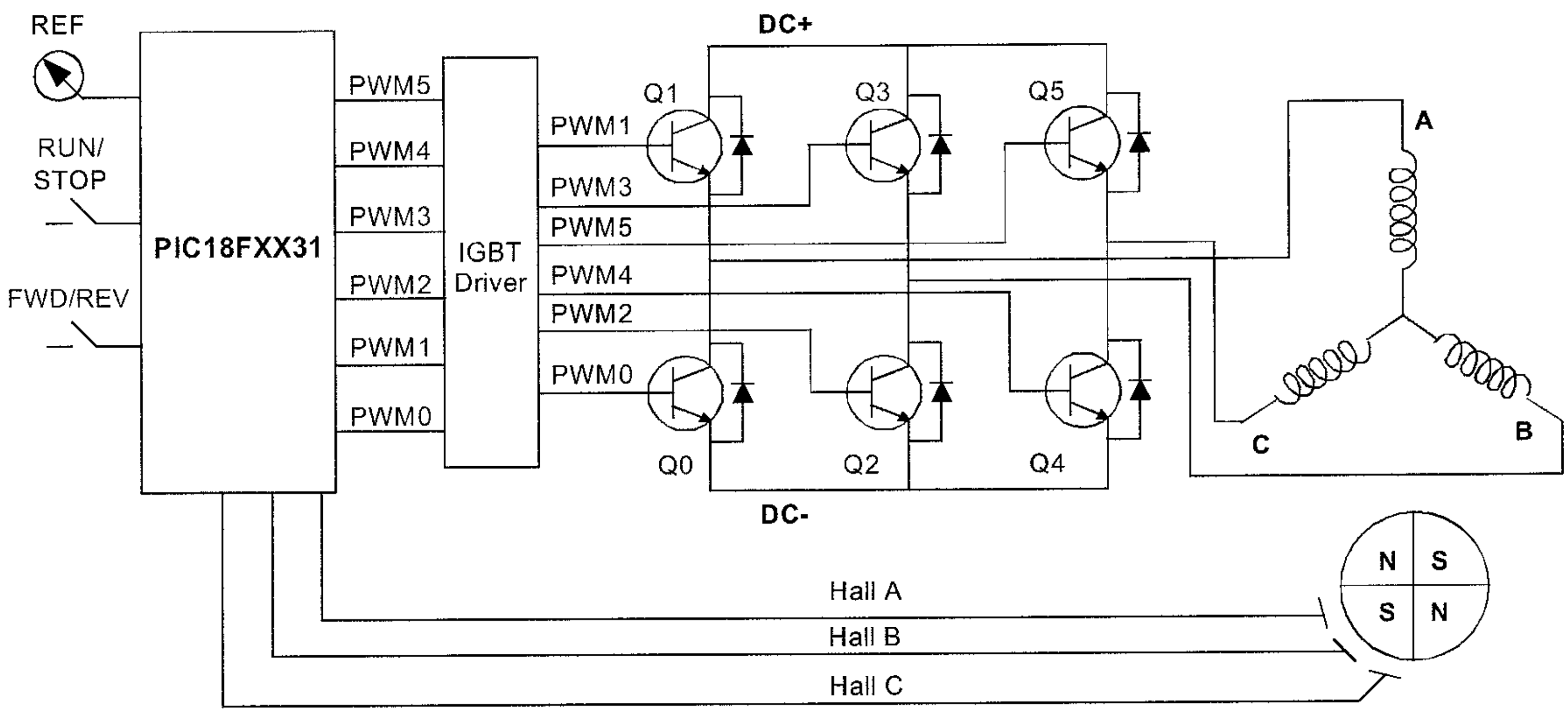
CW


REF
RUN/
STOP
FWD/REV
PIC18FXX31
PWM5
PWM4
PWM3
PWM2
PWM1
PWM0
IGBT
Driver
PWM1
PWM3
PWM5
PWM4
PWM2
PWM0
DC+
DC-
Q1
Q3
Q5
Q0
Q2
Q4
A
B
C
N
S
S
N
Hall A
Hall B
Hall C

CW

Sequence #	Hall Sensor Input			Active PWMs		Phase Current		
	A	B	C			A	B	C
1	0	0	1	PWM1(Q1)	PWM4(Q4)	DC+	Off	DC-
2	0	0	0	PWM1(Q1)	PWM2(Q2)	DC+	DC-	Off
3	1	0	0	PWM5(Q5)	PWM2(Q2)	Off	DC-	DC+
4	1	1	0	PWM5(Q5)	PWM0(Q0)	DC-	Off	DC+
5	1	1	1	PWM3(Q3)	PWM0(Q0)	DC-	DC+	Off
6	0	1	1	PWM3(Q3)	PWM4(Q4)	Off	DC+	DC-

CCW



REF
RUN/
STOP
FWD/REV
PIC18FXX31
PWM5
PWM4
PWM3
PWM2
PWM1
PWM0
IGBT
Driver
PWM1
PWM3
PWM5
PWM4
PWM2
PWM0
DC+
DC-
Q1
Q3
Q5
Q0
Q2
Q4
A
B
C
N
S
S
N
Hall A
Hall B
Hall C

CCW

Sequence #	Hall Sensor Input			Active PWMs		Phase Current		
	A	B	C			A	B	C
1	0	1	1	PWM5(Q5)	PWM2(Q2)	Off	DC-	DC+
2	1	1	1	PWM1(Q1)	PWM2(Q2)	DC+	DC-	Off
3	1	1	0	PWM1(Q1)	PWM4(Q4)	DC+	Off	DC-
4	1	0	0	PWM3(Q3)	PWM4(Q4)	Off	DC+	DC-
5	0	0	0	PWM3(Q3)	PWM0(Q0)	DC-	DC+	Off
6	0	0	1	PWM5(Q5)	PWM0(Q0)	DC-	Off	DC+


Thank you