18

Quality Control and Quality Assurance

PROCESS

A process is defined as "A set of interrelated work activities that are characterized by a set of specific inputs and value-added tasks that produce a set of specific outputs."

A process can be contained within a functional organization, or it can span several functional organizations.

CHARTS

The charts are the pictorial tools for studying the processes and situations and for planning improvement. The use of charts would result in standardisation, simplification, variety reduction, and optimisation of process average.

QUALITY CONTROL

It is defined as "Assurance of conformity of the manufactured products or the process to established specifications by systematic observations, inspections or tests and by regulation of materials, workmanship or other influences.

QUALITY ASSURANCE

It is defined as " All those planned and systematic actions necessary to provide adequate confidence that a system or component will perform satisfactorily in service."

Difference between quality control and quality assurance. Quality control is related to actual inspection or test in order to determine whether a particular component or process is acceptable or not; whereas Quality Assurance encompasses numerous activities such as planning the required actions, establishing acceptance criteria, assigning qualified personnel for the process as well as for the inspection etc.

Factors Affecting Quality

The following nine M's directly affect the quality of products and services, and thus these must be thoroughly recognised and dealt with :

(*i*) Material
(*ii*) Manpower
(*iii*) Money
(*iv*) Market for products, services
(*v*) Motivation of employees
(*vi*) Modern information approaches
(*vii*) Management

(*viii*) Machines used

(*ix*) Mounting product needs.

ORGANISING QUALITY

The quality control function can only be performed effectively and economically if it is organised and managed properly. A properly organised quality control organisation offers the advantages of simplified communication, reduced conflicts in responsibilities and activities, reduced costs, satisfied customers, etc., A well-organised quality control organisation becomes instrumental in producing an item of acceptable quality at competitive price.

Organising for quality involves the following tables :

— Identifying quality related tasks.

— Assigning responsibility for accomplishing quality and related tasks to concerned departments or external agencies.

— Breaking down the overall work into elements, for each department.

— Clearly defining the authority and responsibility for each job.

— Clearly defining the interrelationship among jobs.

— To accomplish the quality mission by composing the work of all departments and external agencies.

PLANNING AN ORGANISATION

The important guidelines for planning an organisation that would function properly are :

— Organisation levels should be minimum.

— Every person should have clearly defined responsibility and he must be accountable (answerable for his duty).

— The responsibility and authority should be close to the point of action and should be clear throughout the organisational structure.

— A person should receive orders from only one superior authority to avoid confusion and complexity.

— Each component must accomplish its own objective and that of present organisation.

— There should be no overlap between the functional and managing duties.

An organisation chart should be designed carefully ensuring that it identifies authority and fundamental relationships, assigns responsibilities, identifies strong or weak control, simplifies the management function, and improves the communication channels.

Organisation of a company could be either by function, or by project, or by matrix method.

QUALITY CONTROL MANUAL

Quality control manual serves as the backbone of the quality control program and serves as a reference document. It contains information on responsibilities; statistical methodology ; personnel; organisational charts; quality policies and procedure ; vendor quality control procedure ; quality costs and inspection procedures; measuring equipment; defect prevention ; marketing.

Such a manual becomes useful when making quality related decisions. It also helps in maintaining continuity of operation of the quality control organisation even if trained persons leave.

IMPLEMENTATION OF QUALITY

— The supplier must establish a *quality system* to demonstrate that products conform to the specified requirements. The documented quality system should include quality management objective, policies, organisation and procedures.

— The supplier should delegate the responsibility and authority to appropriate personnel to identify quality problems and provide effective solutions.

- The supplier should appoint a management representative (preferably independent of other functions) who shall have the necessary authority and the responsibility for ensuring that the requirements of the standard are implemented and maintained.
- The quality system should be periodically and systematically reviewed to ensure its continued effectiveness.
- The supplier should establish a procedure for conducting a sufficiently extensive and timely review of the specified requirements.
- The supplier should develop and maintain clear and complete documented instructions that prescribe the communication to meet the specified requirements and the performance of work in design, development, manufacture and installation, which would be adversely affected by lack of such instructions.
- The supplier should develop and maintain records to demonstrate achievement of the required quality and the effective operation of the quality system.
- The supplier should establish and maintain documented procedures for corrective action.
- The supplier should establish and maintain control of design functions.
- The supplier should establish and maintain control of all documentation.
- The supplier should provide control, calibrate and maintain inspection, measuring and test equipment suitable to demonstrate the conformity of equipment and materials to the specified requirements.
- All purchased equipment, materials and services should conform to the specified requirements.
- The manufacturing control is absolutely essential by the supplier. Satisfactory work instructions on following should be made clear : identification of material, details of operations to be performed, details of tools and test equipment to be employed, checks, tests to be done and calibration procedures, inspection procedure details, environmental conditions to be maintained during operation and inspection criterion for selection/ rejection, sampling techniques etc.

The supplier should establish and maintain control of all special processes (like welding, casting, forging, forming, heat treatment etc.) which can be done by assessing temperature and humidity cycling, vibration, radiography, magnetic particle inspection, penetrant inspection, ultrasonic inspection, spectrographical analysis, etc.

- The supplier should perform all tests on the finished product in support of evidence of full conformance to specified requirements.
- The sampling procedures used should be in accordance with the specified requirements and agreeable to purchaser.
- The supplier should establish and maintain procedures for controlling materials that does not conform to the specified requirements.
- The supplier should establish and maintain a system for identifying the inspection status of material during all stages of manufacture. Some suitable method be adopted to identify the inspected and non-inspected parts.
- The supplier should establish and maintain a system to control packing, preservation and marking processes to ensure conformity to specified requirements.
- It should be ensured that adequate personnel who have to handle contracts, designs, manufacturing, installation, quality erection functions are properly trained to perform their duty effectively.

QUALITY ASSURANCE SYSTEM

The objective of a quality assurance system is to maintain the necessary standard of quality. The important components of the quality assurance system are :

- Developing personnel with adequate understanding and training.

— Monitoring quality assurance programme of suppliers.

— Checking the accuracy of test/ measuring equipment.

— Evaluating and controlling the quality of product in the field.

— Establish a feedback link about quality related information to the management.

— Evaluating, planning and controlling product quality.

— Conducting special quality studies and managing the entire quality system.

— Accounting for the quality and reliability needs during the product design and development phase.

ATTRIBUTES OF QUALITY CONTROL MANAGER

In order to discharge his duties the quality control manager should imbibe following attributes.

— Broad knowledge of engineering, production, research, competence in statistical analysis, finance and marketing functions.

— Ability to listen and to motivate; to plan, organise; delegate, and sell effectively; to think and utilise time effectively; to communicate effectively.

— Creativeness and fairness; honesty and compassion, performance mindedness; impartiality and decision making ability, skill in negotiating, patience and persistence; enthusiasing etc.

QUALITY AUDITING

Quality audits are performed to find whether the end product satisfies the desired quality specifications; proper functioning of all equipment and machinery; operators are carrying out their duties as per specified quality plans.

Special care must be given for auditing of tool and gauge testing, quality plans, specifications and drawings.

Audits should be carried by unbiased persons and without prior announcements and cover each and every person. Audits should be made by check lists and its results recorded and made available to all concerned people. The aim of audit should not be to penalise but to take measures to correct the deficiencies found during the audits.

BASIC CONCEPTS OF QUALITY ASSURANCE PROGRAMMES

Nowadays, there is a growing need for the recognition to provide real value to the customers, which in turn requires improvement in the quality of services. The improvement in the quality is more beneficial to the industry than it is to the customers; because the improved quality results in substantial reduction in the cost of the process and the services. Thus Quality Assurance is a mutually advantageous entity.

According to the concept of Quality management, attempts should be made toward working on improving the system, and working together to understand and measure the work processes for continuous improvement.

GUIDELINES FOR APPLICATION OF QUALITY MANAGEMENT

1. Create constancy of purpose toward improvement of product and service, with the aim to become competitive and to stay in business.

2. Adopt the new philosophy. We are in a new economic age; we must awaken to the challenge, must learn the responsibilities, and take leadership for change.

3. Cease dependence on inspection to achieve quality. Eliminate the need for inspection on a mass basis by building quality into the product in the first item. (Learn how to "do it right the first time !")

4. "Continual Improvement" is essential part of everyone's job. Everyone should think in the terms ; "*We did the right thing the first time and saved rework or other unnecessary time*".

5. The practice of awarding business on the basis of price tag may not prove economical ultimately. Instead the efforts should be made to minimise total cost.

6. Improve constantly and forever the system of production and service, to improve quality and productivity, and thus constantly decrease costs.

7. Institute training on the job.

8. Institute leadership. The aim of leadership should be to help people, machines and system to do a better job. Leadership of management is in need of overhaul, as well as leadership of production workers.

9. Drive out fear, so that everyone may work effectively.

10. Break down barriers between departments. People in research, design, sales and production must work as a team, to foresee problems of production and in use that may be encountered with the product or service.

11. Eliminate slogan's exhortations, and targets for the work force asking for zero defects and new levels of productivity.

(Ask yourself; "did we improve the process ?")

12. Eliminate work standards (quotas) on the production floor. Substitute leadership. Eliminate management by numbers, numerical goals.

13. Remove barriers that deprive the worker of his right to pride of workmanship. The responsibility of supervisors must be changed from sheer numbers to quality. Remove barriers that deprive people in management and in engineering of their right to pride of workmanship.

14. Institute a vigorous program of education and self-improvement.

15. Put everybody in the organisation to work to accomplish the transformation, which is possible only with cooperation of each and every individual.

16. Continual Improvement Process calls for the effective Team Work. Every employee has a role and responsibilities to ensure continual improvement in quality, productivity and profitability. The Quality Assurance Department plays a vital role in creating the *team spirit* and will be the driving force in keeping the team together and keep it working together to continually improve the process. The team concept is a departure from the traditional management style, according to which assignments were given to individuals and the success of these assignments represented the way to get ahead. Today, this concept is changing in favour of success of the assignments made to the teams.

19

Measurements and Instrumentations

SECTION-II

Provide a single word (or a few words) for following statements/facts/definitions.

1. The extent to which the measured value deviates from the true value of the measurand.
2. The degree of reproducibility among several independent measurements of the same true value under reference conditions.
3. The ability of a measuring device to reproduce output readings when the same measurand value is applied to it repeatedly under the same environmental conditions and in the same direction.
4. A measure of the probability that a measuring device will continue to perform within specified limits of error over a specified length of time under specified conditions.
5. The magnitude of discernable or detectable output changes as the measurand is continuously varied over the range.
6. The time required for the output of measuring device to reach a specified percentage of its final value as a result of a step change of measurand.
7. The algebraic difference between the maximum and minimum limits of the range.
8. The ability of a measuring device to retain its repeatability and other characteristics throughout its specified operating life and storage life.
9. The measurand values over which a measuring device is intended to measure, specified by upper or lower limits.
10. The time required for the output of a measuring device to rise from 10% to 90% of its final value.
11. The amount of output measured beyond the final steady output value in response to a step change in the measurand.
12. The maximum deviation of any calibration point, obtained for either increasing or decreasing input, from the best fit straight line having overall minimum deviation.
13. The maximum difference in output for the same measurand value within the range of a measuring device, one obtained by increasing from zero and other by decreasing from a higher value of the measurand.
14. The algebraic difference between the indicated or observed value and the true value of the measurand.
15. The random changes in output under constant measurand and normal operating conditions.
16. A test during which standard values of measurand are applied to the measuring device and the corresponding output readings are compared with the standard values.
17. The time during which a device or system is insensitive, after receiving a stimulus, to any other impulse or stimulus.

18. The utilization of supplemental device, materials, or processes to minimize known sources or error.

19. A calibration during which the measurement varies with time in a specified manner and the output is recorded as a function of time.

20. Characteristics of a measuring device which relate to its response to variations of the measurand with time.

21. The impedance presented to the excitation source, measured across the excitation terminals of a measuring device.

22. The impedance across the output terminals of a measuring device presented by it to the associated external circuitry.

23. The physical quantity, property, or condition that is to be measured.

24. The maximum magnitude of measurand that can be applied to a measuring device without causing a change in performance beyond specified tolerance.

25. A change in output over a specified period of time at specified ambient conditions with input held constant.

26. The period of time, starting with the application of power to the measuring device, required to assure that it will perform within specified tolerance.

27. A device which provides a usable output in response to a specified measurand.

28. The smallest change in the measurand that produces a detectable change in the transducer output.

29. The time required for the output of a transducer to rise to 63.2% of its final value as a result of a step change in the measurand.

30. An excitation and amplification system for use with transducers.

31. The output response of a system or network to a unit step at the input.

32. A characteristic of a system describing the relationship between specified points when system variables are not changing.

33. A process or rule for deriving from a given mathematical entity a corresponding entity.

34. A mathematical expression relating the output of a system or device to its input, usually written as a function of the Laplace complex variable (s).

35. The output of a system after sudden application of a change at the input and before steady-state conditions have become established.

36. A quantity whose value is represented by a single continuous variable.

37. A quantity that can only have discrete values.

38. A general term to describe information.

39. The study of the simultaneous variation of two or more variable quantities.

40. A tendency of a system to break into unwanted oscillation.

41. The conditions of the medium (like temperature, pressure, humidity, vibration, radiation, etc.) surrounding the measuring device.

42. A line midway between two parallel straight-lines close together and enclosing all output versus measurand values, on a calibration curve.

43. A mechanical element of generally cylindrical shape with cylindrical walls having deep convolutions.

44. A pressure sensing element consisting of a twisted or curved tube of non-circular cross section which tends to get straightened on the application of internal pressure.

45. The range of values over which a measured variable can change without affecting the output.

46. A sensing element consisting of a thin flexible circular plate which can be actuated by a pressure differential applied across the plate.

47. The rating applicable to a specified operation for a specified uninterrupted length of time.

48. A pressure sensing element consisting of two corrugated metallic diaphragms joined along their circumference.

49. The rating applicable to a specified operation over a stated number of time intervals of specified duration.

50. The complex impedance presented to the output terminals of a transducer by the associated circuitry or load.

51. The part of the transducer which responds directly to the measurand.

52. The ratio of the change in transducer output to a corresponding change in the value of the measurand.

53. A calibration performed by application of the measurand to the transducer at discrete amplitude intervals.

54. The impedance presented to the transducer's excitation terminals by the excitation source.

55. The response of a transducer (to a step) fast change in the measurand.

56. A point maintained close to ground potential by negative feedback, although not directly connected to the ground.

57. A mathematical relationship between the input and the output, expressed as a ratio of two polynomials.

58. Observation, measurement and mathematical operation performed with time considered as the principal variable.

59. Transmission to a distance of measured quantities, usually by radio or telephony, with suitably coded modulation.

60. A property of a system, whereby the system returns to a state of equilibrium after disturbance.

61. A characteristic of some systems which prevents rapid changes or excessive instability.

62. Variations in a unified pattern which represent relevant pieces of information.

63. The modification of a carrier waveform in response to the information to be carried.

64. A physical variable whose specification requires two points in space.

65. A device which, when actuated by one form of energy, is capable of converting it to another form of energy.

66. The error observed when the instrument is under the reference condition.

67. Difference obtained by subtracting the true value of a quantity from the observed value.

68. The ratio of the absolute error to the true value.

69. Errors caused by such effects as friction, spring hysteresis, noise, and other phenomena.

70. Random errors indicated when repeated measurements of the same quantity result in differing values.

71. Relatively constant errors occurring due to such effects as sensitivity drift, zero effect, known non-linearities, etc.

72. Unwanted disturbances, superimposed on low level input signals due to noise, hum, line pickup, ripple, switching transients and line transients.

73. Deviation observed in the instrument output with time from the initial value, when all other measurement conditions remain same; the deviation may be caused by a change in component values due to variation in ambient conditions or due to ageing.

74. Percentage of the departure from the linear value, *i.e.* maximum deviation of the output curve from the best-fit straight line during any calibration cycle.

75. The maximum error in calibration at any point on the scale to the absolute measurement or theoretical straight line.

76. Linearity referred to a straight line between the theoretical end points.

77. A special case of theoretical slope linearity for which the theoretical end points are 0% and 100% of the full-scale output.

78. Linearity referred to a straight line between the experimental end points.

79. Linearity referred to the best straight line (a line midway between the closest possible two parallel straight lines) enclosing all the output values obtained during one calibration cycle.

80. Linearity referred the straight line for which the sum of the squares of the residuals (deviations of output readings from their corresponding points on the best-fit straight line) are minimised.

81. The deviation of the mean value of repeated measurements from the best fit line.
82. The range of the measurand variable for which an instrument is designed to measure linearly.
83. Probability that a system will perform its assigned functions for a specific period of time under given conditions.
84. Instruments which can be characterized by one parameter (time constant).
85. Instruments which are characterized by two parameters (natural frequency, and damping ratio).
86. An extremely accurate and absolute unit certified by the national standards institution to be within allowable tolerances.
87. The reference calibrated standards, designed and constructed from the primary (absolute) standards.
88. The normal standards needed by the individual establishments and laboratories, having one order of accuracy lower than the secondary standards.
89. Comparison of specific values of the input and output of an instrument with a corresponding reference standard.
90. Transducers operating under energy conversion principles and self-generating devices, without any external energizing source
91. Transducers operating under energy controlling principles which require secondary electrical energy from an external source.
92. Ability to withstand overloads, with safety stops for overload protection.
93. A system in which the output is exactly of the same form as that of the input, but it occurs after a transmission lag.
94. Effect which occurs when a transverse magnetic field is applied to a current-carrying conductor.
95. That part of the expression of the result of a measurement which states the range of values within which the true value is estimated to lie.
96. The smallest increment of the measurand which can be detected with certainty by the instrument.
97. The largest change of the measurand to which the instrument does not respond, and is produced by friction, backlash, or hysteresis in the instrument.
98. The maximum distance or angle through which any part of a mechanical system may be moved in one direction without applying appreciable force or motion to the next part in a mechanical sequence.
99. A measure of the ability of the instrument to restore to zero reading after the measurand has returned to zero, and other variations (like temperature, pressure, humidity, vibration, etc.) have been removed.
100. Force or torque necessary just to initiate motion from rest.
101. The friction force or torque which opposes motion of the output.
102. Friction which varies as a function of the velocity of a mechanism, and produces damping and affects the response of the output due to introduction of lag in motion.
103. Errors subject to irregular or chance causes and can be treated by statistical methods.
104. Errors arising due to use of an inadequate measurement method or caused by unfavourable environmental condition. or by original calibration error, or by human error.
105. The ratio of standard deviation and square root of the number of observations.
106. A way of removing unwanted interference and noise.
107. A semiconductor whose temperature coefficient at room temperature (25°C) is about -4%/°C, normally negative and at least ten times as sensitive as the platinum resistance thermometer.
108. Production of an e.m.f. by light incident upon a p-n semiconductor junction.
109. A crystalline or ceramic material, in which a potential difference appears across opposite faces, as a result of dimensional changes due to the application of a mechanical force.
110. Conversion of the measurand into a voltage ratio by a change in the position of a movable wiper on a resistance element across which excitation is applied.

111. Conversion of a measurand into a change in resistance or conductivity by a change in the magnitude of illumination incident upon the material.

112. Conversion of the measurand into a change in voltage generated when a junction between dissimilar materials is illuminated.

113. Conversion of the measurand into a change of emission of electrons due to a change in the incidence of photons on a photocathode.

114. Conversion of the measurand into a change in electrostatic charge or voltage generated by certain materials when mechanically stressed.

115. Conversion of the measurand into a change in the resistance of a conductor or semiconductor by a change in the mechanical stress applied to it.

116. The change in the resistance of a conductor or semiconductor due to the application of a magnetic field.

117. The change in dimension of a ferromagnetic object when the object is placed in a magnetic field.

118. The device which generates an output signal proportional to the applied force or weight.

119. The quantity of matter in a body.

120. The complex ratio of force to velocity during simple harmonic motion.

121. The generation of charges in certain crystals when unequally heated or cooled.

122. A theoretical slope for which the theoretical end points are 0% and 100% of both measurand and output.

123. The generation of electric charge by friction between surfaces.

124. The part of the transducer in which the output information originates.

125. The sensitivity of a transducer to a specified value of inputs applied in an axis orthogonal to the designed sensitive axis.

126. The step transfer process by which the transducer calibration can be related to the reference standards.

127. Conversion of the measurand into a change in e.m.f. generated by a temperature difference between the junctions of two selected dissimilar metals.

128. The axis along which the input measurand is applied or mounted.

129. Sum of the static pressure and the impact pressure in a fluid flow.

130. A short non-periodic or transient excitation of a mechanical system.

131. A transducer or a device whose characteristics are precisely known relative to a primary standard.

132. The unwanted component (typically or broad frequency spectrum) on the output of a measuring device.

133. A vector unit that specifies the time rate of change of an acceleration.

134. The specified minimum length of time over which the specified continuous or intermittent rating of a measuring device applies without changing its performance beyond specified tolerances.

135. The specified minimum length of time over which a measuring device can be exposed to a specified storage condition, without changing its performance beyond specified tolerances.

136. The specified minimum number of full range excursions or specified partial range excursions over which a measuring device will operate as specified without changing its performance beyond specified tolerances.

137. The DC resistance measured between specified insulated portions of a measuring device when a specified DC voltage is applied.

138. A measuring device whose output is a time integral function of the measurand.

139. The distortion in the output of a measuring device, in the form of harmonic other than the fundamental component.

140. A motion whose instantaneous amplitude varies sinusoidally with time.

141. Conversion of the measurand into a change in ionization current through a gas between two electrodes.

142. The range of frequencies over which the faithful reproduction of the measurand is obtained.

143. The ratio of the Laplace transform of the output quantity to the Laplace transform of the input quantity, when all initial conditions are zero.

144. Minimum value of input below which no output can be detected.

145. The quantity represented by the slope of the input-output curve if the ordinates are represented in actual units.

146. Change in the value of the measured variable due to extraction of some energy to a measuring instrument with an input signal source.

147. For transmission of maximum power from a device, the impedance of external load should match its internal impedance.

148. A device that measures, and generates an opposing effect to maintain zero deflection.

149. A device whose output is an enlarged reproduction of the essential features of the input wave and which draws power from a source other than the input signal.

150. The device which reduces the amplitude of the signal without causing appreciable distortions in it.

151. The ratio of difference between measured value and true value to the true value of the measurand.

152. Signal varying cyclically with time or repeating itself after a constant interval.

153. Signal varying non-cyclically with time, *i.e.* the signal is of a definite duration and becomes zero after a certain period of time.

154. Signal varying randomly with time, with no definite period and amplitude.

155. The output response of an instrument to various types of dynamic input signals obtained by solving its governing equation relating output and input.

156. Variation of output signal against frequency.

157. An instrument having no dynamic error and no time lag of measurement.

158. Technique of analysis of the measured data for evaluating errors and deviations.

159. Time required by a measurement system to begin to respond to a change in the measurand.

160. The largest change of input quantity for which there is no output of the instrument.

161. The magnitude of the impedance of element connected across the signal source.

162. Equivalent impedance as seen by the load connected across a device.

163. Reduction in magnitude, amplitude, or intensity of a physical quantity.

164. A pictorial and functional representation of a system.

165. Section of a frequency spectrum within which component frequencies of a signal can pass.

166. The ability of a device to reduce the effect of a common signal at both input points.

167. A signal applied simultaneously to both inputs of a differential amplifier.

168. A system that controls a variable by using error-sensing through a closed loop.

169. A characteristic of some systems which prevents rapid changes or excessive instability.

170. A logarithmic ratio of powers (P_2/P_1) *i.e.* $10 \log_{10} (P_2/P_1)$.

171. The signal applied between the two ungrounded terminals in a balanced three-terminal system.

172. A device which discriminates between frequencies.

173. Observation, measurement and mathematical operations performed with frequency considered as the principal variable.

174. The process of sharing a single channel with more than one data input.

175. A high-gain d.c. amplifier used with an external feedback path.

176. The introduction of unwanted voltages and currents into signal leads.

177. The ratio of the effective value of an alternating quantity to its average value over a half-period.

178. A graphical representation of the effect on the solutions of a system characteristic equation as a system parameter is varied.

179. A spectrum which characterises the frequency content of a random signal.

180. The process of separating the wanted information from the noise component.

181. The frequency of free oscillations in a system.

182. A point maintained close to ground potential by negative feedback, although not directly connected to ground.

183. The theory which allows analysis and synthesisation of engineering systems with less effort, greater accuracy and more understanding.

ANSWERS

1. accuracy
2. precision
3. repeatability
4. reliability
5. resolution
6. response time
7. span
8. stability
9. range
10. rise time
11. over shoot
12. linearity
13. hysteresis
14. error
15. drift
16. calibration
17. dead time
18. compensation
19. dynamic calibration
20. dynamic characteristics
21. input impedance
22. output impedance
23. measurand
24. overload
25. zero shift
26. warm-up period
27. transducer
28. threshold
29. time constant
30. signal conditioning
31. step response
32. static characteristic
33. transform
34. transfer function
35. transient response
36. analog signal
37. digital signal
38. data
39. correlation
40. instability
41. ambient condition
42. best fit straight line
43. bellows
44. Bourdon tube
45. dead band
46. diaphragm
47. continuous rating
48. capsule
49. intermittent rating
50. lead impedance
51. sensing element
52. sensitivity
53. static calibration
54. source impedance
55. Transient response
56. virtual ground
57. transfer function
58. time domain
59. telemetry
60. stability
61. damping
62. code
63. modulation
64. transvariable
65. transducer
66. intrinsic error
67. absolute error
68. relative error
69. random errors
70. uncertainty
71. systematic errors
72. interference errors
73. zero drift
74. linearity
75. absolute linearity
76. theoretical slope linearity
77. terminal linearity
78. end point linearity
79. independent linearity
80. least square linearity
81. scatter
82. span
83. reliability
84. first-order
85. second-order
86. primary standard
87. secondary standard
88. working standards
89. calibration
90. active transducers
91. passive transducers
92. ruggedness
93. dead-time element
94. Hall-effect
95. uncertainty
96. discrimination
97. dead-band
98. backlash
99. zero stability
100. striction (static friction)
101. dynamic coulomb friction
102. viscous friction
103. random errors
104. systematic errors
105. SEOM (standard error of the mean)
106. signal filtering
107. thermistor
108. photovoltaic effect
109. piezoelectric
110. potentiometric transduction
111. photoconductive transduction
112. photovoltaic transduction
113. photoemissive transduction
114. piezo electric transduction
115. piezovoltaic transduction
116. magneto resistive effect
117. magnetostriction
118. load cell
119. mass
120. mechanical impedance
121. pyroelectric effect
122. terminal line
123. triboelectric effect
124. transduction element
125. transverse sensitivity
126. traceability
127. thermoelectric transuduction
128. sensitive axis
129. stagnation pressure
130. shock
131. reference standard
132. noise
133. jerk
134. operating life
135. storage life
136. life cycling
137. insulation resistance
138. integrating device
139. harmonic distortion
140. harmonic motion

141. ionizing transduction
142. frequency response
143. transfer function
144. threshold
145. sensitivity
146. loading
147. impedance matching
148. null type device
149. amplifier
150. attenuator
151. relative error
152. periodic
153. transient
154. random
155. dynamic response
156. frequency response
157. first-order instrument
158. statistical analysis
159. dead time
160. dead zone
161. input impedance
162. output impedance
163. attenuation
164. block diagram
165. bandwidth
166. common-mode rejection
167. common-mode signal
168. control system
169. damping
170. decibel
171. differential-mode signal
172. filter
173. frequency response
174. multiplexing
175. operational amplifier
176. pickup
177. form factor
178. root locus
179. power-density spectrum
180. signal recovery
181. undamped natural frequency
182. virtual earth
183. Laplace transform

20

Electrical Engineering

Electric current flows from positive to negative polarity but electrons flow in reverse direction. Current flows when electrons find a path to move along.

Since electricity hinges on the presence and flow of electrons, various electric units are defined in terms of electrons as follows.

Coulomb. It is the basic quantity of electricity (electrical charge). One coulomb equals 6.25 billion electrons.

Ampere. It is the unit of current. One ampere current means that one coulomb flows past a point in a circuit every second.

Volt. It is the unit of pressure that passes current through a circuit. One volt will push one ampere through a resistance of one ohm.

Ohm. It is the unit of resistance to current flow. One ohm is the quantity of resistance producing a potential drop of 1 volt when the current in it is 1 ampere.

Mho is the unit of conductance $\left(\text{mho} = \frac{1}{\text{ohm}}\right)$.

A conductance of 1 mho will pass 1 ampere when subjected to 1 volt.

Watt. It measures power in a circuit (watt = current^2 × resistance). One watt is the power used for 1 ampere to flow through 1 ohm.

Watt hour. It measures energy or work done in a circuit.

Farad. It is the unit of capacitance. A condenser has a capacitance of one farad when a charge of one coulomb produces a potential difference of 1 volt.

Henry. It is the unit of inductance. A circuit has inductance of 1 henry if a current change of 1 ampere per second causes 1 volt to be induced in it.

Magnetism induces voltage in any conductor kept moving within magnetic field.

Electrolytic current flows when two dissimilar metals are put in an electrolyte.

Thermoelectric voltage is generated by heating two dissimilar metals at junction.

Photovoltaic cell (lightmeter causes slight voltage when exposed to light).

Static electricity is charge built up on clouds, moving belts etc.

Resistance, Inductance and Capacitance. Like friction, resistance is always present. It is directly proportional to length of conductors and inversely proportional to its cross sectional area. These give off energy as heat.

Inductance stems from shaping wire into a coil. Resulting magnetic fields will join forces and induce a counter voltage in coil. Induced voltage will be in opposition to that impressed on coil. Inductors store energy in their magnetic fields. Capacitance depends on presence of two plates separated by insulator called dielectric. Energy can be stored on plates as electric charge. If well-insulated, charge takes several hours to leak off.

All circuits contain all these three components either as separate elements or distributed throughout.

Direct-Current Circuits

Ohm's law. In direct current circuits, current flows in one direction and inductance and capacitance can be neglected. Current equals the voltage across the circuit divided by circuit resistance.

D.C. Power. It is the product of voltage and current flowing through the circuit. Wattage is also equal to current^2 × resistance or voltage^2/resistance.

Series Circuit. In series circuit, same current flows through each circuit component. Total resistance is the sum of separate resistances. Voltage across each is proportional to its resistance. Current through the circuit is voltage divided by the total resistance added up.

Parallel Circuit. When two circuit components are connected in parallel, the total current through common leg splits up through each inversely as the resistance of component. Total resistance is reciprocal of sum of reciprocals of separate resistances. Voltage is same across all parallel resistors.

Series-Parallel Circuits. Total resistance in such cases is found by reducing each parallel group to a single equivalent series resistance, and then adding up all series and equivalent series resistors.

Induction in D.C. Circuits. When switch (*S*) is closed on d.c. circuit with a coil, (Refer Fig. 20.1) current increases as coil's magnetic field begins to build up because changing magnetic field's strength induces counter-voltage opposing applied voltage. As field builds up, counter-voltage decreases, current increases to constant value.

When switch (*S*) is opened, the magnetic field surrounding coil collapses. This induces high voltage.

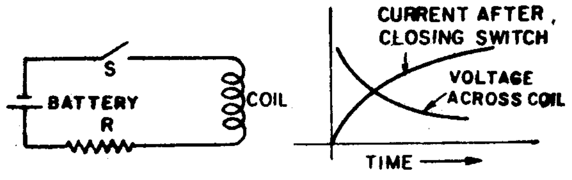


Fig. 20.1.

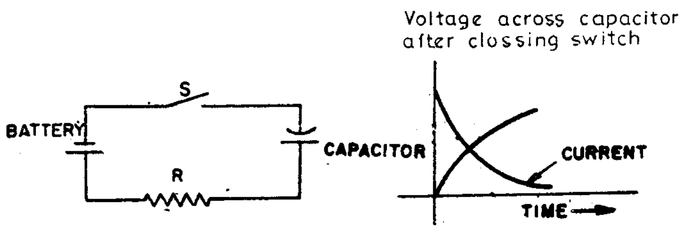


Fig. 20.2.

Capacitor action. In the case of capacitor, reverse action takes place. When switch (*S*) is first closed, there is no charge on the plates, so there can be no voltage across the condenser (Refer Fig. 20.2). Initial current is maximum, decreasing with time as charge builds up. Once charge has built up to capacity, condenser acts as a block to flow of d.c. current, thus acting as a spring. However, capacitor passes a.c. current (but not d.c. after steady state is reached). Equivalent capacitance in parallel circuit is sum of each capacitor.

In series $$\frac{1}{C_{series}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$$

Alternating Current circuits. Pattern of a.c. voltage is of sine waveform, since the voltage generated is in sine form, varying from 0 to maximum +ve value, falling to zero, going towards –ve maximum and again reaching zero and repeating same waveform again. For single phase, effective voltage or r.m.s. value is 0.707 × maximum voltage. Volts and amperes measured by meters are effective values, since 1 r.m.s. ampere will generate the same amount of heat in a 1 ohm resistor as will one ampere of d.c. current.

A.C. current in Resistance, inductance, and capacitance. (Refer Fig. 20.3) In case of pure resistance, current is right in step with voltage.

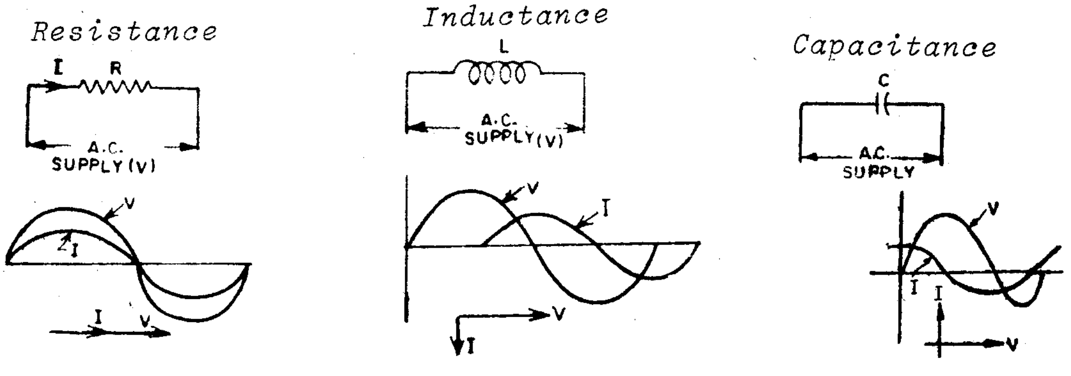


Fig. 20.3.

In case of inductance, inductive current lags voltage. Reactance X_e in ohms $= 6.28 \times f \times L$ (L is inductance in henries, f = frequency in cycles/sec.) In case of capacitance, capacitor current leads volts. Reactance $X_c = 0.159 \div (f \times C)$; C = capacitance in farads, f = frequency in cycles/sec.

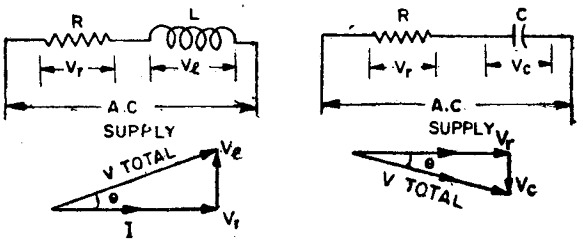


Fig. 20.4.

Basic Components in Series. In case of series connections, current is same throughout, but voltage drops across resistor and reactance will be out of step (phase) although their vector sum equalises the impressed voltage. Resultant current I_t lags behind V_t in inductive circuit and leads V_t in capacitive circuit (Refer Fig. 20.4). However, voltage drop across resistor and current flowing through it are in phase. $(V_t = V_{\text{TOTAL}})$'.

Basic components in parallel. To find total current in case of parallel circuit, first current is found for each leg and also its phase angle and then vectors are added as shown in Fig. 20.5.

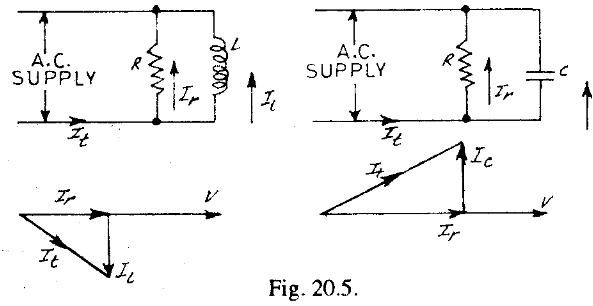


Fig. 20.5.

Resistance, inductive and capacitive reactances can be combined vectorially as one quantity, impedance $Z = V/I_t$, Z can be found by laying out R ohms horizontally, X_l ohms 90° down, and X_c ohms 90° up. Then Z is the resultant at the power factor angle.

Power factor. An a.c. electrical system carries two types of power (*i*) true power, watts, that pulls the load and (*ii*) reactive power, vars, that generates magnetism within inductive equipment. The vector sum of these two will give

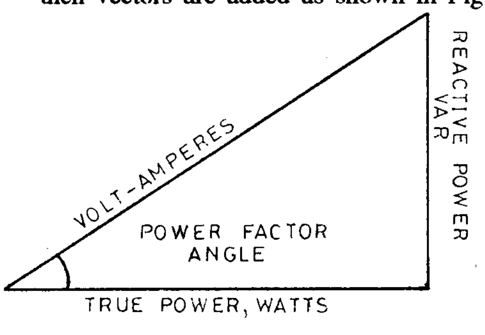


Fig. 20.6.

actual volt-amperes flowing in the circuit. Power factor is the cosine of the angle between true power and volt amperes.

Single-Phase Power. Power of a single-phase a.c. circuit equals voltage times current times power factor (p.f.).

$$P_{watts} = E_{volts} \times I_{amp} \times \text{p.f.}$$

Reactive power, vars can be found by relation

$$\text{vars} = \sqrt{(\text{volt} \times \text{amp})^2 - (\text{power})^2}$$

Three-phase AC Circuits. Three phase is the most common polyphase system. This system has three distinct voltages out of step at 120° with one another. At any instant, the algebraic sum of these three voltages is zero. When one voltage is zero, the other two are 86.6% maximum and have opposite signs (Refer Fig. 20.7).

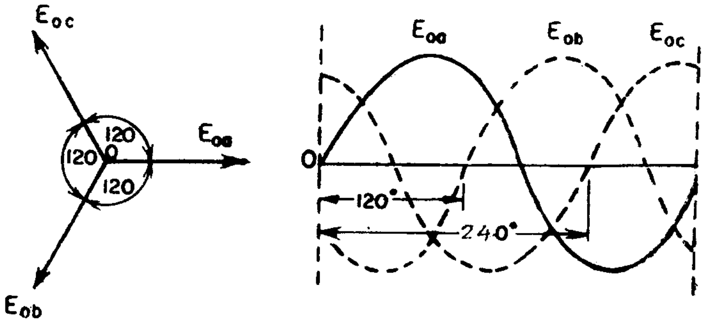
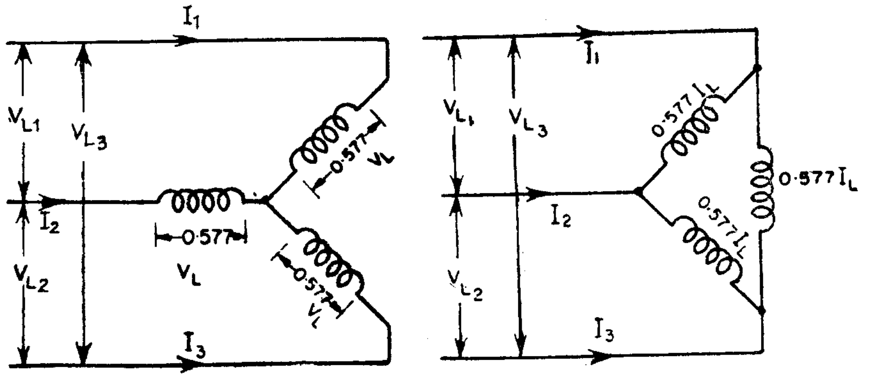
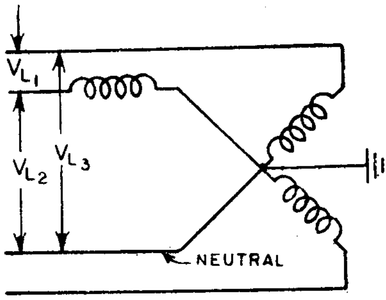


Fig. 20.7.



Y-connection Delta connection



Four-wire connection.

Fig. 20.8.

The three phases are generated by placing each phase coil in the generator 120 degrees apart, mechanically. Rotating d.c. field will then cut each phase coil in turn, inducing voltage in each out of phase with the other two. The voltages of three phases are available on three separate wires, but are shown on common base in Fig. 20.7 for comparison purposes.

The three phases could be connected as Y or star connection, delta connection, or 4 (four) wire connection as shown in Fig. 20.8 In case of Y-connection, current in all phases is line current, but voltage across each is 0.577 × line voltage.

In case of delta connection, voltage in each phase is line voltage, but current splits up so that 0.577 I_t flows through each.

In case of 4 wire system, voltage between phase and neutral is line voltage between phase to phase divided by 1.732. For balanced load, current through neutral line is zero.

Power in any balanced polyphase system (more than one phase)

$$= V_L \times I_L \times \text{p.f.} \times \sqrt{\text{No. of phases}}$$

Thus for three phase, power $= \sqrt{3}\, V_L I_L \times$ p.f. Power in one phase is phase volts times phase current times power factor. Total power is the sum of all phase powers. Thus for balanced three phase,

$$\text{total power} = 3\, V_P I_P \times \text{p.f.}$$

Transformers

It is a device to step up or step down the voltage level. Current in primary sets up magnetic field (flux) in core which in turn induces voltage across secondary. The secondary voltage V_2 is proportional to primary voltage V_1 in the same ratio as number of turns N_2 to N_1. Currents are inversely proportional to turn ratio. Thus

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}.$$

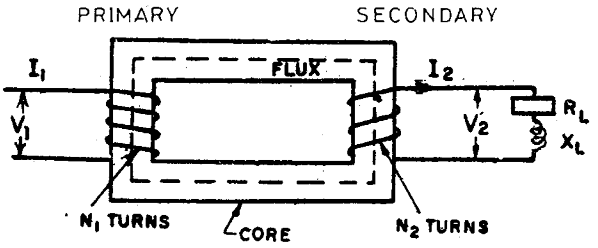


Fig. 20.9.

Impedance of secondary load and impedance of the secondary itself are both reflected back into the primary circuit as the square of the turns ratio.

Thus total impedance

$$Z_t = Z_1 + Z_2\left(\frac{N_1}{N_2}\right)^2 + Z_L\left(\frac{N_1}{N_2}\right)^2$$

$$R_t = R_1 + R_2\left(\frac{N_1}{N_2}\right)^2 + R_L\left(\frac{N_1}{N_2}\right)^2$$

$$X_t = X_1 + X_2\left(\frac{N_1}{N_2}\right)^2 + X_L\left(\frac{N_1}{N_2}\right)^2$$

$$R_t = \frac{P}{I_1^2},\ Z_t = \frac{V_1}{I_1},\ X_t = \sqrt{Z_t - R_t^2}$$

$$\text{Power factor} = \frac{R_t}{Z_t}$$

Lighting

Light is radiant energy like heat and radio waves and it is visible. Light intensity is expressed in candle power and unit of quantity of light is lumen. One lumen is defined as the amount of light falling on a one square foot spherical section, all points of which are 1 foot away from a one candle power source. A one candle power source emits 12.57 lumens. Illumination (or light density) is measured in foot candles (one foot candle being equal to 1 lumen per sq. ft.). Light brightness is measured in foot-lambert (no. of foot candle reflected from a surface). According to inverse square law, foot candles of illumination vary inversely as square of the distance from light source. Thus if illumination is 1 foot candle at a particular distance from the source of light, it will be 1/4 foot candle at double the distance.

Batteries

It produces electrical energy from chemical energy. It consists of two dissimilar electrodes immersed in an electrolyte. Chemical action between the electrodes and the electrolyte causes current to flow from one electrode to the other through the electrolyte when the electrodes are connected to an external load.

Batteries are rated in ampere-hours. A battery rated at 100 amperes hours will furnish roughly 10 amperes for 10 hours, 5 amperes for 20 hours etc. before getting exhausted. Constant use at heavy currents results in shorter than rated life.

In secondary batteries or storage batteries, materials of electrodes are such that they can be restored through charging. (For example, lead–acid, nickle–iron–alkaline, silver–cadmium–alkaline etc.). Water is added from time to time to maintain the required amount of electrolytic solution.

A battery charger is an electrically powered unit designed to re-establish the chemical characteristics which give a charge to a secondary battery.

Wires and Cables

These are the most common type of conductors used to carry electric current throughout all types of circuits and systems. These are available in different sizes, insulation, outer jacketing, no. of conductors etc. These must have sufficient mechanical strength to protect against damage, insulation to keep the conductors from improper contact with anything external to the circuit and adequate cross-sectional area to assure easy flow of the desired current.

A wire is a single, solid length of drawn metal. It is generally covered with insulation.

A conductor may be a wire or a number of uninsulated wires twisted together. It represents a single path for conduction of electric circuit.

A standard conductor is a conductor made up of a number of uninsulated wires twisted or braided together.

A cable may be either a single conductor cable or a multi-conductor cable.

Protective Devices

Electrical wires, cables, devices, equipment and apparatus are rated according to the normal value of voltage which can be applied to them and the current which they can safely carry. If other than the safe value of voltage were applied to a conductor or equipment, or if higher than rated current were to flow, the equipment would be seriously damaged.

In addition, a general condition of hazard to personnel would result. To protect conductor and equipment against abnormal operating conditions (overloading, short circuit etc.) and their consequences, a special group of protective devices are used in electrical systems. These include fuses, circuit breakers, relays etc. Various types of fuses are plug fuses, cartridge fuses, (single element fuses, non-renewable fuses, renewable fuses, current limiting fuses for short circuit protection, time delay operation fuses for overload protection etc.).

An electrical installation is usually of complex nature. Coordinated selective protection is thus essential and is possible with modern fast acting protective devices to isolate faulted circuit from the remainder system.

Circuit breakers find widespread application as circuit and equipment protective devices. A circuit breaker is simply switching device which provides automatic interruption of current flowing through it when current conditions are abnormal, (both overload and short circuit conditions) without causing damage to itself. These are thermal type, magnetic air circuit breakers, oil circuit breakers, vacuum type etc.

Switch boards and Panel Boards. These provide points in electrical systems at which blocks of electric power are broken down from large conductors and apportioned, as required by loads, among smaller conductors. In addition, they afford a logical point for using switches or circuit breakers as control devices for the flow of energy or for disconnecting loads for safe maintenance. Protection of conductors and equipment against overload, shorting etc. is also accomplished from them.

Switches refer to a device for making, breaking or changing the connections in an electrical circuit, under a certain rated load but not under short-circuited conditions. There are many types and sizes of switches suited to particular conditions of application.

Relays. A relay is a magnetically operated switching device used for a wide range of control applications. It consists of an electromagnet assembly which moves an armature to open or close one or more sets of normally open and/or normally open and/or normally-closed contacts. The coil is energised to operate the contacts.

Rectifiers are devices which convert alternating current power into direct current power. These are of various types *viz.* mechanical, copper-oxide, selenium, germanium, hot-cathode, mercury-arc types, thyratrons, ignitrons, excitrons etc.

Invertors are devices which convert direct current to alternate current.

Selection of Motors

It must be understood that the motors generally operate at best power factor and efficiency when fully loaded. The various requirements of driven machines are following and should be properly considered : HP required, torque, operating cycle *i.e.* frequency of starts and stops, speed, operating position (*i.e.* horizontal, vertical or tilted), direction of rotation, endplay and thrust, ambient temperature, surrounding conditions. Various electrical parameters are voltage, number of phases, frequency, limitation on starting current etc.

Torque. The starting torque of motor right from standstill to full load under all conditions should be more than the torque requirements of load. For fluctuating torque, it is best to use a high slip motor with a flywheel. For steady load, efficient low-slip motor can be used.

Enclosure. Surrounding conditions like water, gas, corrosion etc. need to be properly analysed. Type of motor enclosure required depends on these. It should be understood that more enclosed a motor is, more it costs and more is the tendency of it to get hotter. Various types of motor enclosures commonly used are : open type (full openings in frame for maximum ventilation); semi-protected (screen in top openings to keep out falling objects); drip-proof (upper parts covered to keep drippings falling at angle not over 15° from vertical); splash proof (baffled at bottom to keep out particles coming at angle not over 10° from vertical); totally enclosed : fan cooled (totally enclosed with double covers; fan behind vented outer shroud run by motor).

Insulation. Type of insulation to be employed is determined by surroundings and operating temperature. Insulation life is dependent on the total temperature attained by the motor. Various insulations are class A (cotton, silk paper, or other organics impregnated with insulating varnish and it allows 105°C total temperature); class B (mica, asbestos, fibreglass, other inorganics and it allows 130°C total temperature), class H (includes silicone family also and is meant for high temperature applications). Ambient temperature is assumed to be 40°C. Tropical design is for excessive moisture, high ambients, corrosion, fungus, vermin, insects etc. and is recommended for Indian conditions.

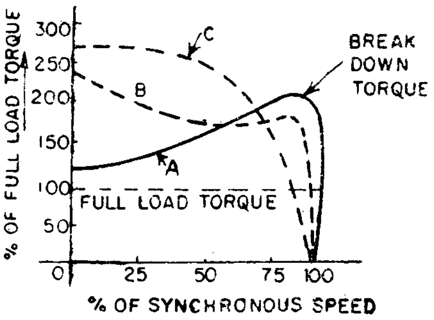
Squirrel cage Induction Motors

These are normally classified according to locked rotor torque, breakdown torque, slip, starting current etc.

Fig. 20.10 shows the characteristics of three types of induction motors commonly used.

Various methods of starting

Full voltage, across-the-line starting is used where power supply sources permit kVA inrush, and full voltage torque and acceleration are not objectionable. It is possible to have reduced voltage below certain h.p. thus limiting starting current to fixed % of full load. Reduction in starting kVA cuts locked rotor and accelerating torques. Voltage on starting can be reduced by auto-transformer. Series resistance (or reactor) provides closed transition from start to run, raising motor kVA and torque by steps.



A—Normal starting torque, low starting current
B—High starting torque, low starting current
C—High starting torque, high slip.

Fig. 20.10.

Wound-rotor motors

In case of wound-rotor or slip-ring inductor motor, its rotor winding is connected through slip rings to an external resistance that can be cut in and out by a controller. Resistance of rotor winding affects torque developed at any speed. While low-resistance rotor produces low slip at full load, good efficiency and moderate rotor heating, high resistance rotor produces high starting torque with low starting current. These motors are used for high-inertia loads where high slip losses that would have to be dissipated in the rotor of a squirrel-cage motor, in coming up to speed, can be given off as heat in wound rotor's external resistance, where frequent starting, stopping and control are needed; and for continuous operation at reduced speed.

Synchronous motors. These run at fixed speed at all the loads (speed in r.p.m. = 120 × frequency + no. of poles). Speed is kept constant by locking action of an externally excited d.c. field.

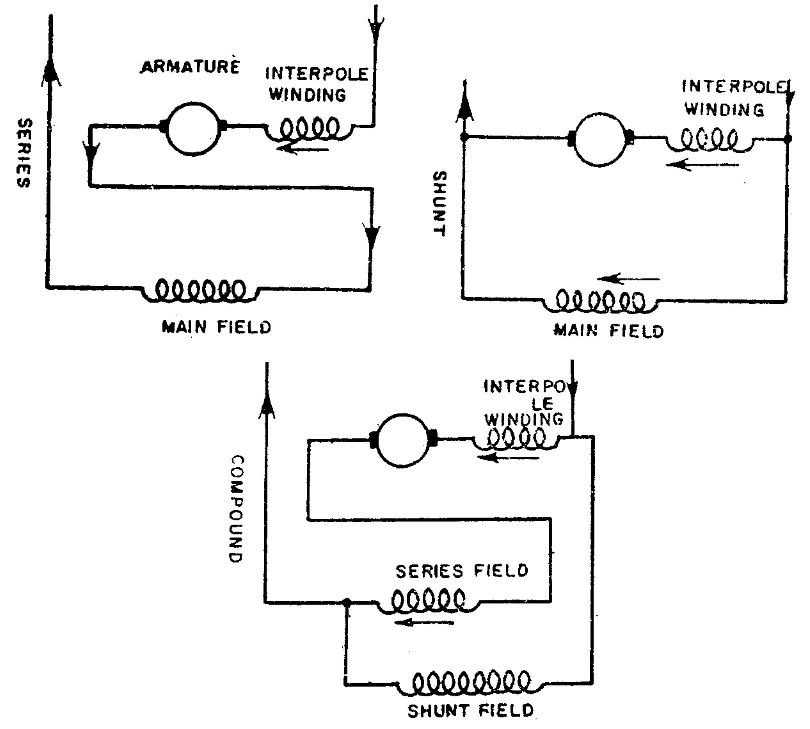


Fig. 20.11.

Power factor can vary from 1.0 to 0.2 leading by increasing d.c. field current. These are not self starting. Driven machine is usually started without load.

D.C. Motors. Wide and economical ranges of speed control and starting torques are possible with D.C. motors. However, AC motors are preferred for constant speed service because these are more rugged and less expensive. These are generally classified as series, shunt and compound type as shown in Fig. 20.11.

Series. At light loads, flux varies directly with the current, so torque varies as the square of the current. Series motors can develop higher starting torques at same current, since torque increases as current squared.

In series motor, speed decreases much more with increased load, and races at low loads, dangerously, if load is completely removed. Speed can be reduced by adding resistance into armature circuit.

Shunt. Torque is proportional to armature current, because field flux remains practically constant for a given setting of field resistance. Shunt motor speeds drop only slightly (5% or less) from no load to full load. Decreasing field current raises speed, increasing field reduces speed. Speed is practically constant for any one field setting. Speed can be controlled by resistance in the armature circuit but regulation is poor.

Compound. These develop starting torques higher than shunt motors according to amount of compounding. These have less constant speed than shunt motors and can be controlled by shunt-field resistance.

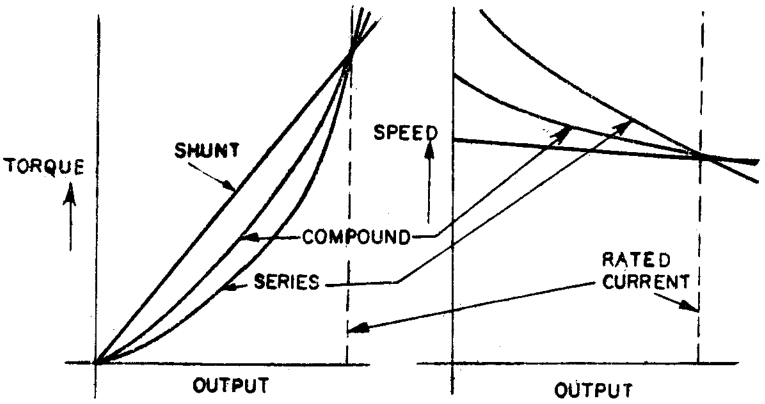


Fig. 20.12.

The torque and speed characteristics of three types are shown in Fig. 20.12.

Motor Characteristics and Applications

Type of motor 1	*Speed regulation and speed control* 2	*Starting torque* 3	*Pull-out Torque* 4	*Applications* 5
1. Squirrel-cage Induction motors (*a*) General Purpose	drops to 3–5% depending on size, designed for 2 to 4 fixed speeds.	200% of full load for 2 pole to 105% for 16-pole	200% of full load	Constant speed, where starting torque is not too high. (Fans, blowers, centrifugal pumps etc.)
(*b*) High-torque	drops to 3–6%, designed for 2 to 4 fixed speeds	250% at full load for high speed motors and 200% for low speed motors	200% for full load	Constant speed with high starting torque (400% starting current) at frequent intervals. (Reciprocating pumps etc.)
(*c*) High-slip	drops 10–15%, from no load to full load, designed for 2 to 4 fixed speeds	225–300% of full load, depending on speed with rotor resistance	200% usually not stall until loaded to max. torque.	Constant speed and high starting torque if starting is not too frequent and for taking high peak loads (Punch presses, shears etc.)
(*d*) Low-torque	drops 3–5% depending on size, designed for 2 to 4 fixed speeds	50% of full load for high speed to 90% for low speed motors	150–170% full load.	Constant speed with light starting duty (Fans, blowers, centrifugal pumps etc.)