# CHAPTER 9

# TESTING OF ROTATING ELECTRICAL MACHINES

## 9.1 Introduction

Rotating electrical machine is an electrical apparatus which consists of a stationary part known as stator and a rotating part known as rotor. Depending upon the type of electromechanical energy conversion, these machines are classified into generators or motors. In generators, the machine converts mechanical energy into electrical energy and in motors electrical energy is converted into mechanical energy. Electric motors are the most important type of electric load in every industry. The motor driven systems account for about seventy percent of the energy consumed by industry. In this chapter, we consider various features of '***Single phase ac induction motors for general purpose***' and '***Line operated three phase ac motors***'.

### *SINGLE PHASE AC INDUCTION MOTORS FOR GENERAL PURPOSE*

## 9.2 Single phase a.c. induction motors for general purpose

Single phase ac induction motors of the capacitor types, split phase and shaded pole types for voltages up to and including 250 V and having windings with Class B, Class F and Class H insulation an output upto and including 2200 W are covered in IS 996. The preferred values of voltage, frequency, output and speed are given in 9.4 of this chapter. Motors for use on systems complying to voltages and frequencies other than the preferred values are also considered as complying with IS 996 provided they comply in all other respects of IS 996. The voltages and the frequency for which the motors are designed are required to be stated on the rating plate.

The torque characteristics of various types of motors are given below:

a) ***Capacitor Start - Induction Run***: These motors have higher starting torques and lower starting currents than split-phase motors and are generally more suitable for loads of higher inertia and more frequent starting.

b) ***Capacitor Start - Capacitor Run***: These motors have characteristics similar to those covered by capacitor start – induction run motors, but are more applicable where a greater degree of quietness or a higher efficiency and power factor are desirable.

c) ***Capacitor Start and Run***: These motors are for use where low starting torques are acceptable. They are also generally quieter than split phase or capacitor start – induction run motors.

d) ***Split Phase***: Owing to their high starting currents, split-phase motors are generally used for loads of low inertia and infrequent starting. When higher starting currents can be tolerated, motors of the higher torque rating can be used.

e) ***Shaded Poles***: These motors are suitable for all applications where only a very low starting torque is required and motor efficiency is not important.

## 9.3 Terminology

The following definitions are considered relevant:

***Rotor***: The rotating portion of a machine.

***Stator***: The portion of a machine which includes the stationary magnetic parts with their associated windings.

***Single-phase machine***: A machine which generates or utilizes single-phase alternating current.

***Polyphase machine***: A machine which generates or utilizes polyphase alternating current.

***Direct current motor***: A motor for operation by direct current.

***Alternating current motor***: A motor for operation by alternating current.

***Universal motor***: A motor which can be operated by either direct current or single-phase alternating current of normal supply frequencies.

***Induction motor***: An alternating current motor without a commutator, in which one part only, either the rotor or the stator, is connected to the supply network, the other working by induction.

***Terminal***: A conducting element of a winding intended for connection to an external electrical conductor.

***Starting***: The process of bringing a machine up to speed from rest.

***Starting current***: The rms current drawn.by the motor during the starting period.

***Starting torque***: The electromagnetic torque exerted by a motor during the starting period.

***No-load***: The state of a machine rotating at normal speed under rated conditions, but when no output is required of it.

***Output***: The useful mechanical power measured at the shaft of a motor.

***Rated Output***: The value of the output included in the rating.

***Input***: The active electrical power supplied to the terminals of a motor.

***Breakaway***: The condition of a machine at the instant of change from rest of rotation.

***Rated load torque***: The shaft torque of a motor corresponding to rated output and speed.

***Locked-rotor torque***: The minimum measured torque which the motor will develop with the rotor locked and rated voltage applied at rated frequency.

***Breakaway (Starting) torque***: The lowest torque developed by the motor in the stand-still condition when the motor is supplied at the rated voltage and rated frequency.

***Pull- up torque***: The smallest torque developed by the motor between zero speed and the speed which corresponds to the pull-out torque when the motor is supplied at the rated voltage and rated frequency.

***Pull-out torque***: The highest torque that the motor can develop while running at rated voltage and rated frequency.

***Locked-rotor current***: The measured steady-state root mean square current taken from the line with the motor at rest, with rated voltage and frequency applied.

***Breakaway starting current***: The highest root mean square current absorbed by the motor when at rest, and when it is supplied at the rated voltage and frequency.

***Duty***: Statement of the loads, including no-load and rest and de-energized periods to which the machine is subjected, including their duration and sequence in time.

***Intermittent duty***: A duty in which the load changes regularly or irregularly with time.

***Continuous running duty-type***: Operation at constant load of sufficient duration for thermal equilibrium to be reached.

***Rated value***: The numerical value of a quantity included in the rating.

***Performance tests***: The tests required to determine the characteristics of a machine and to show that the machine complies with its specification.

***Efficiency***: The ratio of output to input, usually given as a percentage.

***Total loss***: The difference between the input and the output.

***No-load test***: A test in which the machine is run as a motor providing no useful mechanical output from the shaft.

***Locked-rotor test***: A test on an energized machine with the rotor held stationary for the purpose of determining the locked rotor torque.

***Starting test***: A test taken on a machine while it is accelerating from standstill under specified conditions for the purpose of determining the starting torque.

***Temperature-rise test***: A test undertaken to determine the temperature-rise of one or more parts of a machine under specified operating conditions.

***Overload****:* Any load in excess of rated output expressed as a percentage of rated output.

***Momentary Overload***: Any overload the duration of which is so short as not to affect appreciably the temperature of the motor.

***General Purpose Motor:*** A motor designed in standard ratings with standard operating characteristics and mechanical construction for use under usual service conditions without restrictions to a specific application or type of application.

## 9.4 Rated conditions of voltage, frequency, output and speed of motors

The preferred rated values are as given below:

a) ***Rated Voltage -*** The preferred rated voltage is 230V.

b) ***Rated Frequency***- The rated frequency is 50 Hz.

c) ***Rated Output***- The preferred output ratings are 2.5, 4, 7, 12, 18, 25, 40, 60, 90, 120, 180, 250, 370, 550, 750, 1100, 1500 and 2200 Watt.

d) ***Rated Speeds***- The preferred rated speeds are those corresponding to 2, 4, and 6 poles.

### 9.5 Site conditions

The following constitutes the normal site conditions:

a) ***Altitude and Temperature -*** Motors shall be designed for the following site conditions unless otherwise agreed between the manufacturer and the purchaser:

*Altitude*- Altitude not exceeding 1000 m.

*Temperature*- The cooling air temperature not exceeding 40°C.

***b) Voltage and Frequency Variation*** - Motors as per IS 996 shall be capable of delivering rated output with,

i) terminal voltage differing from its rated value by not more than ± 6 percent, or

ii) frequency differing from its rated value by not more than ± 3 percent, or

iii) any combination of (i) and (ii).

***c) Variation from Rated Speed*** The variation shall be in accordance with Table 9.1.

**Table 9.1 Performance parameters - Tolerance**

| Performance Parameter | Tolerance |
|---|---|
| Efficiency | -15 percent of (100 - η) |
| Power factor | -1/5 (1-cos ϕ), *Min* -0.02, *Max* -0.12 |
| Speed of motor at rated full load | ±50 percent of rated slip at full load |
| Breakaway (starting) torque | -20 percent of the stated breakaway (starting) torque |
| Pull out torque | -10 percent of the stated pull-out torque |
| Pull up torque | -20 percent of the stated pull up torque |
| Breakaway (starting) current (locked rotor) | +20 percent of the stated breakaway (starting) current |

### 9.6 Dimensions

The recommended dimensions for rigid base mounted, resilient base mounted and flange mounted motors are given in IS 1231 ‘Dimensions and Output Series of Foot Mounted Induction Motors - Frame Numbers 56 to 315 L’ and IS 2223 ‘Dimensions of Flange Mounted AC

Induction Motors'. Considering the wide variety of usage and application, these motors may be manufactured in frame sizes and dimensions other than those specified. Whenever the motor construction requires deviation from the recommended dimensions, the dimensional requirements shall be a matter of agreement between the manufacturer and the user. Dimensional requirements of motors smaller than those corresponding to frame 56 shall be subject to an agreement between the manufacturer and the user. However, unless otherwise specified, the dimensional tolerances (on the declared dimensions) in such cases shall be corresponding to the nearest frame size.

### 9.7 Duty and Rating

The duty and rating of the motors are as given below:

a) ***Continuous Rating* -** The general-purpose motors shall be continuously rated.

b) ***Short Time Rating* -** If the motors are short time rated, the preferred periods shall be 5, 15, 30 or 60 min.

### 9.8 Constructional features

The general constructional requirements of the motors vary with respect to its mounting. Various mounting constructions are possible with shaft horizontal, vertically upwards or vertically downwards and the different types of mountings. The type of construction normally forms a subject matter of agreement between the manufacturer and the user. The different types of mountings are as given below:

a) ***Foot-mounted motor***: A motor with feet, the feet being used for fixing it in position.

b) ***Flange-mounted motor***: A motor with flange, the flange being used for fixing it in position.

c) ***Foot-cum-flange mounted motor***: A motor with flange and feet, the feet being used for fixing it in position.

d) ***Resilient-ring mounted motor***: A motor provided with resilient mounting so that it is supported between two resilient rings affixed to its end shields, the rings being used for mounting by the user.

e) ***Resilient-base mounted motor***: A resilient-ring mounted motor provided with mounting base, the base being used for fixing it in position.

f) ***Stator-pad mounted motor***: A motor provided with three or four pads on stator body, equispaced in angular position, duly tapped, the pads being used for fixing motor in position.

g) ***End shield pad mounting***: A motor provided with three or four pads on end shield equispaced in angular position in same plane, duly tapped, the pads being used for fixing motor in position.

h) ***Foot-cum-end shield-pad mounting***: An end shield pad mounted motor with feet, the feet being used for fixing motor in position.

i) ***Extended bolt mounting:*** A motor where extended threaded studs or motor bolts are provided to be used for fixing motor in position.

j) ***Frame-mounted motor***: A motor without driving end shield, the frame or stator body being used for fixing it in position.

The motors shall be processed in a careful manner and the manufacturer shall use good measurement and production techniques so as to ensure the highest degree of product reliability and uniformity corresponding to the materials used in the product. The following are the general considerations in this regard:

a) ***Non-metallic Material Enclosure*** - If the enclosure or main structure of the motor is non-metallic, the material of such enclosure or main structure shall be non-flame supporting or self-extinguishing.

b) ***Thermal Protector*** - When motors are provided with thermal protectors, it shall bear a warning label stating 'THERMAL PROTECTOR FITTED' or 'THERMALLY PROTECTED' and shall be conspicuous.

c) ***Manual Resetting Protector*** - When such protectors are of manual resetting type the resetting arrangement shall be readily accessible and identifiable through clear marking.

d) ***Lubrication*** - Readily accessible lubricating points shall be provided, wherever necessary.

e) ***Lubricant Temperature*** - The lubricant of the motor bearings shall be suitable for bearing temperatures which can result from the operating conditions of the motor.

f) ***Centrifugal Switch*** - To ensure satisfactory operation, the centrifugal switch where fitted, shall be in such a manner that it shall not be exposed to lubricating grease or oil which may be discharged from over lubricated bearings.

g) ***Resilient Mounting Material*** - When resilient mountings are an integral part of the motor, the mounting shall be oil resistant and resistant to heat which is produced by the motor. The resilient base mounted motor shall withstand without slippage between the frame and base an applied torque of 1.5 times the maximum value of any torque that can be developed by the motor at rated voltage.

h) ***Insulating Material*** - Insulating materials used shall be in accordance with the class of insulation, stated in the rating plate or superior.

i) ***Insulation of Leads*** - The insulation material of connection/external leads supplied with the motor shall be suitable for the maximum temperature of the part of motor coming in contact with these leads.

j) ***Capacitors*** - Capacitors where used shall comply to IS 2993.

All materials and components used in the manufacture of the motor shall conform to the relevant Indian Standard, wherever they exist. All surfaces exposed to atmosphere which are not adequately protected by metal deposition shall be protected against corrosion by painting, enamelling, oxidizing or phosphatizing.

## 9.9 Earthing

The requirements for earthing are as given below:

a) ***Earthing Terminal*** - At least one separate earthing terminal of adequate current carrying capacity conveniently located and visible shall be provided on the motor. The earthing terminal shall be of suitable material adequately protected against corrosion and shall have the symbol '' or the marking 'E' on or adjacent to it.

b) ***Lead Earthing*** - If resilient mounted motor is supplied with external/loose leads to the motor windings, a separate earthing cord or lead shall be supplied.

c) ***Plug Earthing*** - If any type of motor is supplied with external/loose lead and plug, the motor frame shall be connected to the earth pin of the plug.

## 9.10 Types of Enclosures

The following are the different types of enclosures and its associated degree of protection as outlined in IS/IEC 60034 (Part 5) 'Degrees of protection provided by the integral design of rotating electrical machines (IP code)':

a) ***Open Ventilated Motor*** - A motor having no protective enclosure. In case of non-protected motors, additional protection shall be provided by the user.

b) ***Ventilated Motor*** - A motor having an enclosure so constructed as to give protection while ventilation is not materially impeded. The protection provided by enclosure shall meet requirements of IP20.

c) ***Drip Proof Motor*** - A ventilated motor so constructed as to exclude vertically falling water or dirt. The protection provided by enclosure shall meet requirements of IP21.

d) ***Water Protected Motor*** - A drip proof motor so constructed that drops of water falling at an angle up to 15° from the vertical shall have no harmful effect, the protection provided by enclosure shall meet requirements of IP22.

e) ***Totally Enclosed Motor*** - A motor so constructed as to prevent the free exchange of air between inside and outside of enclosing case. The protection provided by enclosure shall meet requirements of IP44.

f) ***Totally Enclosed Fan Cooled Motor*** - A totally enclosed motor with augmented cooling by means of a fan driven by the motor itself, blowing air over motor body or cooling passage, if any. The protection provided by enclosure shall meet requirements of IP44.

g) ***Environment Proof Motor*** - A motor so constructed that it can work without further protection from the weather conditions specified by the user. The enclosure shall be designated by the letter 'E'- example IPE44 or IPE55.

h) ***Weather Proof Motor*** - A motor is weather proof when its design reduces the ingress of rain, snow and airborne particles to an amount consistent with a correct operation. The enclosure shall be designated by the letter 'W' (placed between IP and the numerals, for example IPW44).

i) ***Hose Proof Motors*** - A motor having enclosure which provides type of protection IP55.

j) ***Motors for Appliances*** - Motors which are intended ultimately to be incorporated in appliances may have enclosures not providing a specific degree of protection.

Besides the enclosures defined above, IS 996 also recognizes enclosures arising out of various degrees of protection stated in IS/IEC 60034 (Part 5). The first characteristic numeral of the IP code indicates the degree of protection provided by the enclosure to persons and to the parts of the machine inside the enclosure. The second characteristic numeral of the IP code indicates the degree of protection provided by the enclosure with respect to harmful effects due to ingress of water. The description of the degrees of protection is given in Table 9.2.

**Table 9.2 Degrees of Protection**

| First numeral | Brief description | Second numeral | Brief description |
|---|---|---|---|
| **0** | Non-protected machine | **0** | Non-protected machine |
| **1** | Machine protected against solid objects greater than 50 mm | **1** | Machine protected against dripping water |
| **2** | Machine protected against solid objects greater than 12 mm | **2** | Machine protected against dripping water when tilted up to 15° |
| **3** | Machine protected against solid objects greater than 2.5 mm | **3** | Machine protected against spraying water |
| **4** | Machine protected against solid objects greater than 1 mm | **4** | Machine protected against splashing water |
| **5** | Dust-protected machine | **5** | Machine protected against water jets |
| **6** | Dust-tight machines | **6** | Machine protected against heavy seas |
| --- | --- | **7** | Machine protected against the effects of immersion |
| --- | --- | 8 | Machine protected against the effects of continuous submersion |

### 9.11 Methods of Cooling

The various cooling methods of motors are as given below:

a) According to **origin of cooling**:

i) ***Natural cooling*** - The motor is cooled without the use of a fan by the movement of air and radiation.

ii) ***Self-cooling*** - The motor is cooled by cooling air driven by a fan mounted on the rotor or one driven by it.

iii) ***Separate cooling*** - The motor is cooled by a fan not driven by its shaft.

b) According to **manner of cooling**:

i) ***Open circuit ventilation*** - The heat is given up directly to the cooling air flowing through the motor which is being replaced continuously.

ii) ***Surface ventilation*** - The heat is given up to the cooling air from the external surface of a totally enclosed motor.

The method of cooling of motors and their designations are given in IS 6362 'Designation of methods of cooling of rotating electrical machines (IC code)'. This Standard identifies the circuit arrangements and methods of movement of coolant in rotating electrical machines, classifies the methods of cooling and gives a designation system for them. The designation of method of cooling consists of the letters "IC", followed by numerals and letters representing the circuit arrangement, the coolant and the method of movement of the coolant.

## 9.12 Performance characteristics and testing

### *9.12.1 Torques at rated voltage and frequency*

With rated voltage and frequency applied to terminals, the breakaway (starting), pull-up and pull-out torques shall comply with the requirements given in Table 9.3.

**Table 9.3 Torques at rated voltage and frequency**

| Type of Motor | Minimum Pull Out Torque (Percent of FLT) | Minimum Pull up Torque | Minimum Break away Torque |
|---|---|---|---|
| Capacitor-start Induction-run | 200 | 150 | 200 |
| Capacitor start and run | 150 | 20 | 30 |
| Capacitor start and capacitor run | 200 | 150 | 200 |
| Shaded pole | 120 | 20 | 30 |
| Split phase | 200<br>250 | 125<br>200 | 150<br>225 |

***9.12.1.1 Torque*** - The torque may be measured with rope and pulley or by dynamometer or with a brake or beam. All motors are subject to variations in locked rotor torque and these variations depend upon the angular position of the rotor with respect to the stator. The locked rotor torque is defined as the minimum torque developed at rest in the direction(s) of rotation specified and in any angular position(s) of the rotor with the entire motor at a temperature not less than 20°C nor greater than 40°C.

***9.12.1.2 Speed-Torque characteristics*** - The speed-torque characteristic is the relation between torque and speed, embracing the range from zero to synchronous speed. This relation, when expressed as a curve, includes pull out (maximum running) torque, pull-up (minimum running) torque, and locked rotor torque of induction motors. The speed-torque tests may be made with a dynamometer or by rope and pulley methods. Measurements of current, voltage and speed shall be made. Data for these characteristics shall be taken at or near rated voltage.

***9.12.1.3 Pull-out Torque*** - This test may be made by allowing the motor to run light and then increasing the torque until the speed of the motor falls off abruptly. This test should be made as rapidly as is possible, consistent with accuracy, but not so rapidly as to introduce inertia errors into the readings.

***9.12.1.4 Pull-up Torque*** - The pull-up torque of an alternating current motor is the minimum external torque developed by the motor during the period of acceleration from rest to the speed at which pull-out torque occurs. For motors which do not have a definite pull-out torque, the pull-up torque is the minimum torque developed up to rated speed. The pull-up torque may be determined by brake, dynamometer, or rope and pulley.

***9.12.1.5 Momentary Overload for Motors*** - Motors rated in accordance with IS 996 are not expected to carry sustained overloads. However, they shall be capable of withstanding overloads in torque as per Table 9.4 (under gradual increase of torque) without injury, for 15 s, after having their rated load.

**Table 9.4 Momentary Overload**

| Type of Motor | Excess Torque as percentage of rated torque |
|---|---|
| Capacitor-start Induction-run | 50 |
| Capacitor start and run | 25 |
| Capacitor start and capacitor run | 50 |
| Shaded pole | 10 |
| Split phase | 60 |

***9.12.2 Temperature Rise***

Temperature rise of motors for all types of enclosures, when tested under rated conditions and in accordance with the requirements of IS 996 shall not exceed the limits given in Table 7 of IS 15999 (Part 1). For motors having short time rating, these limits may be increased by 10°C. Motors shall, however, be capable of operating without injurious heating at extreme voltage limits (i.e ± 6 percent of rated voltage) or extremes of voltage range specified on the rating plate. The temperature rise of motors to be incorporated in appliances shall be tested when the motor is installed in the appliance.

This test is intended primarily to determine the temperature-rise on different parts of the motor while running at rated conditions. While preparing for temperature-rise test, the motor should be shielded from currents of air coming from adjacent pulleys, belts and other machines as incorrect results may be obtained if this is not done. A small current of air may cause great discrepancy in results obtained. Sufficient floor space should be left between machines to allow free circulation of air. Under ordinary conditions, a distance of two metres is sufficient.

The duration of temperature-rise test is dependent on the type of rating of the motor. For motors with continuous rating, the temperature-rise test should be continued till thermal equilibrium has been reached. Whenever possible, the temperature should be measured both while running and after shut down. For motors with short time rating, the duration of the test should correspond to the declared short time rating. At the end of the test, the specified temperature-rise limits should not be exceeded. At the beginning of the test, the temperature of the motor should be within 5°C of that of cooling air. In the case of motor for periodic duty and for continuous duty with intermittent load, the test should be continued till thermal equilibrium has been reached. Unless otherwise agreed, the duration of one cycle should be 10 minutes, for the purpose of this test. Temperature measurement should be made at the end of no-load period for the purpose of establishing thermal equilibrium. At the end of first half of the last period of no-load operation, the temperature-rise should not exceed the specified limit. When thermal equilibrium is reached, the motor shall be stopped as quickly as possible and measurements taken both while the motor is running and after shut down (wherever possible). No corrections for observed temperatures are necessary if the stopping period does not exceed 30 seconds. In case where successive measurements show increasing temperature after shut down, the highest value shall be taken. Whenever rotor temperature also is required, this is found out by recording the highest temperature reached in the thermometers placed on the rotor bars and on winding in the case of wound rotor motor. Thermometers should be applied as soon as the rotating parts come to rest.

***9.12.2.1 Methods of measuring temperature-rise of parts of motor*** – The temperature-rise of a part of a motor shall be the difference in temperature between the part of the motor and cooling medium. The commonly used methods for measuring temperature are listed below:

a) Thermometer method (using liquid-in-glass thermometer, resistance thermometer or thermocouple).
b) Applied thermocouple method
c) Resistance method

The thermometer method is usually not as accurate as the other methods for measuring temperatures in small fractional horsepower motors because of the difficulties encountered in properly placing the thermometer. Furthermore, thermocouples do not conduct away as much of the coil heat as thermometers do. The applied thermocouple method is quite often used in conjunction with either the thermometer or resistance method.

***9.12.2.2 Thermometer method*** - Liquid-in-glass thermometers, before being used should be examined for broken liquid columns. When the thermometer is in position, the level of its bulb shall not be higher than that of its stem. The bulb should be secured in position with a felt pad, a small piece of putty, or the equivalent, in such a manner as to shield it from the surrounding air. There should be restriction of the natural windage of the motor or of the heat radiation from the coil of which the temperature is being measured. The liquid-in-glass thermometer, resistance thermometer, or thermocouple are applied to the hottest parts accessible without alteration of the structure. The temperature shall be measured on the surface of the coil ends at two peripherally spaced locations.

***9.12.2.3 Applied thermocouple method*** - In using this method, thermocouples are applied to the conductor insulation in the hottest parts accessible to them. After being well tucked in, they are covered with a small piece of putty or modelling clay.

***9.12.2.4 Resistance method*** - The average temperature throughout a motor winding is determined by comparing the resistance of the winding at the temperature to be determined with the resistance at a known temperature. Extreme care shall be taken to secure accurate resistance measurements because a small error shall cause a comparatively large error in the calculated temperature. The cold resistance shall be taken only after the motor has remained in a constant ambient long enough that the winding is at that ambient temperature.

***9.12.2.5 Measurement of Cooling Air or Gas Temperature During Tests***--The cooling air temperature shall be measured by means of several thermometers placed at different points around and half-way up the motor at a distance of 1 to 2 metres and protected from heat radiation and draughts. The value to be adopted for the temperature of the cooling air or gas during a test shall be the mean of the readings of the thermometers (placed as mentioned above), taken at equal intervals of time during the last quarter of the duration of the test.

***9.12.3 Performance Values***

***9.12.3.1 No-Load test*** - This test is intended to find out the no-load current, power input and speed at rated voltage and frequency. The motor is run at no-load with the running windings excited at normal frequency and voltage until the power input is constant to assure that the temperature of the oil or grease and the bearings has become constant. Readings of volts, amperes and watts input at rated frequency are taken, but with voltages ranging from 125 percent of rated voltage down to a point where further voltage reduction increases the current. The voltage adjustment is accomplished preferably by a variable-voltage transformer.

***9.12.3.2 Locked rotor test*** - The testing of induction motors under locked rotor conditions involves unusual mechanical stresses and high rates of heating. Therefore, it is necessary that the mechanical means of locking the rotor be of adequate strength to prevent possible injury to personnel or damage to equipment. The current and torque readings shall be taken at approximately rated voltage and at rated frequency and that the motor shall be at approximately ambient temperature. The voltage shall be within 5 percent of the rated voltage.

***9.12.3.3*** The values of minimum full load speed, maximum full load current, nominal efficiency and maximum breakaway starting current for 2 pole, 4 pole and 6 pole general purpose ac single phase motors at rated voltage of 230 V, 50 Hz shall be in accordance with Tables 1 to 13 of IS 996.

### *9.12.4 Insulation Resistance*

Insulation resistance shall be measured between individual windings and frame (earth). Insulation resistance between all the windings combined and the motor frame shall be not less than 5 MΏ at 500 V d.c. The test shall also be repeated on hot motor, soon after the temperature rise test.

### *9.12.5 High voltage test*

The motor windings shall be capable of withstanding without failure, the test voltages of 500 V for motors having rated voltage of 50 V or less. The test voltage shall be 1500 V for motors having rated voltage above 50 V upto and including 250 V.

The test voltage shall be applied between the windings and the frame of the motor, with the core connected to the frame and the windings not under test. The test voltage shall be applied once and only once to a new and completed motor in normal working condition, with all its parts in place, and the test shall be carried out together with the insulation resistance test.

The test shall be made with alternating voltage of any convenient frequency, preferably between 40 and 60 Hz. The test voltage shall be of approximately sine-wave form and, during the application of voltage, the peak value, as determined by spark gap, by oscillograph or by any other method, shall be not more than 1.45 times the rms value. The rms value of the applied voltage shall be measured by means of a voltmeter used with a suitable calibrated potential transformer or by means of voltmeter used in connection with a special calibrated voltmeter winding or testing transformers, or by any other suitable voltmeter connected to the output side of the testing transformer. It is generally advisable that the high voltage test should not be applied if insulation resistance is less than that specified.

***9.12.5.1 Duration of High Voltage Test (Type test)*** - The test shall be commenced at a voltage of about one-third of the test voltage which shall be increased to the full test voltage as rapidly as is consistent with its value being indicated by the measuring instrument. The full test voltage shall be maintained for one minute. At the end of this period, the test voltage shall be rapidly diminished to one-third of its full value before switching off.

***9.12.5.2 Duration of High Voltage Test (Flash Test) (Routine Test)*** - As routine test, the test voltage shall be applied between the windings and the frame of the motor, with the core connected to the frame and the windings not under test for 5 seconds.

### *9.12.6 Leakage current*

The leakage current shall not exceed 3.5 mA (rms) when a voltage equal to 1.1 times the rated voltage is applied to the motor and is measured between supply terminal of the system and the accessible metal parts, if any, and a metal foil covering the outer parts of the insulating material. The resistance of the test circuit shall be 2000 ± 50 Ω. The test is to be conducted in the no-load condition with the motor placed on an insulating pad of suitable material.

**9.13 Line operated three phase a.c. motors**

Electric motor systems include a number of energy using products, such as motors, drives, pumps or fans, compressors, blowers and other machines Energy efficient motors form a major component in contributing to the energy saving by way of increased efficiency of the product itself. By use of such motors in electric systems, there is a large potential for cost effective solution by about twenty to thirty percent. IS 12615 specifies the efficiency classes (IE Code – International Energy Efficiency Class) and performance requirements of single-speed line operated three phase a.c. motors.

The motors specified here are rated for operation on a sinusoidal voltage supply and have rated power from 0.12 kW to 1 000 kW, covering 2, 4, 6 or 8 poles and having a rated voltage $U_n$ up to 1000 V with a rated frequency of 50 Hz. These motors are capable of continuous operation at their rated power with a winding temperature rise within the specified insulation temperature class.

**9.14 Terminology**

The definitions given at 9.3 of this chapter are considered relevant.

**9.15 Site Conditions**

The following constitutes the normal site conditions:

***a) Altitude and Temperature*** - Motors shall be designed for the site conditions specified below unless otherwise agreed between the manufacturer and the purchaser:

*Altitude* - Altitudes up to and including 4 000 m.

*Temperature* - Ambient temperatures between -20°C to + 60°C.

***b) Voltage and Frequency Variation* -** Motors as per IS 12615 shall be capable of delivering rated output with,

i) terminal voltage differing from its rated value by not more than ± 10 percent.

ii) frequency differing from its rated value by not more than ± 5 percent, or

iii) Combined variation — The sum of absolute percent variations of (i) and (ii) not exceeding 10 percent.

**9.16 Type of Enclosures**

The motors shall have at least IP44 or better degree of protection provided by the enclosures as outlined in IS/IEC 60034 (Part 5) ‘Degrees of protection provided by the integral design of rotating electrical machines (IP code)’.

**9.17 Methods of Cooling**

Method of cooling shall be IC411. However, motors (using heat exchangers) with method of cooling IC511 and IC611 shall also be considered.

The cooling methods IC416, IC516 and IC616) are not preferred for motors meant for operation on line supply. If a manufacturer wishes to mark such a cooling method with an IE class, then the motor must meet the efficiency requirement when tested on a sinusoidal supply, and power input to the auxiliary fan motor is also included in the power input to the main motor to determine the efficiency of such a method of cooling.

The cooling methods IC417, IC517 or IC617 will be eligible for IE marking provided the manufacturer is able to establish the committed temperature rise and the efficiency by simulating the air-flow conditions.

**9.18 Dimensions, frame number and output relationship**

For frame size from 56 up to and including 315 M, the frame to output co-relation shall be as specified in Table 3 of IS 1231 'Dimensions and Output Series of Foot Mounted Induction Motors - Frame Numbers 56 to 315 L'). For frame size 315 L having dimensions as per IS 1231, the output rating can be as declared by the motor manufacturer. Frame size 355 and above, with dimensions and output ratings as declared by the motor manufacturer and conforming to IS 8223 'Dimensions and output series for rotating electrical machines' can also be used. The fixing dimensions and shaft extensions of motors shall generally conform to the values specified in IS 1231 and IS 2223 'Dimensions of Flange Mounted AC Induction Motors' as relevant for outputs up to 132 kW. In addition, special customized dimensions are also permitted.

**9.19 Earthing**

The earthing on the motor shall be provided in accordance with the following:

The motors shall be provided with an earthing terminal or another device to permit the connection of a protective conductor or an earthing conductor. The symbol  or legend shall identify this device. However, motors shall neither be earthed nor be provided with an earthing terminal when:

a) they are fitted with supplementary insulation, or;

b) they are intended for assembly in apparatus having supplementary insulation, or;

c) they have rated voltages up to 50 V a.c. and are intended for use on SELV circuits.

In the case of motors having rated voltages greater than 50 V a.c. but not exceeding 1000 V a.c., the terminal for the earthing conductor shall be situated in the vicinity of the terminals for the line conductors, being placed in the terminal box, if one is provided. Motors having rated outputs in excess of 100 kW shall have in addition an earthing terminal fitted on the frame.

The earthing terminal shall be designed to ensure a good connection with the earthing conductor without any damage to the conductor or terminal. Accessible conducting parts which are not part of the operating circuit shall have good electrical contact with each other and with the earthing terminal. When all bearings and the rotor winding of the motor are insulated, the shaft shall be electrically connected to the earthing terminal, unless the manufacturer and the purchaser agree to alternative means of protection. When an earthing terminal is provided in the terminal box, the earthing conductor shall be made of the same metal as the lead conductors. When an earthing terminal is provided on the frame, the earthing conductor may, by agreement, be made of another metal (for example, steel). In this case, in designing the terminal, proper consideration shall be given to the conductivity of the conductor.

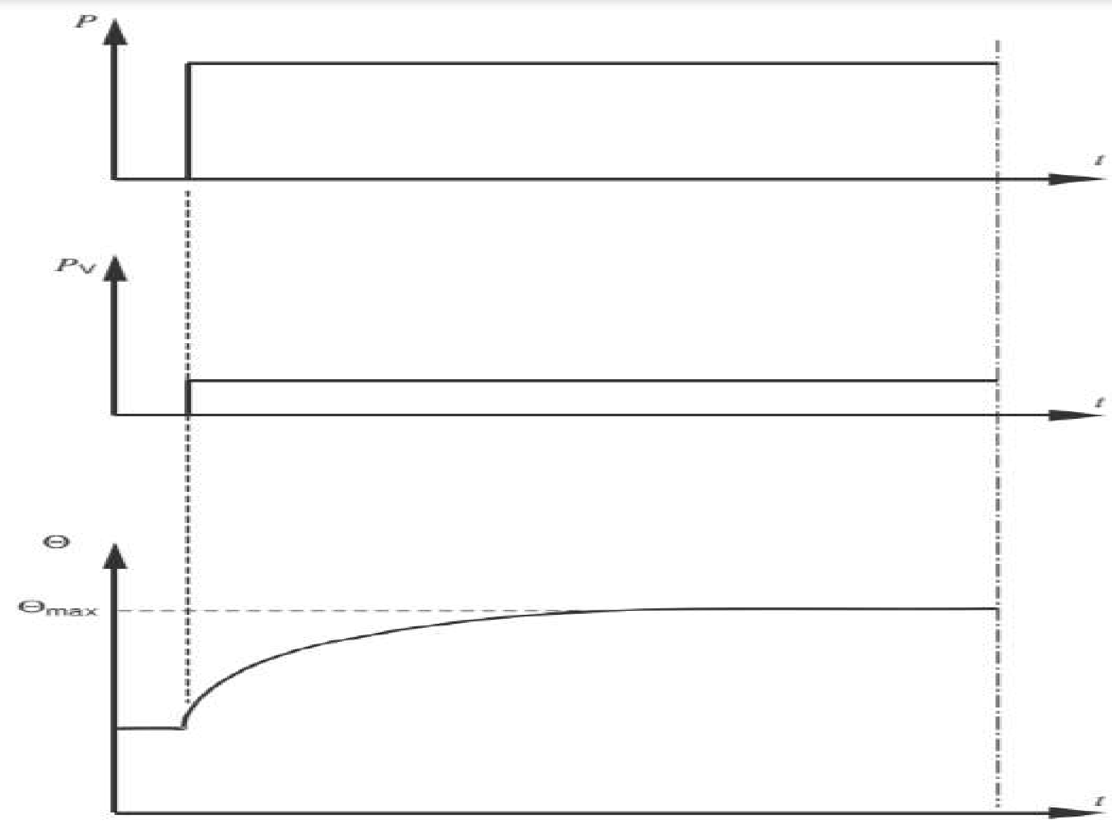
### 9.20 Rated voltage and frequency

***Rated Voltage*** – Design shall be for terminal voltages up to and including 1000 V.

***Rated Frequency*** - The rated frequency is 50 Hz. However, if 60 Hz motors are operated on a 50 Hz supply, they must meet the performance requirements as applicable to 50 Hz motors.

### 9.21 Duty and rating

The motors shall be rated for duty type S1 (continuous duty) where the operation at a constant load is maintained for sufficient time to allow the machine to reach thermal equilibrium. The characteristics are shown in Figure 9.1.




P - load, $P_V$ - electrical losses, Θ – temperature, $\Theta_{max}$ - maximum temperature attained, t - time

**Fig. 9.1 Continuous running duty – Duty type S1**

### 9.22 Performance characteristics and testing

#### *9.22.1 Overload*

a) ***Momentary Excess Torque*** - The motor shall be capable of withstanding 1.6 times the rated torque for 15 s without stalling or abrupt change in speed (under gradual increase of torque), the voltage and frequency being maintained at their rated values (at the motor terminals).

b) ***Pull-up-Torque*** - Unless otherwise specified, the minimum pull-up torque of motors, at rated voltage and frequency shall be at least 0.5 times the rated full load torque.

c) ***Sustained Overloads*** - Motor rated in accordance with this standard are not expected to be capable of carrying sustained overloads.

#### *9.22.2 Temperature Rise*

The temperature rise test shall be continued until thermal equilibrium has been reached for motors with rating for continuous running duty. The temperature of windings and other parts can be measured by the methods given below:

a) ***Resistance method*****:** The temperature of the windings is determined from the increase of the resistance of the windings. One of the following methods shall be used:

- direct measurement at the beginning and the end of the test, using an instrument having a suitable range;
- measurement by d.c. current/voltage in a.c. windings, by injecting direct current into the winding when de-energized.

b) ***Embedded temperature detector (ETD) method*****:** The temperature is determined by means of temperature detectors (for example, resistance thermometers, thermocouples or semi-conductor negative coefficient detectors) built into the machine during construction, at points which are inaccessible after the machine is completed. The detectors shall be suitably distributed throughout the winding and the number of detectors installed shall be not less than six. All reasonable efforts, consistent with safety, shall be made to place the detectors at the points where the highest temperatures are likely to occur, in such a manner that they are effectively protected against contact with the primary coolant. The highest reading from the ETD elements shall be used to determine the temperature of the winding.

c) ***Thermometer method*****:** The temperature is determined by thermometers applied to accessible surfaces of the completed machine. The term 'thermometer' includes not only bulb-thermometers, but also non-embedded thermocouples and resistance thermometers. When bulb-thermometers are used in places where there is a strong varying or moving magnetic field, alcohol thermometers shall be used in preference to mercury thermometers. All reasonable efforts, consistent with safety, shall be made to place thermometers at the point, or points where the highest temperatures are likely to occur (e.g. in the end windings close to the core iron) in such a manner that they are effectively protected against contact with the primary coolant and are in good thermal contact with the winding or other part of the machine. The highest reading from any thermometer shall be taken to be the temperature of the winding or other part of the machine.

***9.22.2.1 Determination of winding temperature - Choice of method***

In general, for measuring the temperature of the windings, the resistance method in accordance shall be applied. For line operated three phase ac motors having a rated output greater than 200 kW and upto 1000 kW, the manufacturer shall choose either the resistance or the ETD method. For machines having a rated output less than or equal to 600 W, when the windings are non-uniform or severe complications are involved in making the necessary connections, the temperature may be determined by means of thermometers.

The thermometer method is recognized in the following cases:

a) when it is not practicable to determine the temperature rise by the resistance method as, for example, with low-resistance commutating coils and compensating windings and, in general, in the case of low-resistance windings, especially when the resistance of joints and connections forms a considerable proportion of the total resistance;

b) single layer windings, rotating or stationary;

c) during routine tests on machines manufactured in large numbers.

The limits of temperature rise when measured by resistance method shall be not more than 80 K over an ambient of 40°C for motors with Class B or Class F insulation.

**9.22.3 *Performance Values***

Operating at rated voltage and rated frequency, the performance of the motor at rated conditions shall be as specified in Table 1 to 4 of IS 12615. All the performance values are subject to tolerance as specified in Table 20 of IS 15999 (Part 1).

**9.22.4 Efficiency**

The various methods for determining efficiency and losses are enumerated below:

***a. Determination from direct measurement*** **–** In this method, efficiency is determined by measuring directly the input power and the output power as detailed in the tests given below:

> ***i) Torque measurement test*** – This test can be performed by using torque meter or dynamometer. In torque meter test, the mechanical power output of a machine acting as a motor is determined by measurement of the shaft torque by means of a torque meter together with the rotational speed. Alternatively, if the machine acts as a generator, the mechanical power input is determined. The motor under test is coupled to a load machine or the generator under test is coupled to a motor with the torque meter. The machine is operated at the required load. In the dynamometer test, the shaft torque is measured by means of a dynamometer instead of torque meter.
>
> *Efficiency* $\eta = P_2/P_1$, *where*
>
> $P_2$ = *Input Power and* $P_1$ = *Output Power*

**ii)** ***Dual-supply back-to-back test*** – In this test, two identical machines are mechanically coupled together, and run at essentially the same rated conditions. The total losses of both machines are calculated from the difference between the electrical input to one machine and the electrical output of the other machine. The efficiency is calculated from half the total losses and the average input power of the motor and generator.

*Efficiency* $\eta = 1 - [P_T \div (P_1 + P_2)/2]$*, where*

*Total losses* $P_T = (P_1 - P_2)/2$

***iii) Calibrated-machine test*** – In this test, the mechanical input or output of an electrical machine is calculated from the electrical output or input of a calibrated machine mechanically coupled to the machine on test. When the machine is running in this condition at rated speed, voltage and current, the efficiency is taken as the ratio of output to input.

***b) Determination from indirect measurement*** **–** In this method, efficiency is determined by measuring the input power or the output power and determining the total losses. Those losses are added to the output power, thus giving the input power, or subtracted from the input power, thus giving the output power. The details of the tests are given below:

***i) Single-supply back-to-back test*** – In this test, two identical machines are mechanically coupled together, and both connected electrically to the same power system, and run at essentially rated conditions. The total losses of both machines are taken as the input power drawn from the system. The efficiency is calculated by assigning half the total losses to each machine.

*Efficiency* $\eta = 1 - (P_T \div P_M)$*, where*

$P_M$ *is the power absorbed at the terminals of the machine acting as motor,*

$P_T$ *is the total losses.*

***ii) Summation of separate losses*** – In this method, the separate losses are determined. The total loss is taken as the sum of constant losses, load losses and additional load losses.

***iii) Calorimetric method*** – In this method, losses in a machine are deduced from the heat produced by them. The losses are calculated from the product of the amount of coolant and its temperature rise, and the heat dissipated in the surrounding media.

If the limit of temperature rise agreed between motor manufacturer and user is more than 80 K and up to 105 K, then efficiency determination shall be done as per Calorimetric method.

The rated efficiency shall be determined at rated power, rated voltage, and rated frequency of 50 *Hz*. Motors rated for an extended voltage tolerance (for example, 415 *V* ± 10 *%*) shall be assigned a single rated efficiency, at base voltage. i.e. the extended voltage tolerance shall be disregarded. Motors with rated voltage/frequency combinations of the same magnetic flux and power, for example 230 V/400 V (delta/star) or 230 V/460 V (double-star/star), shall have only one rated efficiency and efficiency class (IE code). Motors with more than one rated voltage/

frequency/ power combination should be assigned a rated efficiency and a rated efficiency-class (IE code) for each rated voltage/ frequency/ power combination. However, as a minimum the lowest efficiency value and the associated IE code (of all rated voltage/frequency/power combinations) shall always be printed on the rating plate.

***9.22.4.1 Auxiliary devices***

Some electric motors covered by IS 12615 may be equipped with auxiliary devices such as shaft seals, external fans, mechanical brakes, back-stops and unidirectional bearings, speed sensors, tacho-generators in various combinations. However, as long as these auxiliary devices are not an integral part of the basic motor design, the determination of efficiency in all possible combinations is not practical. Tests for efficiency of such modified standard motors shall be performed on basic motors with original cooling without auxiliary devices installed.

The losses of a separately driven fan are to be included in the efficiency determination procedure when the external fan is an integral part of the basic motor construction. When the external fan is just an optional add-on to a mass-produced motor, which normally carries a shaft-mounted fan, the losses of the basic motor (with the shaft-mounted fan) can be used.

Angular-contact bearings (thrust bearings) or Roller Bearings for vertical mounted motors may be replaced by standard bearings during efficiency testing. Such motors may be tested horizontally.

Some types of motors (such as geared motors. pump motors and others) are equipped with shaft seals to prevent ingress of oil or water into the motor. External seals shall be removed for efficiency testing. This applies only to seals that are accessible from the outside without dismantling of the motor (dismantling of the fan-cover and the fan is accepted).

Electro-mechanical brakes shall be removed during testing of motor efficiency. When the motor construction prohibits a removal of the brake, the brake-coil shall be energized from a separate power source and the energy consumption of the brake-coil shall be disregarded in the calculation of motor efficiency.

The efficiency declared by the manufacturer on the rating plate (rated efficiency) shall be greater or equal to the nominal efficiency as defined in IS 12615 (according to the efficiency class IE code). The full-load efficiency of any motor, when tested at rated voltage and rated frequency shall not be less than the rated-/classified efficiency minus the specified tolerance.

***9.22.5 Locked rotor readings of voltage, current and power input at a suitable reduced voltage***

The test is carried out at reduced voltage.

***9.22.6 Reduced voltage running up test at no-load***

The test is conducted to check the ability of the motor to run up to its rated speed at no load. The motor shall be supplied with reduced voltage $1/\sqrt{3}$ of rated value for each direction of rotation. This test is applicable for squirrel cage motor up to 37 kW only.

### *9.22.7 High voltage test*

High voltage test is to be done at a test voltage as given in Table 16 of IS 15999 (Part 1). The test voltage shall be applied between the windings under test and the frame of the motor, with the core and the windings not under test connected to the frame. It shall be applied only to a new and completed machine with all its parts in place under conditions equivalent to normal working conditions. When a thermal test is carried out, the withstand voltage test shall be carried out immediately after that test. The test shall be commenced at a voltage not exceeding half of the full test voltage. The voltage shall then be increased to the full value, steadily or in steps of not more than 5 % of the full value, the time allowed for the voltage increase from half to full value being not less than 10 s. The full test voltage shall then be maintained for 1 min. There shall be no failure during this period. During the routine testing of motors up to 200 kW and rated for $U_n \leq 1000$ V, the 1 min test may be replaced by a test of 1 s at 120 % of the test voltage.

The withstand voltage test at full voltage made on the windings shall not be repeated. However, if a second test is to be carried out, it shall be done only after further drying if considered necessary and, the test voltage shall be 80 % of the test voltage. The leakage current drawn by the motor during high voltage test, will vary depending upon frame size, power, insulation and polarity of the motor. This leakage current test may also be conducted only once at full test voltage. Subsequent tests, if done, must be conducted at 80% voltage of the test voltage.

### *9.22.8 Dimensions*

The preferred dimensions of the motors shall be as specified in IS 1231 'Dimensions and Output Series of Foot Mounted Induction Motors - Frame Numbers 56 to 315 L', IS 2223 'Dimensions of Flange Mounted AC Induction Motors', IS 2254 'Dimensions of vertical shaft motors for pumps' and IS 8223 'Dimensions and output series for rotating electrical machines' as applicable. The dimensions can be special as agreed between manufacturer and buyer. However, the efficiency should be as per the relevant IE code.

### *9.22.9 Locked rotor test*

This test is carried out to determine the soundness of rotor in case of squirrel cage induction motors and their starting current, power factor, starting torque and impedance. This also enables a circle diagram to be drawn in case of squirrel cage induction motors and wound rotor motors. This test may be carried out at reduced voltage, one of the readings may be at a voltage that will produce rated current of the motor. Locked rotor torque test is not done on wound rotor motors but on squirrel cage motors to determine the torque developed. Locked rotor current test is carried out on both squirrel cage and wound rotor motors.

The testing of motors under locked rotor conditions involves unusual stresses and high rates of heating. Therefore, it is necessary that the direction of rotation be established prior to the test. The mechanical means of locking the rotor shall be of adequate strength to prevent possible injury to personnel or damage to equipment. As the windings gets heated very rapidly, the test shall be carried out as rapidly as possible. Care should be taken to ensure that the motor temperature does not exceed the value of permissible temperature of given class of insulation. The readings at any point shall be taken within 6s.

The following mechanical arrangements may be used to measure the developed torque:

a) Dynamometer,
b) Rope and pulley,
c) Brake or beam clamped rigidly to motor shaft, and
d) Torque transducer.

The torque should be measured with the rotor in various positions wherever possible and the minimum value shall be taken as starting torque. The readings of voltage, current, frequency and power input should be taken. The starting torque and starting current should be extrapolated in for rated voltage, when the test is carried out at reduced voltage. For extrapolation of the test results at the rated voltage, the test shall be carried out at least at three test voltages. At each test voltage, the readings of voltage, current, torque, frequency and power input should be taken. Then a curve between values of the current and the applied test voltage should be drawn. Similarly, another curve shall be drawn between the torque value and the square of the applied test voltage. The values of starting current and starting torque shall be extrapolated from these curves. Effect of the magnetic saturation is not considered in this test method.

***9.22.10 Determination of Starting Characteristics - Locked Rotor Current***

The locked rotor current of induction machines shall be determined from the result of the locked rotor test by either of the methods given below. When the voltage for a constant current varies conspicuously depending on the rotor position at locked rotor test, the minimum value of the voltage shall be adopted.

***a) Direct proportion method -*** Locked rotor test shall be carried out at a current equal to nearly 100 percent of rated current and the locked rotor current is determined from the result by the following formula:

$I_{st} = I_{s1} (V_1/V_{s1}) (A)$, where:

*$V_1$ = rated voltage, in V;*

*$V_{s1}$= voltage at locked rotor test, in V;*

*$I_{s1}$= current at locked rotor test (mean value of line currents), in A.*

***b) Logarithmic proportion method (I) -*** This method applies to machines with totally-enclosed rotor slots. Locked rotor test shall be carried out at currents nearly equal to 100 percent and 200 percent of the rated current. The currents $I_{s1}$ and $I_{s3}$ at the locked rotor test and the voltages $V_{s1}$ and $V_{s3}$ corresponding to the currents shall be measured. Locked rotor current is determined by the following formula.

$I_{st} = I_{st} (V_1/V_{s1})^B$

$B = 0.7a + 0.35$

$a = \log (I_{s3}/I_{s1})/\log (V_{s3}/V_{s1})$

***c) Logarithmic proportion method (II) -*** This method applies to machines with totally-enclosed rotor slots. Besides the locked rotor test in the logarithmic proportion method (I), a locked rotor test shall be performed at a current nearly equal to 150 percent of the rated current. The current $I_{s2}$ at the locked rotor test and the voltage $V_{s2}$ corresponding to the current shall be measured. Locked rotor current is determined by following formula.

$I_{st} = 1.04\, I_{s3} (V_1/V_{s3})^y$

$y = 1.05y_2 – 0.35(y_1 – 1)$ (when $y_2 > y_1$)

$= 0.7y_2 + 0.35$ (when $y_2 < y_1$)

$y_1 = \log (I_{s2}/I_{s1})/\log (V_{s2}/V_{s1})$

$y_2 = \log (I_{s3}/I_{s2})/\log (V_{s3}/V_{s2})$

***9.22.11 Momentary overload test***

The motors shall be capable of withstanding for 15 *s* without stalling or abrupt change in speed (under gradual increase of torque) 1.6 times their rated torque, the voltage and frequency being maintained at their rated values (at the motor terminals). Motor overloading test can be shown by loading the motor at 160% of rated load for 15 seconds only.

# EXERCISE 9

a) What are rotating electrical machines? How are they classified?
b) List the various types of single phase induction motors?
c) What are the types of insulation permitted as per IS 996?
d) Name the three variants of capacitor type motors? Compare each type with respect to the torque characteristics?
e) Distinguish between split-phase and shaded-pole motors?
f) Define 'duty' of a motor? How does a 'short-time' rated motor differ from 'continuous' rated motor?
g) Briefly explain any three type of mountings for a motor?
h) Briefly explain the degree of protection associated with the following type of motors?
    i) Ventilated motor
    ii) Drip proof motor
    iii) Totally enclosed motor
    iv) Weather proof motor
i) Explain the three different types of construction of motors with respect to origin of cooling?
j) Differentiate between IE code and IC code. Give two examples for each code?
k) What are the different methods of measurement of torque of a motor?
l) What is the significance of temperature rise test of motors? How is the test carried out?
m) Briefly explain any two methods of temperature rise measurement of motors?
n) What is meant by locked rotor test. What precautions should you take while conducting this test?
o) Explain the high voltage testing of motors?
p) How does HV (Type) test differ from HV (Flash) test?
q) How are energy-efficient motors important?
r) What are the considerations for choice of method for determining winding temperature?
s) What is the basic difference in determination of efficiency from direct measurement and indirect measurement?
t) Briefly explain any one direct method and indirect method of determination of efficiency?
u) Under what condition is calorimetric method of measurement of efficiency used?
v) Briefly explain about 'summation of separate losses' method of measurement of efficiency?