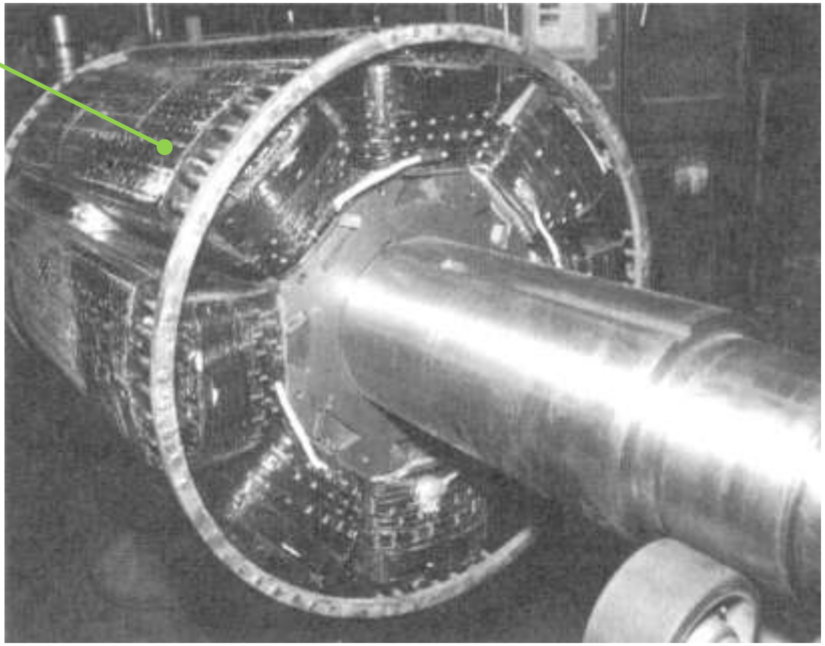
SYNCRONOUS MACHINES

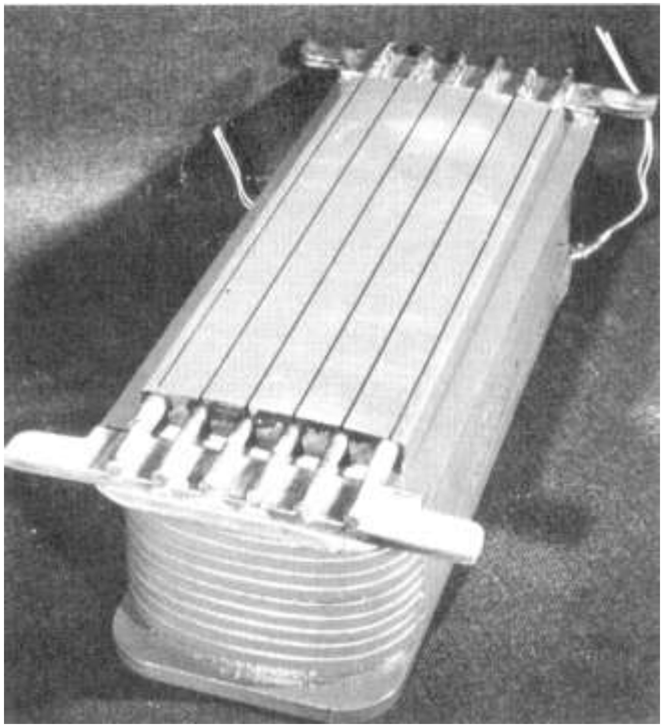
Introduction:

- Synchronous machines are AC machines that have a field circuit supplied by an external DC source.
- In a synchronous generator, a DC current is applied to the rotor winding producing a rotor magnetic field. The rotor is then turned by external means producing a rotating magnetic field, which induces a 3-phase voltage within the stator winding.
- In a synchronous motor, a 3-phase set of stator currents produces a rotating magnetic field causing the rotor magnetic field to align with it. The rotor magnetic field is produced by a DC current applied to the rotor winding.
- Field windings are the windings producing the main magnetic field (rotor windings for synchronous machines); armature windings are the windings where the main voltage is induced (stator windings for synchronous machines).

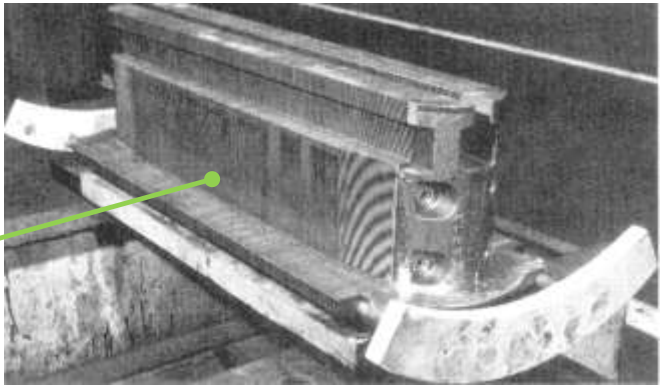
Construction of synchronous machines

A synchronous rotor with 8 salient poles





Salient pole with field windings



Salient pole without field windings – observe laminations

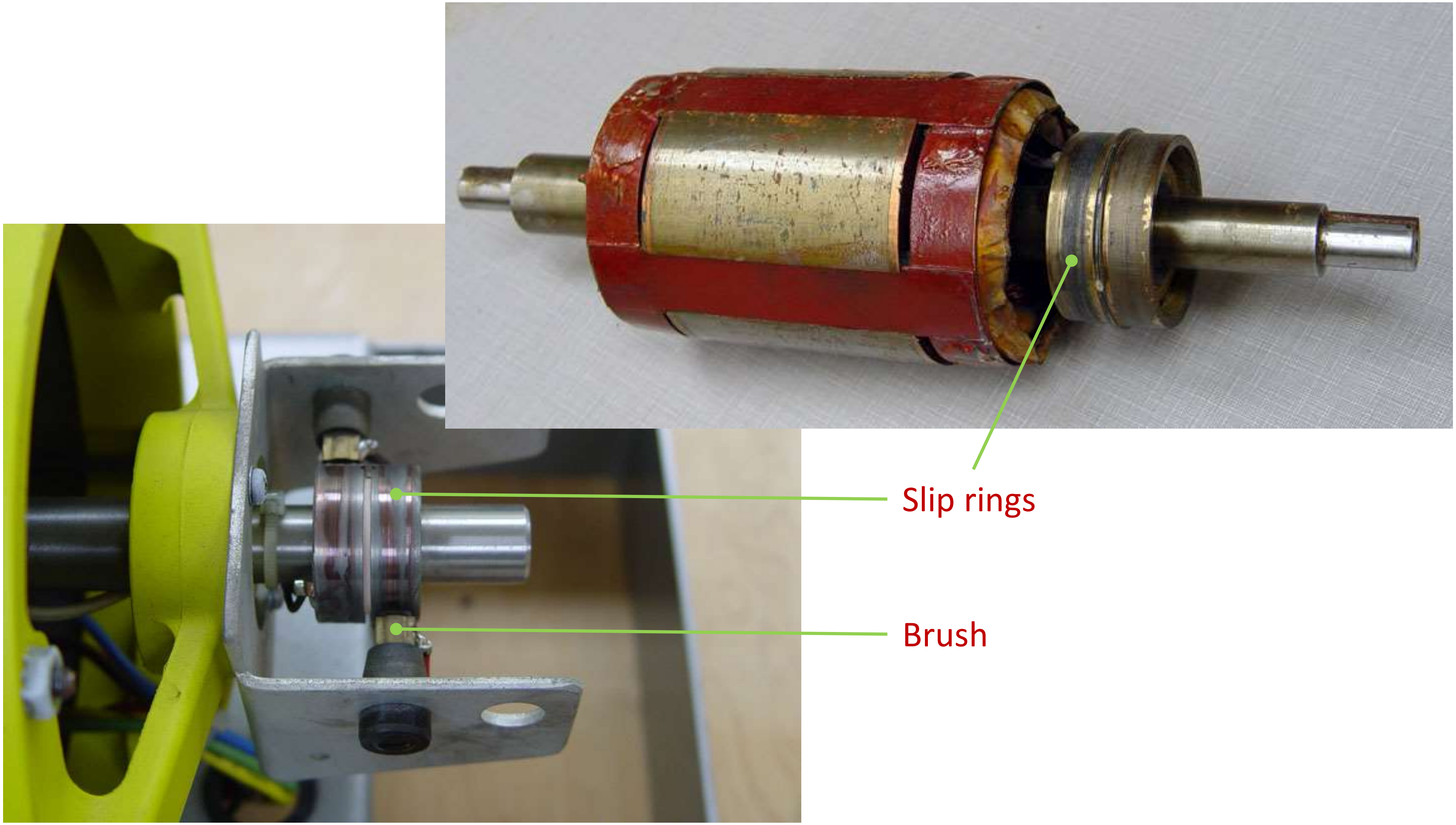
Construction of synchronous machines

Two common approaches are used to supply a DC current to the field circuits on the rotating rotor:

1. Supply the DC power from an external DC source to the rotor by means of slip rings and brushes;
2. Supply the DC power from a special DC power source mounted directly on the shaft of the machine.

Slip rings are metal rings completely encircling the shaft of a machine but insulated from it. One end of a DC rotor winding is connected to each of the two slip rings on the machine’s shaft. Graphite-like carbon brushes connected to DC terminals ride on each slip ring supplying DC voltage to field windings regardless the position or speed of the rotor.

Construction of synchronous machines



Construction of synchronous machines

Slip rings and brushes have certain disadvantages: increased friction and wear (therefore, needed maintenance), brush voltage drop can introduce significant power losses. Still this approach is used in most *small* synchronous machines.

Construction of synchronous machines

On large generators and motors, brushless exciters are used.

❖A brushless exciter is a small AC generator whose field circuits are mounted on the stator and armature circuits are mounted on the rotor shaft.

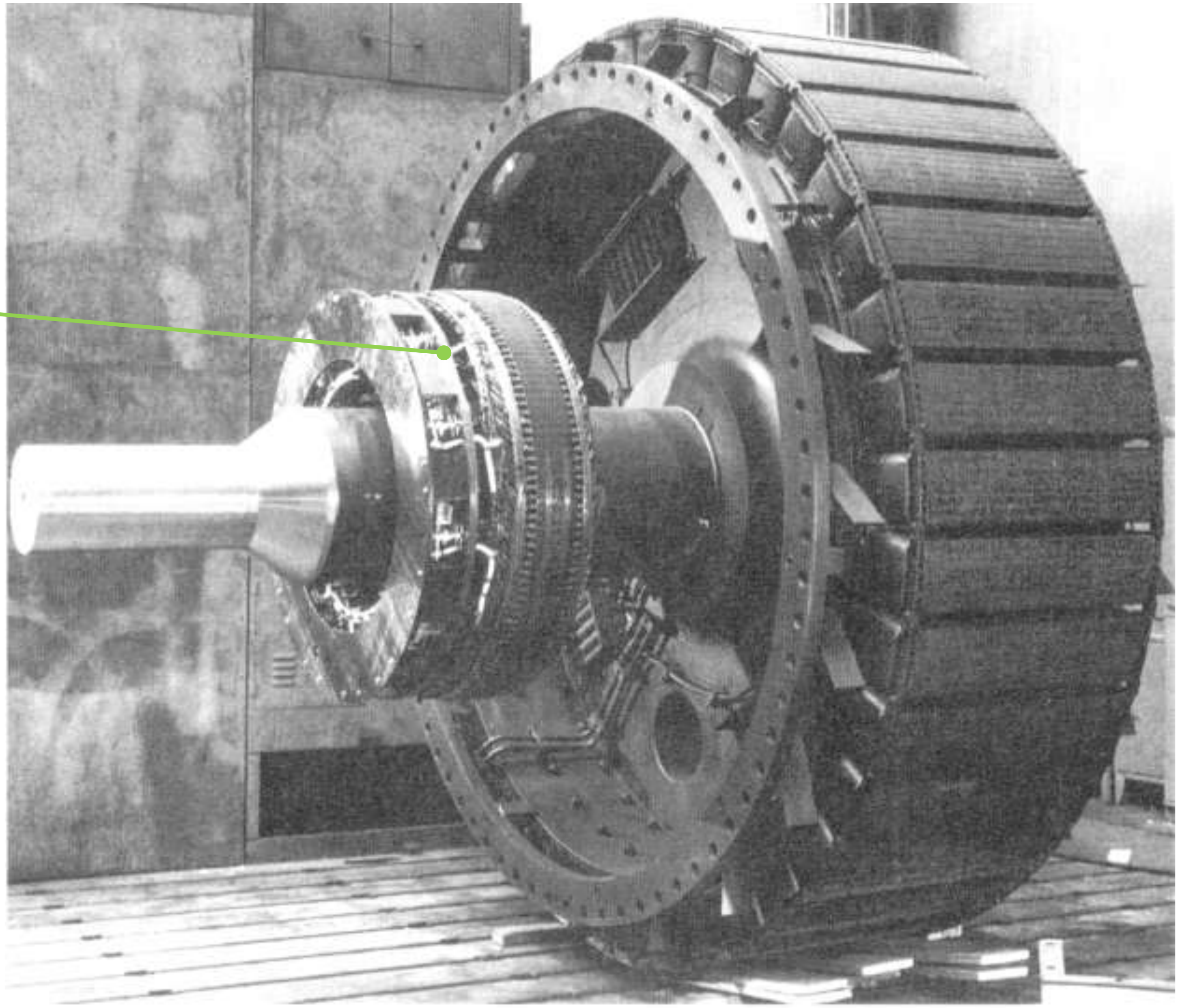
❖The exciter generator’s 3-phase output is rectified to DC by a 3-phase rectifier (mounted on the shaft) and fed into the main DC field circuit.

❖It is possible to adjust the field current on the main machine by controlling the small DC field current of the exciter generator (located on the stator).

❖ Since no mechanical contact occurs between the rotor and the stator and exciters of this type require much less maintenance.

Construction of synchronous machines

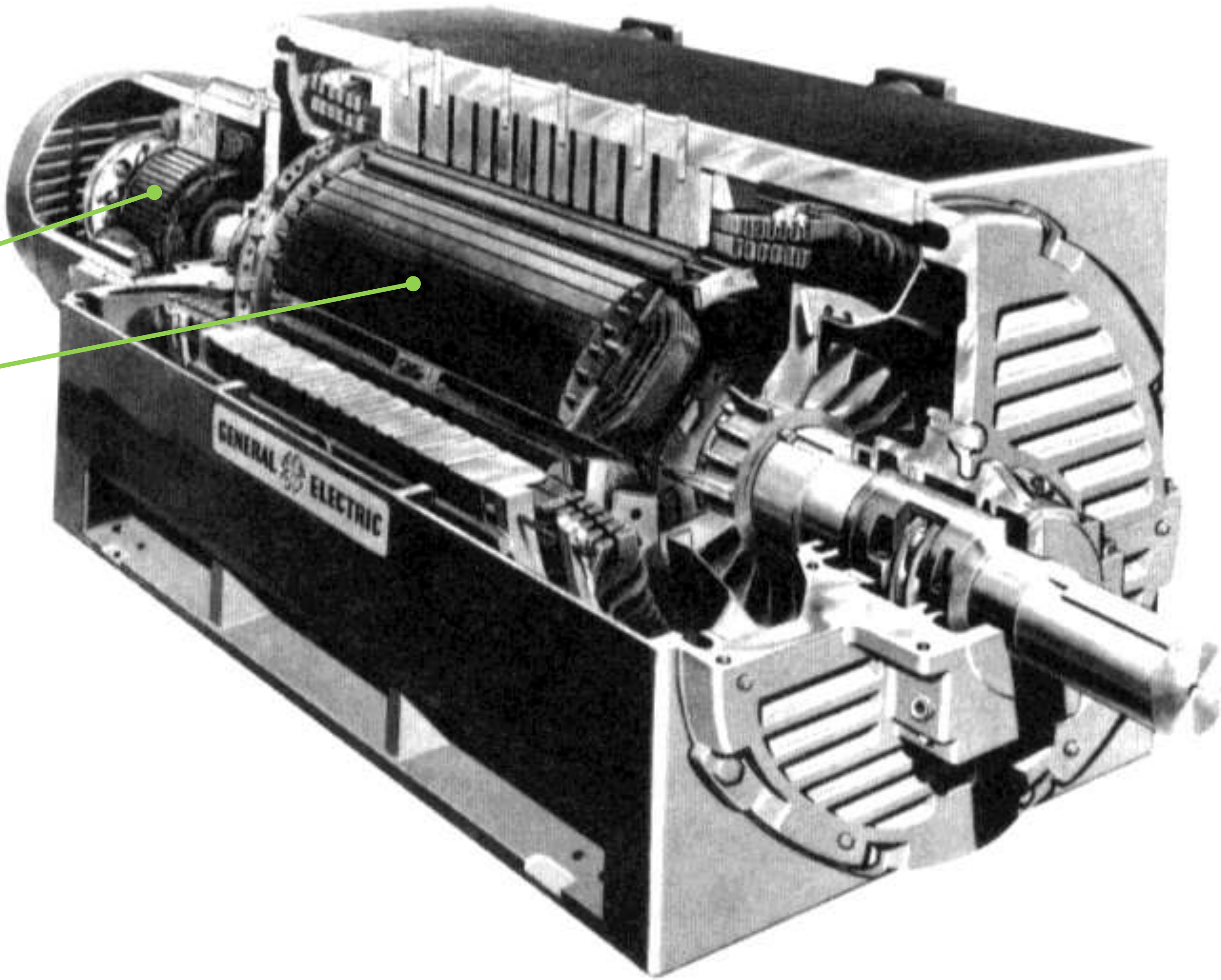
A rotor of large synchronous machine with a brushless exciter mounted on the same shaft.



Many synchronous generators having brushless exciters also include slip rings and brushes to provide emergency source of the field DC current.

Construction of synchronous machines

A large synchronous machine with the exciter and salient poles.



SYNCRONOUS MACHINES

SPCIFICATION:

1. Rated Voltage:3.3kV,6.6kV,11kV
2. Power Ratings: 10MW,20MW,50MW,100MW,500MW
3. Excitation Voltage: 100V-1000V dc
4. Excitation Current: 5-20A
5. Speed: in RPM about 3000rpm
6. Cooling System: Forced air, Hydrogen Cooled, Water Cooled
7. Type of Rotor: Salient/Non-Salient
8. Short circuit Ratio: 0.5-1.5
9. Class of insulation
10. Temperature Limits
11. Connections
12. Frequency

SYNCRONOUS MACHINES

Technical Specifications:

Sl.No	Particulars	Turbo generator	Hydro Generator
1	Power Rating	60MW,100MW,200MW, 500 MW, 1000MW	5MW,10MW,20MW,50MW,100 MW, 150MW
2	Voltage	11.5kV,13kV,15kV,22kV	6.6kV, 11.5kV
3	Excitation Voltage	425V dc	1000V dc
4	Cooling System	Forced Air, Hydrogen & Water cooled.	Forced Air
5	Rotor	Smooth cylindrical	Projected pole (salient pole)
6	Speed	3000 rpm,3600rpm	75 rpm, 1000rpm
7	Short circuit ratio	0.5 to 0.6	1.0 to 1.5
8	Excitation response(rate of change of exciter voltage & is expressed interms of volt/sec)	0.5	Higher

Installation

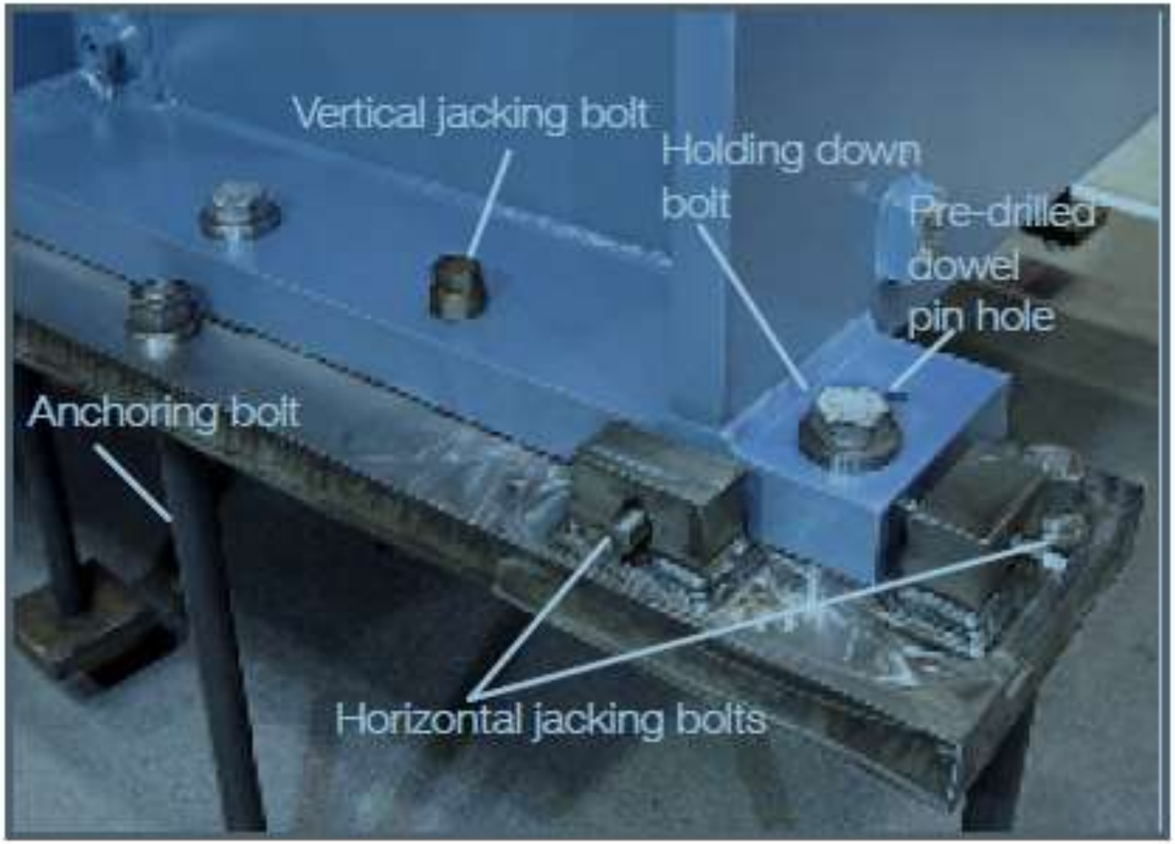
Physical Inspection:

- Check for damage/missing of parts.
- Machines to be stored in safe place.

Foundation Details:

- Based on type of mounting :horizontal/vertical
- Generally alternators are mounted vertically covering two floors basement and ground.
- Basic dimension need to be provided by the manufacturer.
- Provided with holes to receive fix bolts securing the bed plates.
- Holes and anchor bolts should be fixed in the concrete.

Foundation Details for ABB synchronous Motor



Foundation design :

The customer is responsible for ensuring that the foundation is dimensioned correctly. Factors to be taken into consideration include local conditions, prevailing forces, routing of pipes and cables, and the need to ensure that service and maintenance can be performed.

Steps in Installation of an Alternator

1. Install bedplate with leveling of bed plate.
2. Install bearing pedestals& leveling of the bearing pedestals.
3. Check on stator & rotor.
4. Assembly of the rotor onto the shaft.
5. Installation of the stator.
6. Installing the rotor in the stator.
7. Checking of airgap between stator & rotor.
8. Preparation of shaft coupling.
9. Mounting of shaft coupling on shaft.
10. Preparation of shaft & alignment of shaft.
11. Installation of cooling system
12. Drying out
13. Testing
14. Commissioning.

Contd..

Alignment:

- **Shaft alignment must be perfect to get free mechanical performance of the generator with driven equipment.**

Procedure to start Synchronous Generator

Process is slow and complex and involves:

1. **Starting of boiler**
2. **Turbine auxiliaries**
3. **Boiler auxiliaries etc.**

From cold

1. **Starting of boiler auxiliaries**
2. **Starting of turbine and auxiliaries.**
3. **Starting of boiler.**
4. **Roll turbine.**
5. **Keep the unit as spinning reverse.**

Excitation System

- Should include all equipment required for supply of field current & voltage regulator system.
- Excitation response is in terms of voltage/sec.
- Maximum voltage need to be attained by the exciter at load.
- Excitation system provides supply & regulate field current.
- Example: Brushless Excitation system.

Excitation System

Necessity :

- Source of field current for the excitation of a electrical machine including its control.
- Source can be AC or DC machine and system provide to regulate or control the amount of field current delivered.
- Exciter Ceiling voltage : maximum voltage attained by an exciter with specified conditions of load.(at rated speed and specified field temperature).
- Exciter Response rate can be increased or decreased by the exciter voltage.
- excitation-system.ppt

Brushless Excitation System

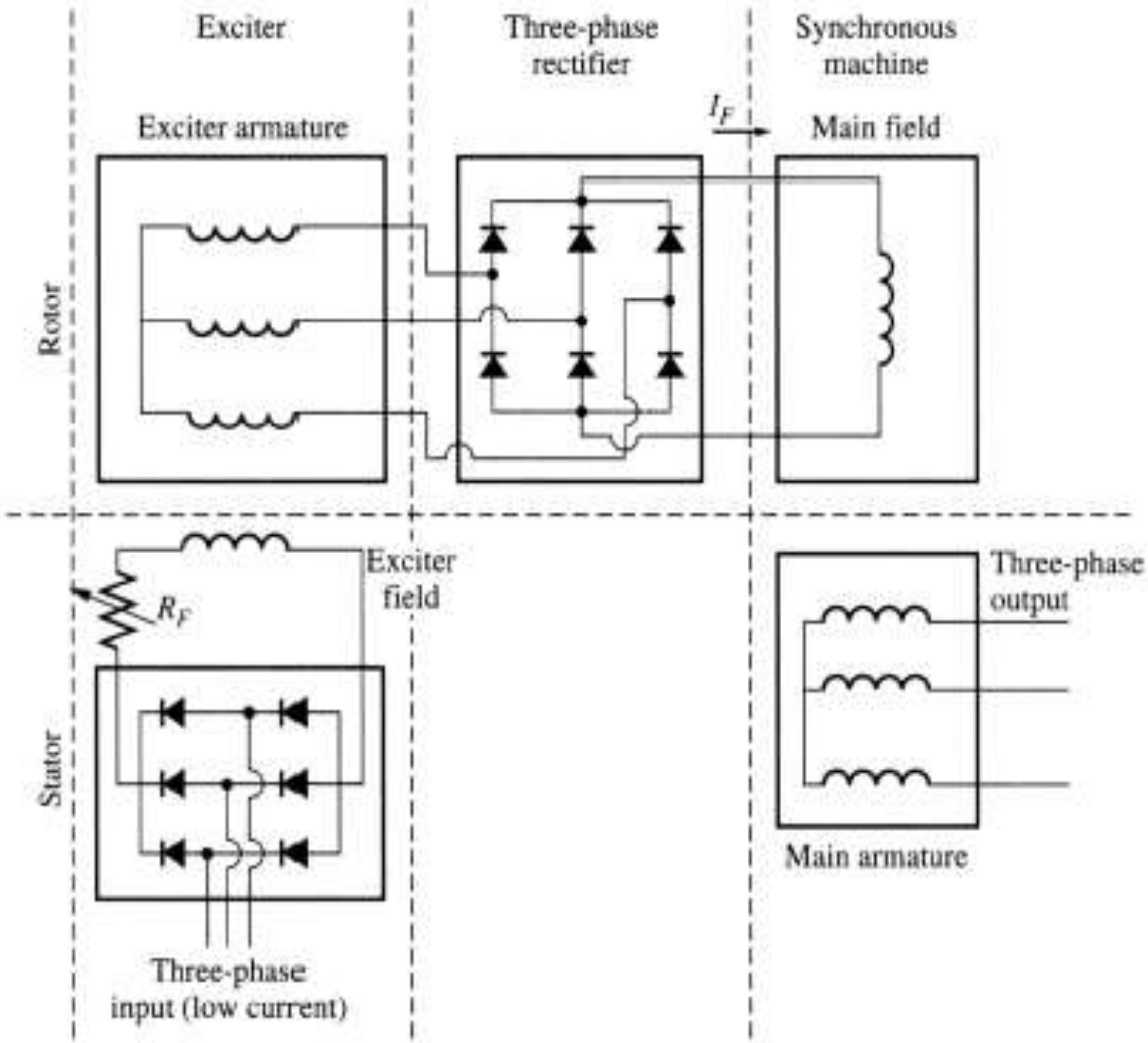
Requirement:

- Separate AC generator.
- Mounted on the motor shaft.
- Located at the non-drive end.
- Fixed speed motor excitation control & related protection based on a separate excitation control system.
- System also include:
    - Excitation field application logic.
    - Minimum & maximum field protection.
    - Too long start protection.

Brushless Excitation System

A brushless exciter: a low 3-phase current is rectified and used to supply the field circuit of the exciter (located on the stator).

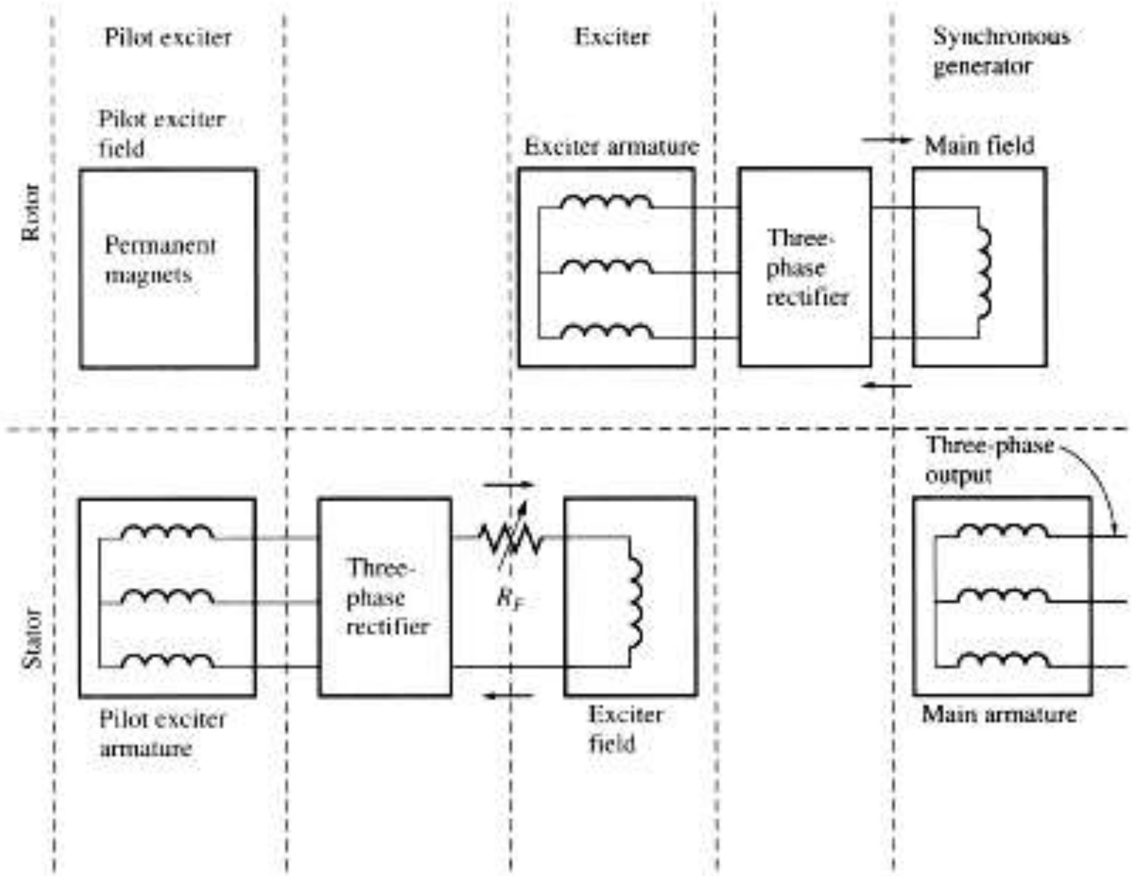
The output of the exciter's armature circuit (on the rotor) is rectified and used as the field current of the main machine.



Brushless Excitation System

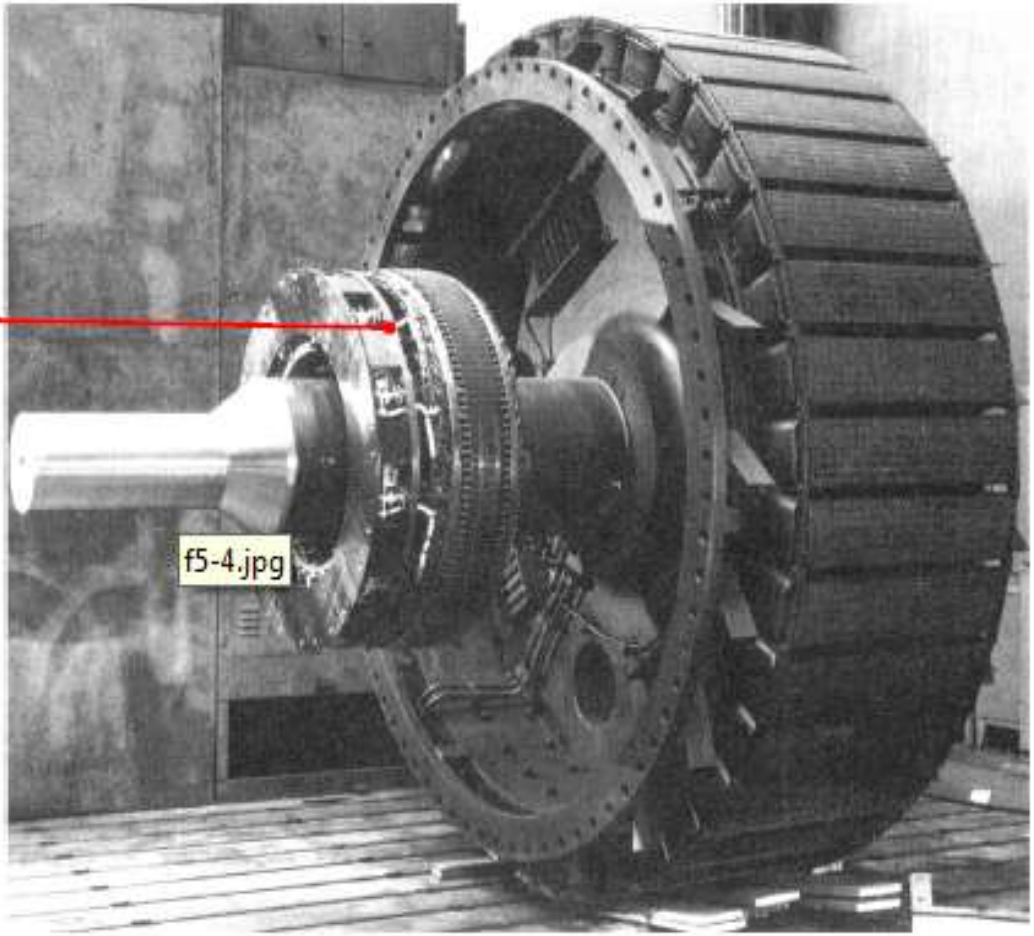
To make the excitation of a generator completely independent of any external power source, a small pilot exciter is often added to the circuit.

The pilot exciter is an AC generator with a permanent magnet mounted on the rotor shaft and a 3-phase winding on the stator producing the power for the field circuit of the exciter.

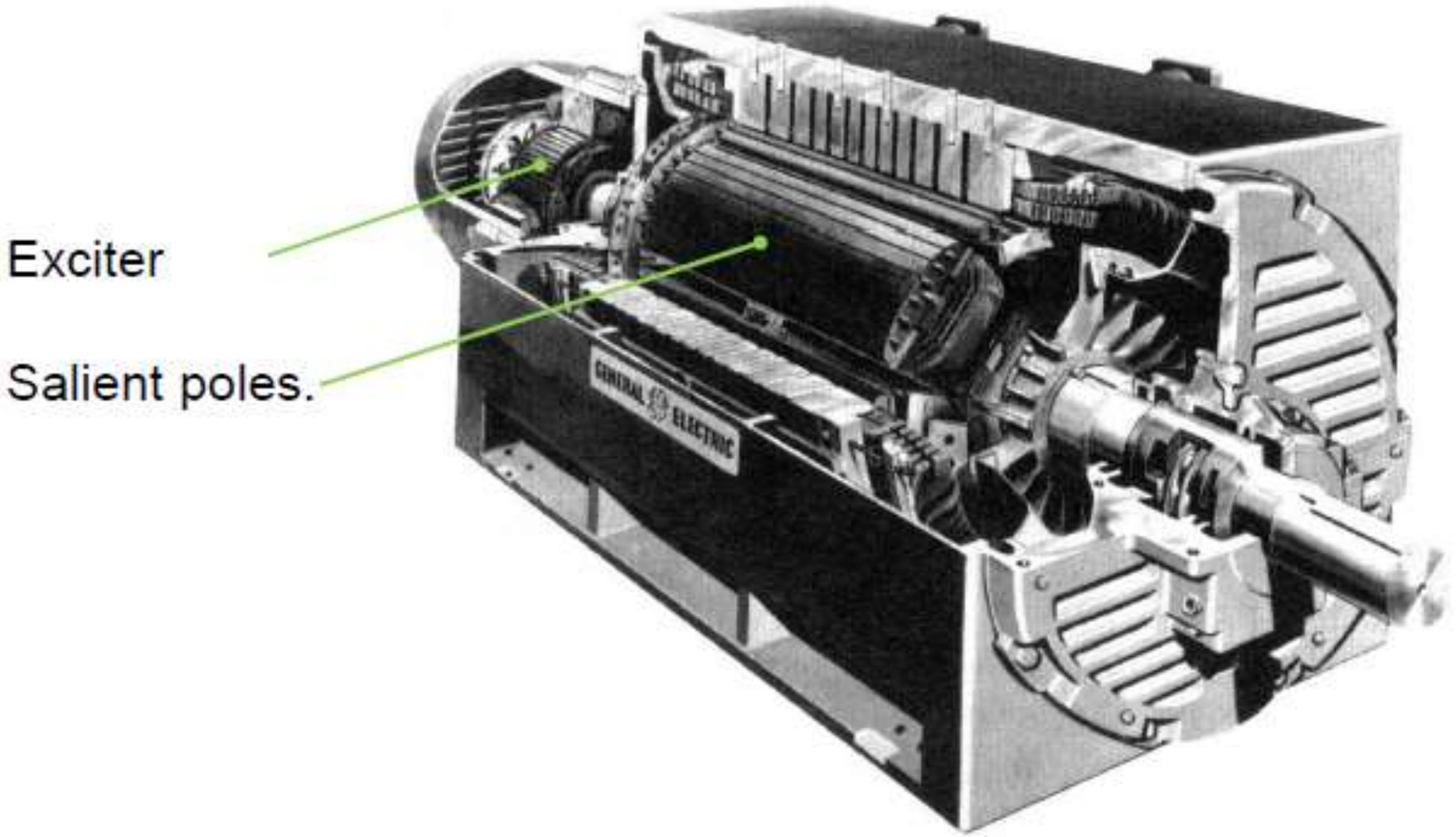


Brushless Excitation System

A rotor of large synchronous machine with a brushless exciter mounted on the same shaft.



Brushless Excitation System



Excitation System :ABB Synchronous Motor

Fixed speed synchronous motors typically have a brushless exciter and an automatic voltage regulator. The brushless system has no wearing parts, and the external excitation power requirement is small.

Variable speed synchronous motors requiring very fast speed or torque control are generally equipped with brushes and a slip ring unit for excitation and control of the motor from the converter. For dynamically less demanding applications the brushless system is optimal.

Variable speed synchronous motors based on permanent magnet rotors do not require any excitation system.

Cooling

Objective : The different methods of cooling of Synchronous machine.

- The I^2R losses and other losses in electrical machine appear as heat ,raising the temperature of each internal part above the ambient temperature of the surrounding air.
- The temperature rise is significant as it affects the life of the winding insulation.
- Heat is removed by a combination of conduction, convection and by radiation from Outer surfaces.

Cooling

Primary coolant: A medium, being at lower temperature than that part of machine and is in contact with it which removes the heat.

Secondary coolant: A medium, which being at Lower temperature than that of primary coolant which removes the heat given up by primary coolant.

Cooling

Heat exchanger: A component of cooling system that transfers heat from one coolant to another by keeping the two coolants separate.

Inner cooled (direct cooled) winding: A winding which has either hollow conductors or tubes which form an integral part of the winding, through which the coolant flows.

Cooling

Open circuit cooling: A method of cooling in which the coolant is drawn from the medium surrounding the machine, passes through the machine and then returns to the surrounding medium.

Closed circuit cooling: The primary coolant is circulated in a closed circuit through the machine and if necessary, through heat exchanges. Heat is transferred to the secondary coolant.

Cooling

❖ Cooling system may be Standby or emergency cooling system.

Components:

❖ Dependent circulating circuit components

❖ Independent circulating circuit components

❖ Integral circulating circuit components

❖ Machine mounted circulating circuit components

❖ Separately mounted circulating components

Nature of the coolant are designated by, one of the following letters.

Gases:
Air - A
Hydrogen - H
Nitrogen- N
Carbon dioxide - C

Liquid:
Water – W
Oil - U

Cooling

Hydrogen cooling of turbo - generators:

Characteristics of Hydrogen:

- The thermal conductivity of hydrogen is about 7 times that of air.
- The density of hydrogen is 0.07 times that of air.
- The specific heat of hydrogen is 14 times that of air.
- Hence hydrogen gas is preferred to air as a coolant in large turbo generators of capacity 60 MW and above.
- It reduces noise and improves heat transfer.
- The hydrogen cooling is direct cooling i.e. the cooling medium is in direct contact with conductors.

Cooling

Hydrogen cooling of turbo - generators:

- The stator conductors are hollow and hydrogen gas from a separate circuit is circulated through the stator conductors.
- The pressure of the gas is of the order of 1.5 Kg/m^2 and flow rate is about 15 m^3 /sec.
- Hydrogen blowers are required to circulate hydrogen gas through direct cooled machine.

Advantages :

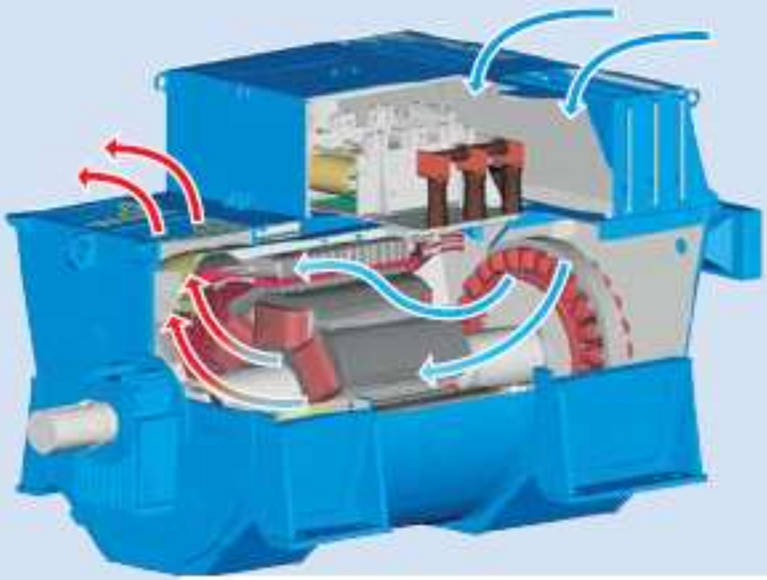
- Increase efficiency.
- Increase in rating
- Increasing life span
- Less noise.
- Lesser size cooler.

Cooling

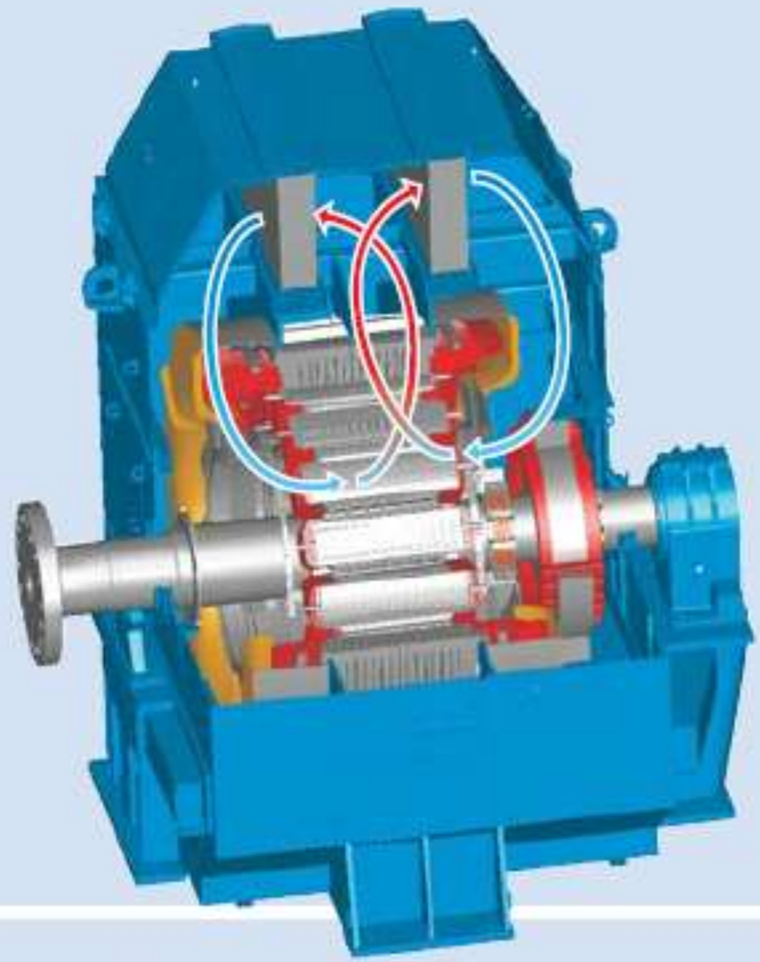
Water cooled machines:

- In direct water cooling, water is the cooling medium and it is circulated through stator conductors and rotor conductors.
- The speed of the water flow in the chillness is about 2.5m/sec
- The water at higher speed, efficiently removes the heat.

ABB Synchronous Motor

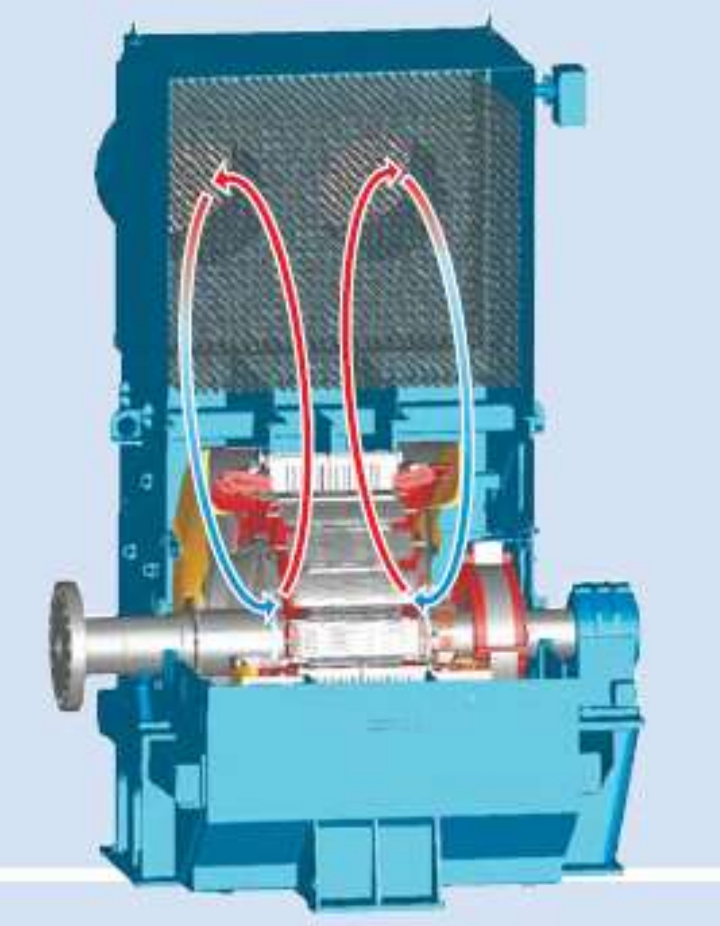


An open air cooled motor (IC0A1) with drip proof protection (IP23)



A totally enclosed motor (IP54) using an air-to-water heat exchanger (IC8A1W7)

ABB Synchronous Motor



A totally enclosed motor (IP54) using an air-to-air heat exchanger (IC6A1A6)

Air-to-air Closed Circuit Cooling

The cooling air circulates in a closed circuit through the active parts of the motor and through an air-to-air heat exchanger.
This solution is generally used in situations where a closed circuit cooling system - such as air-to-water cooling - is required but water is not readily available. This cooling arrangement requires an additional shaft mounted or separate electric fan to ensure sufficient air flow through the cooler.

Types of Enclosure

- The method of cooling is closely related to the construction and the type of enclosure of the machine.

Open - pedestal: In this the stator and rotor ends are open to the outside ambient air, the rotor being supported on pedestal bearings mounted on the bed plate.

Types of Enclosure

Open end bracket: In this the bearings forms part of the end shields which are fixed to the stator housing. The air is in comparatively free contact with the stator and rotor through the openings. This is common for small and medium size motors and generators.

Types of Enclosure

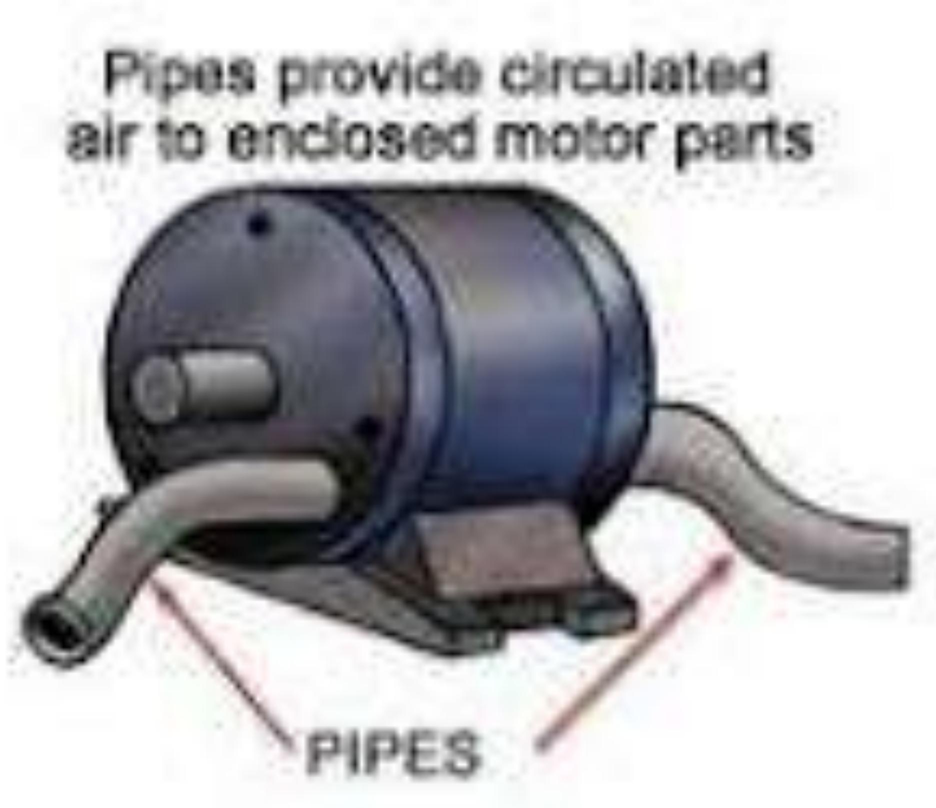
Protected or end-cover type with guarded openings: The protector may be screen or fine-mesh over.

Types of Enclosure

Drip, splash or hose proof: This is a protected machine with the openings in the end shield for cooling. The end shields are designed to prevent entry of falling water or dirt or jets of liquid.

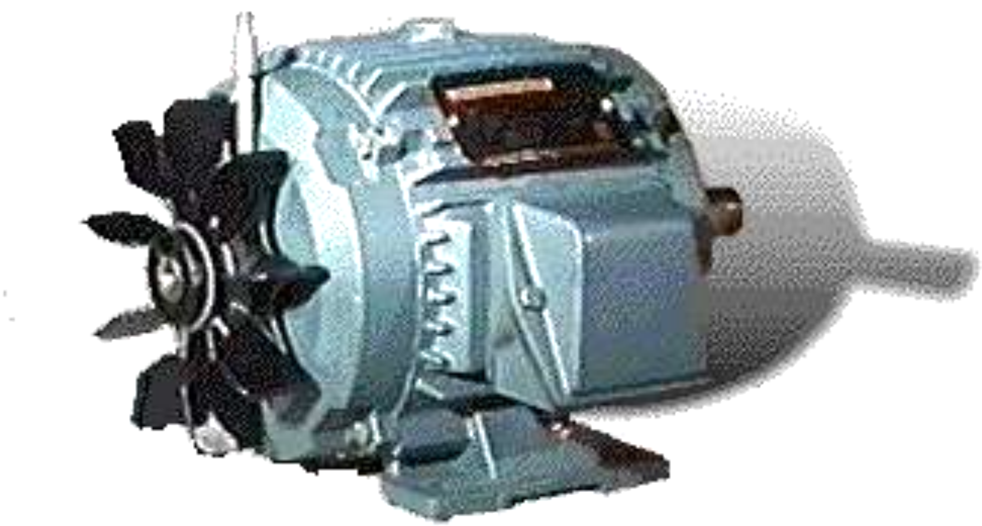
Types of Enclosure

Pipe or duct cooled: With end covers closed except for flanged openings for connection to cooling pipes.



Types of Enclosure

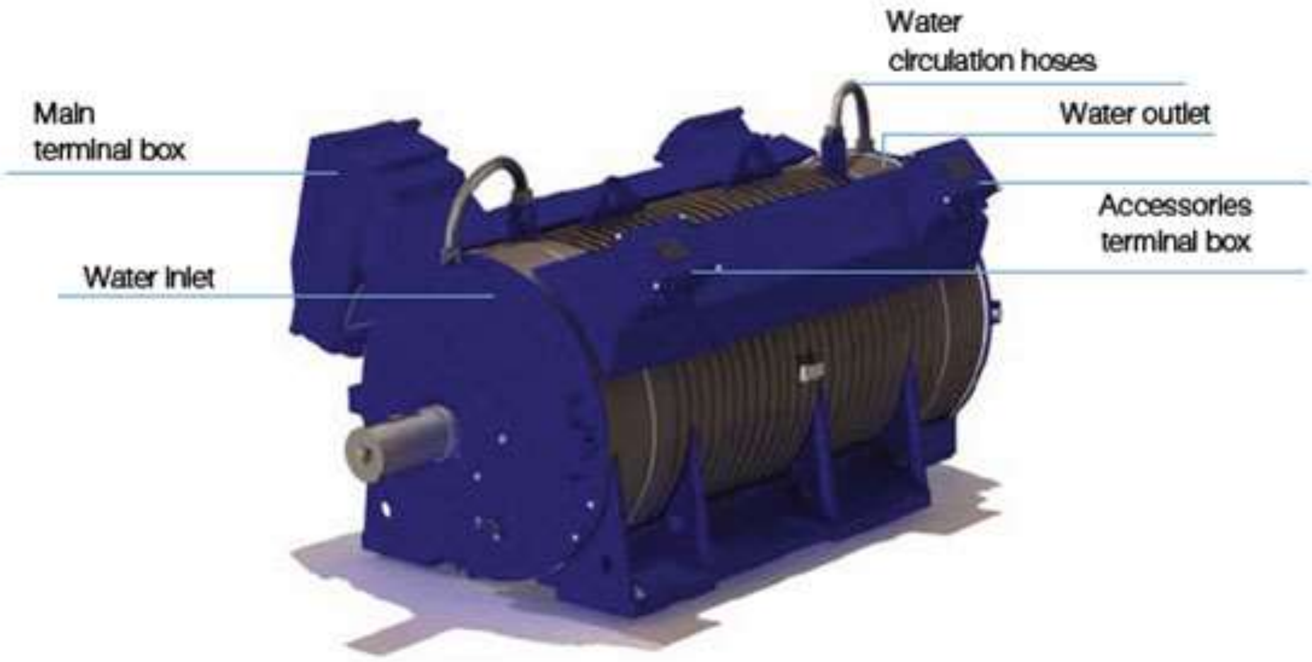
Totally enclosed: The air will not be in contact with the ambient air. The machine is totally air tight. Total enclosure may be associated with an internal rotor fan, an external fan, cooling or closed air circuit cooling in which the air is circulated to a cooler and returned to the machine.



Totally Enclosed Fan Cooled (TEFC)

Types of Enclosure

Water cooled



Types of Enclosure

Flame proof or explosion proof: This motor is used in hazardous location such as mines, chemical industries etc.

Note: The ratings of machines are dependent upon their respective cooling systems. For complex cooling systems, the machines may have to be de-rated.

Duty of Rotating Machines

- The variations of load with time is termed as duty of motor.
- The duty requirement may be declared numerically or with the aid of time sequence graphs.
- The duty is very important in case of electrical motors as they have a time rate of temperature rise.

General Requirements and Constructional Details

- These motors are provided with class E, B or F insulation.
- For HV motors class F insulation is preferred.
- The rating plate shall be of stainless steel and non corrosive material.
- In addition to the general parameters of a 3 phase induction motor, following are to be mentioned:
- Reference to the standard, :IEC, IS and BS standard specifications

Classes of Duty

Following are the classes of duty:

1. S1 – Continuous duty
2. S2 – Short time duty
3. S3 – Intermittent periodic duty
4. S4 – Intermittent periodic duty with starting
5. S5 – Intermittent periodic duty with starting and electric braking
6. S6 – Continuous duty with intermittent periodic loading
7. S7 – Continuous duty with starting and electric braking
8. S8 – Continuous duty with periodic speed changes

Classes of Duty

The symbols for operating duty:

- N - ‘Operation' with normal rated load
- R - Machine at rest and de-energized
- D - Starting duty
- F - Braking duty,
- V - Operation at no load, but rotating

Cyclic duration factor: ratio of operating period to the total period of a cycle.

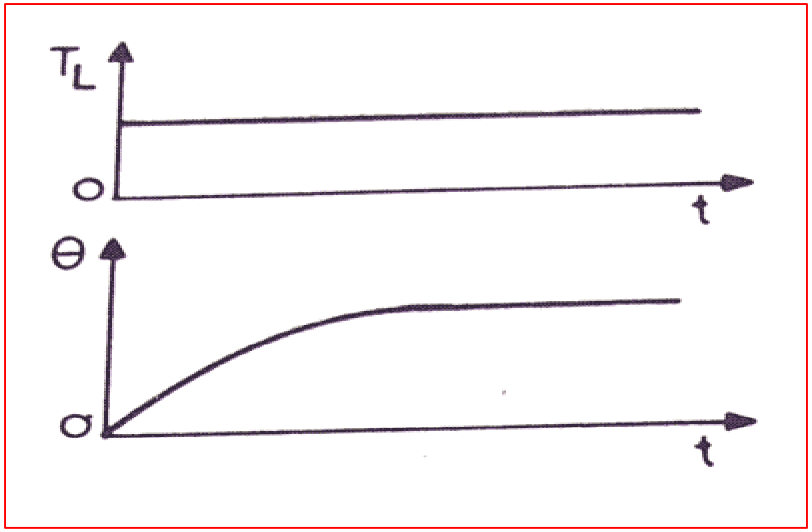
Classes of Duty

Cyclic duration factor for different duty

Duty	Cyclic duration factor for rotating machine
S3	N/(N+R)
S4	D+N/(D+N+R)
S5	N+N+F/(D+N+R+F)
S6	N/(N+V)

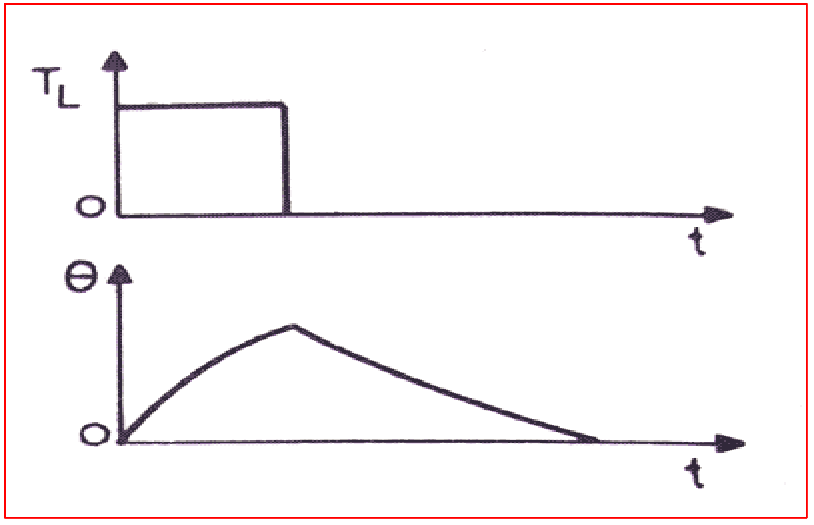
Continuous duty (S1)

- Motor is running long enough and temperature reaches steady value.
- Used in paper mill drives, conveyors, compressors.



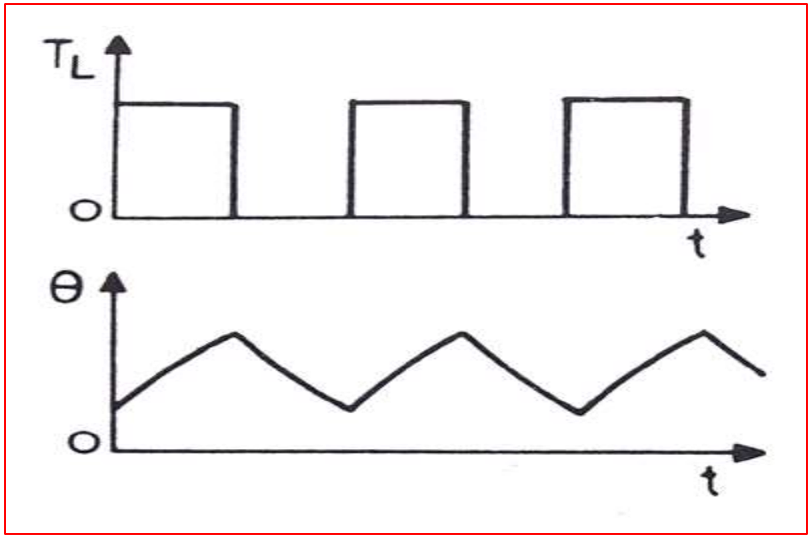
Short time duty(S2)

- In these motors, the time of operation is very low and the heating time is much lower than the cooling time.
- These motors are used in crane drives, drives for house hold appliances, valve drives etc.



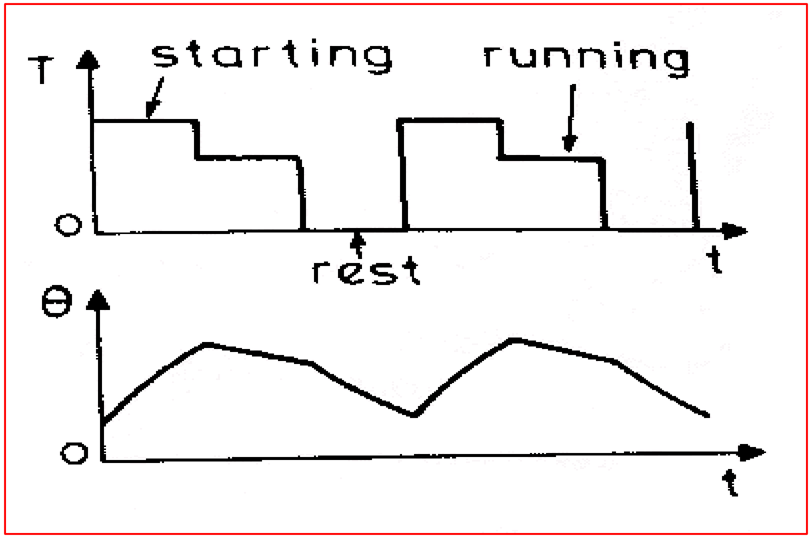
Intermittent periodic duty (S3)

- Here the motor operates for some time and then there is rest period.
- This is seen at press and drilling machine drives.



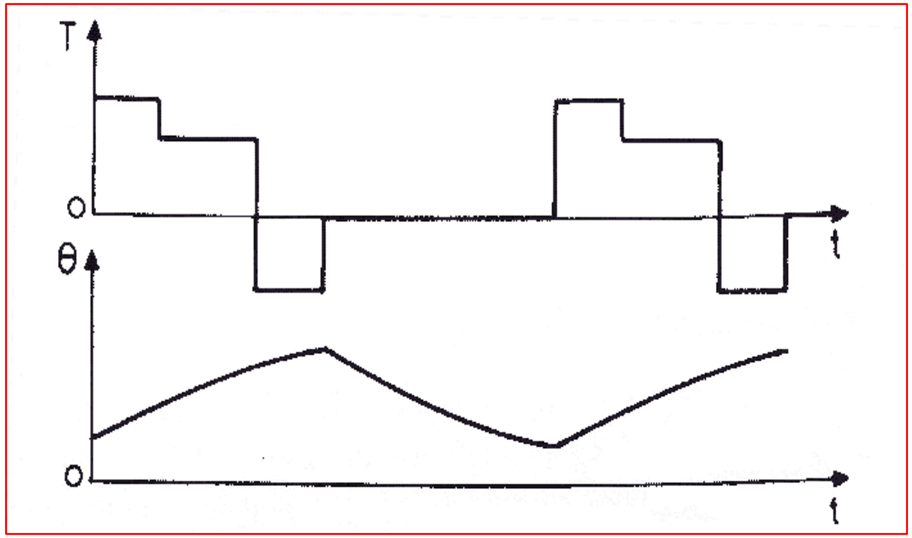
Intermittent periodic duty with starting (S4)

- In this type of duty, there is a period of starting, which cannot be ignored and there is a heat loss at that time.
- This motor duty class is widely used in metal cutting and drilling tool drives, mine hoist etc.



Intermittent periodic duty with starting and braking

- In this type of drives, heat loss during starting and braking cannot be ignored.
- The corresponding periods are starting period, operating period, braking period and resting period.



These techniques are used in billet mill drive, manipulator drive, mine hoist etc.

Continuous duty with intermittent periodic loading

- In this type of motor duty, everything is same as the periodic duty but here a no load running period is occurred instead of the rest period.
- Pressing, cutting are the examples of this system.

Continuous duty with starting and braking

- Consists of periodic cycles each having a period of starting, a period of running at a constant load and a period of braking.
- There is no period of rest.
- The main drive of Blooming mill is an example.

Continuous duty with periodic speed changes

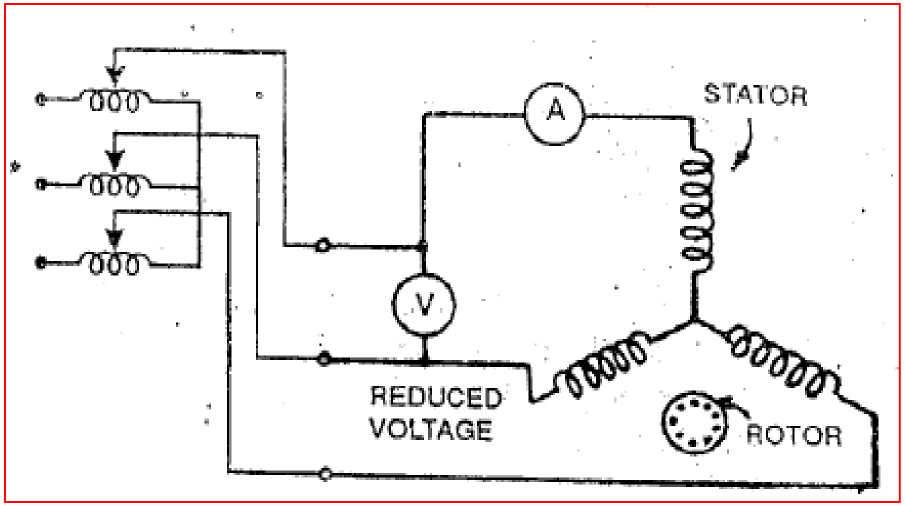
- Consists of periodic duty cycle each having a period of running at one load and speed, and another period of running at different load and speed.
- There is no period of rest.
- Several paper mill drives are examples.

Drying out of synchronous machines

- The insulation of rotating machines is hygroscopic in nature.
- The moisture absorbed by the insulation is to be removed by drying till the insulation resistance reaches specified value.
- The moisture is evaporated from the winding due to thermal diffusion.
- Moisture gradient depends on temperature gradient within wet insulation.
- The desired temperature is obtained by heating the winding.
- During drying it is necessary to record the temperature at various stages of drying out, insulation resistance and time.

Drying out of Synchronous Machines

1. The machine stator windings are supplied with low voltage.
2. The input voltage, current, power & temperature of winding, temperature
3. of body, temperature of air are periodically measured.
4. The end shields of the machine are removed.
5. The machine body is covered with tarpaulin. No cool air blow shall come over the hot winding.



6.The preparation, precautions and log book keeping during Drying. The machine should be always attended when drying out is in progress .

Note: Polarization index to be found .

Testing of Synchronous Machines

The tests are conducted to demonstrate that the machine gives the required performance.

Testing of Synchronous Generators

1. Open circuit test (no Load test)
2. Short circuit test
3. Zero Power factor characteristics tests and loss measurement
4. Temperature rise test by
   - Full load ZPF over excited run
   - By equivalent heat run
5. Over speed test
6. High voltage tests
7. Insulation resistance tests
8. Waveform interference, gap length, balance, vibration, bearing currents, magnetic symmetry etc
9. Measurement of DC resistance of armature and field windings.
10. Dielectric test

Testing of Synchronous Generators

Commissioning test

1. Insulation resistance tests
2. Measurement of DC resistance of armature and field windings.
3. Waveform interference test
4. Line charging capacity

Performance test

1. Slip test
2. Sudden short circuit test
3. Determination of transient and sub transient parameters
4. Determination of sequence impedance
5. Separation of losses
6. Temperature rise test & retardation test

Testing of Synchronous Generators

Factory test

1. Gap length
2. Magnetic symmetry
3. Balancing vibrations &
4. Bearing performance
5. Open circuit test
6. Short circuit test
7. Zero Power factor characteristics tests and loss measurement
8. Over speed test
9. High voltage tests
10. Waveform interference test, Gap length, Balance, Vibrations , Bearing currents, Magnetic symmetry etc
11. Dielectric test

Testing of Synchronous Motors

1. Measurement of DC resistance of armature and field windings.
2. Dielectric test on armature and field windings.
3. Mechanical balancing test
4. Temperature rise test
5. Over speed test
6. Harmonic analysis
7. Telephone interference
8. Short circuit test
9. Reactance and time constants
10. Speed torque characteristics
11. Efficiency calculations
12. Bearing insulation test
13. Direction of rotation
14. Current balance on no load
15. Commissioning tests

Measurement of Insulation Resistance

- The insulation resistance of

1. stator winding to earthed frame,
2. rotor winding to earthed frame,
3. phase to phase winding pedestal
4. and bearing insulation resistance is measured using megger.

- The megger readings for 15 seconds and 60 seconds are taken to find the polarization index.
- The polarization index gives the extent of dryness of the insulation and is given by

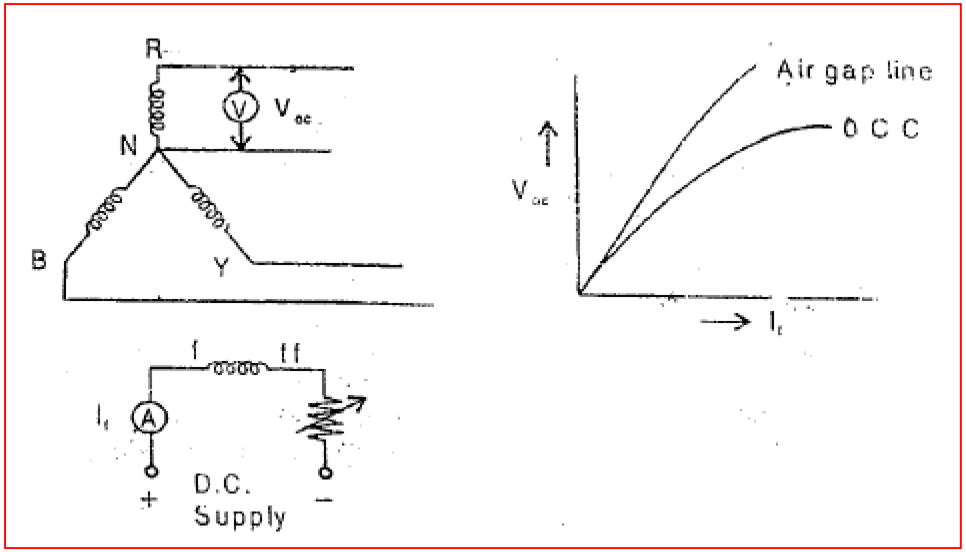
$$PI = \mathbf{IR_{60}/IR_{15}}$$

Measurement of DC winding Resistance

1. **Voltmeter ammeter method:** **V**oltage applied across the winding and current through the winding are noted at the specified temperature. Then the resistance is calculated. This method is suitable for field resistance measurement only.
2. **Bridge method:** Built in bridges like **Wheatstone** bridge and **Kelvin's double** bridge are used to measure field resistance & armature resistance respectively & temperature is also recorded and three to five readings are taken.

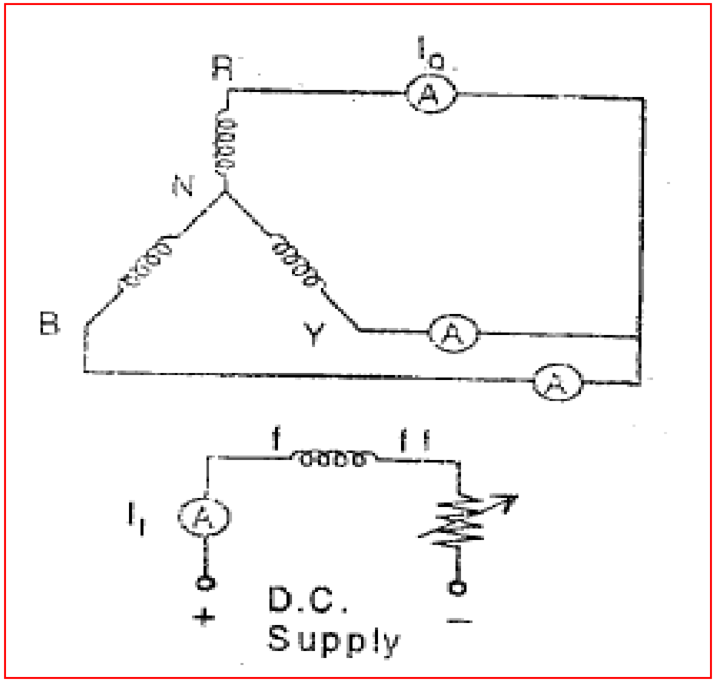
Open-circuit test

- The generator is turned at the rated speed
- The terminals are disconnected from all loads, and the field current is set to zero.
- Then the field current is gradually increased in steps, and the terminal voltage is measured at each step along the way.
- It is thus possible to obtain an open-circuit characteristic of a generator (V_{oc} versus I_f) from this information



Sustained three phase short circuit test

- The synchronous generator terminals shorted through ammeters.
- The field current is gradually increased till the armature current reaches a maximum safe value (about 1.5 times rated current).



- The relation between field current and short circuit current is drawn and is known as the short circuit characteristics.
- In sustained short circuit test, the values of field current and armature current refer to the steady state values and are measured using indicating meters.

Short Circuit Ratio (SCR)

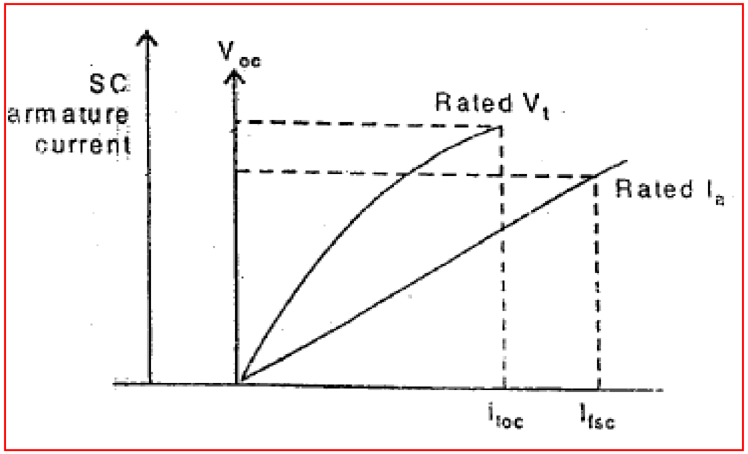
- The short circuit ratio of synchronous machine is defined as the ratio of field current $I_{f\,OC}$ required to obtain rated open circuit voltage to the field current I_{fsc} required for obtaining rated sustained short circuit current when running at rated speed.

$$\mathbf{SCR = I_{foc}/I_{fsc}}$$

- The short circuit ratio is obtained from the data of no-load test and sustained short circuit test conducted on the machine.

Short Circuit Ratio (SCR)

- The impedance under steady state condition is known as the synchronous impedance and is defined as the ratio of field current at rated armature current on sustained symmetrical short circuit to the field current at normal open circuit voltage on the air gap line.
- Zs= V rated/Ia rated
- *SCR* is just the reciprocal of the per unit value of the saturated synchronous reactance



$$SCR = \frac{I_{F\_Vrated}}{I_{F\_Iscrated}}$$

$$= \frac{1}{X_{s\_sat}[in\ p.u.]}$$

Short Circuit Ratio (SCR)

Significance of SCR:

1. Low value of SCR Xs increases and IaXs drop increases.
2. Low value of SCR indicates smaller air gap and poor regulation due to large IaXs drop.
3. Synchronous power is inversely proportional to Xs which lead lower stability.

DC Test

– The purpose of the DC test is to determine R_a. A variable DC voltage source is connected between two stator terminals.

– The DC source is adjusted to provide approximately rated stator current, and the resistance between the two stator leads is determined from the voltmeter and ammeter readings

– then

$$R_{DC} = \frac{V_{DC}}{I_{DC}}$$

– If the stator is Y-connected, the per phase stator resistance is

$$\boldsymbol{R_a = \frac{R_{DC}}{2}}$$

– If the stator is delta-connected, the per phase stator resistance is

$$\boldsymbol{R_a = \frac{3}{2} R_{DC}}$$

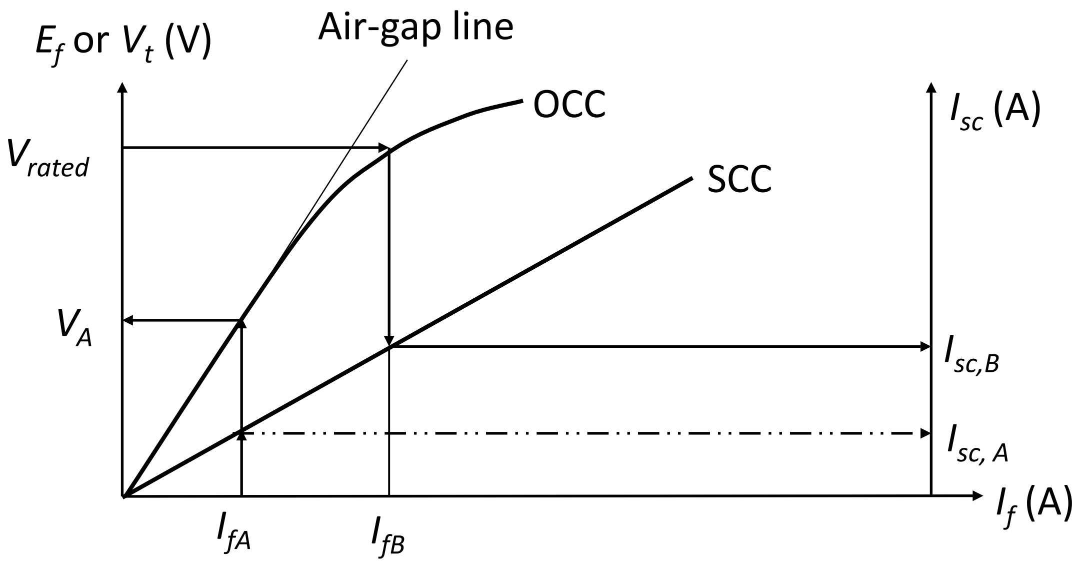
Determination of X_s

- For a particular field current I_{fA}, the internal voltage E_f (=V_A) could be found from the occ and the short-circuit current flow $I_{sc,A}$ could be found from the scc.
- Then the synchronous reactance X_s could be obtained using

$$Z_{s,unsat} = \sqrt{R_a^2 + X_{s,unsat}^2} = \frac{V_A\left(=E_f\right)}{\left|I_{scA}\right|}$$

$$X_{s,unsat} = \sqrt{Z_{s,unsat}^2 - R_a^2}$$

: R_a is known from the DC test.



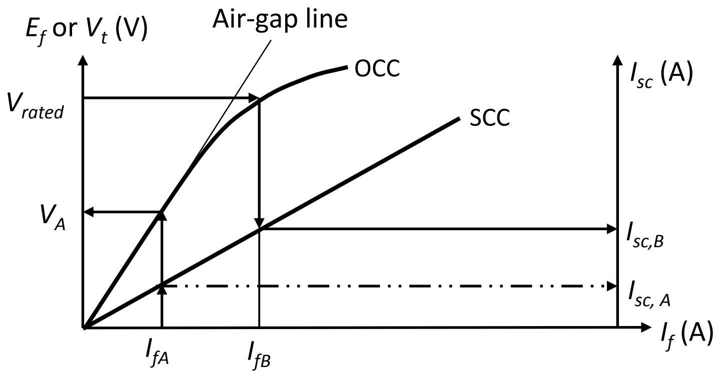
Since $X_{s,unsat} >> R_a$,

$$X_{s,unsat} \approx \frac{E_f}{I_{scA}} = \frac{V_{t,oc}}{I_{scA}}$$

X_s under saturated condition

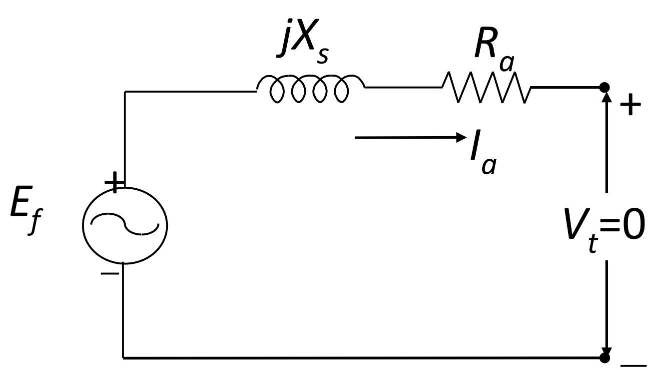
At $V = V_{rated}$,

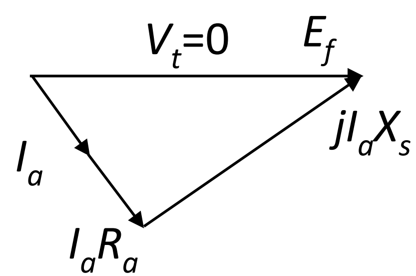
$$Z_{s,sat} = \sqrt{R_a^2 + X_{s,sat}^2} = \frac{V_{rated}(= E_f)}{|I_{scB}|}$$



$$X_{s,sat} = \sqrt{Z_{s,sat}^2 - R_a^2}$$ R_a is known from the DC test.

Equivalent circuit and phasor diagram under condition





Sudden 3-phase short circuit test on generator

- When an alternator is subjected to sudden short circuit, the current in all the three phases increases suddenly to a high value (10 to 8 time's full Load current) during the first quarter cycle.
- The flux crossing the air gap is Large during first couple of cycles.
- The reactance during this period is least and the short circuit current is high.

Sudden 3-phase short circuit test on generator

- This reactance offered during sub transient period is called as sub transient reactance Xd".
- The first few cycles are covered under sub transient state.
- After few cycles the decrement in rms value of short circuit current is less rapid than that during the first few cycles.

Sudden 3-phase short circuit test on generator

- This state is called as Transient state and the reactance offered during this period is called as transient reactance Xd'.
- The circuit breaker contacts open during this period.
- Finally the transient dies out and the current reaches a steady sinusoidal state called the steady state and the reactance offered during this state is called as steady state reactance Xd.

Sudden 3-phase short circuit test on generator

- Since the short circuit current lag the voltage by 90°, the reactance involved is direct axis reactance.
- The sudden 3phase short circuit test is conducted at rated speed and at desired no load voltage.
- The 3 phases are shorted suddenly.
- To measure the short circuit current storage oscilloscope with proper probe multiplier is used.

Sudden 3-phase short circuit test on generator

- The terminal voltages of the machine, the excitation current and winding temperature are measured just before the short circuit.
- To obtain quantities corresponding to the unsaturated state of the machine, the test is performed at several armature voltage of 0.1 to 0.3 pu rated value.

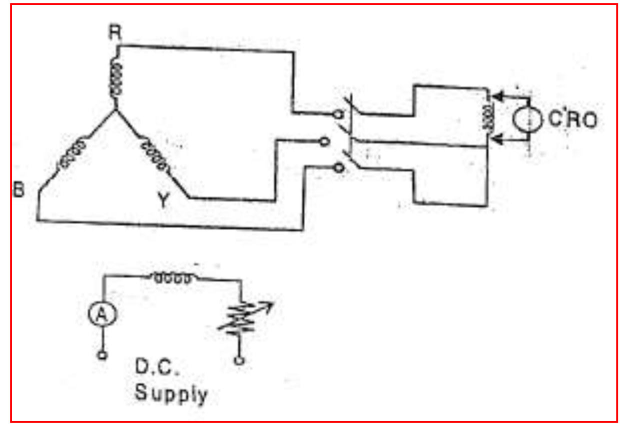
Sudden 3-phase short circuit test on generator

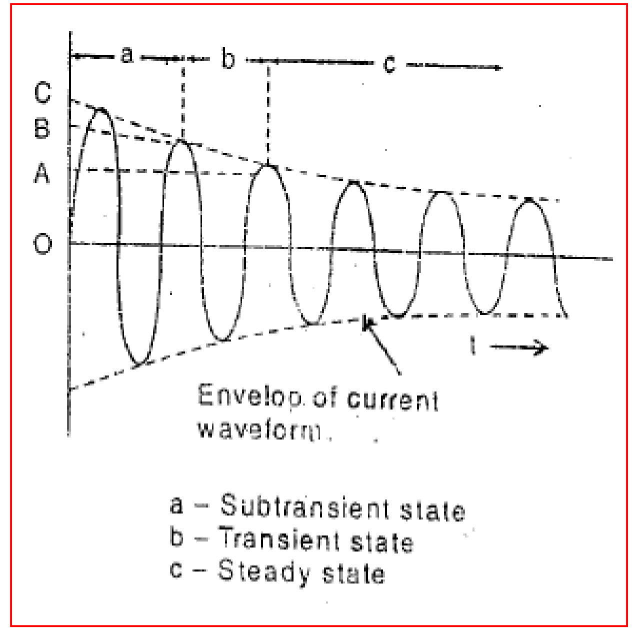
- To get quantities corresponding to saturated state of the machine , the test is conducted with rated voltage at the terminals of the machine before applying short circuit to the armature winding.
- If sudden short circuit test cannot be performed at rated armature voltage it is recommended that the
- test should be conducted at several armature voltages (eg: 0.3, 0.5 and 0.2 pu of rated armature voltage).

Sudden 3-phase short circuit test on generator

- To determine the machine quantities, oscillogram is taken of the armature current in each phase and the current in the excitation circuit.
- Short circuit is initiated by closing the circuit breaker and is removed by operating the circuit breaker.

Sudden 3-phase short circuit test on generator





Oscillogram of current in the phase having zero dc components

OA,OB,OC are the intercept of X-axis as shown. **Ea=+ve sequence emf/phase -rms** value, the emf induced by the Generator.

The current & reactance are given by the expressions:

I=OA/=Ea/Xd; Xd=Ea/I;

I'=OB/=Ea/Xd'; Xd'=Ea/I';

I"=OC/=Ea/Xd";Xd"=Ea/I";

(I=Steady I'=Transient I"=Sub-transient state SC current)

Xd=Direct axis (synchronous)reactance

Xd'=Transient reactance (Direct axis)

Xd"=Sub-transient reactance (direct axis)

Negative phase sequence test

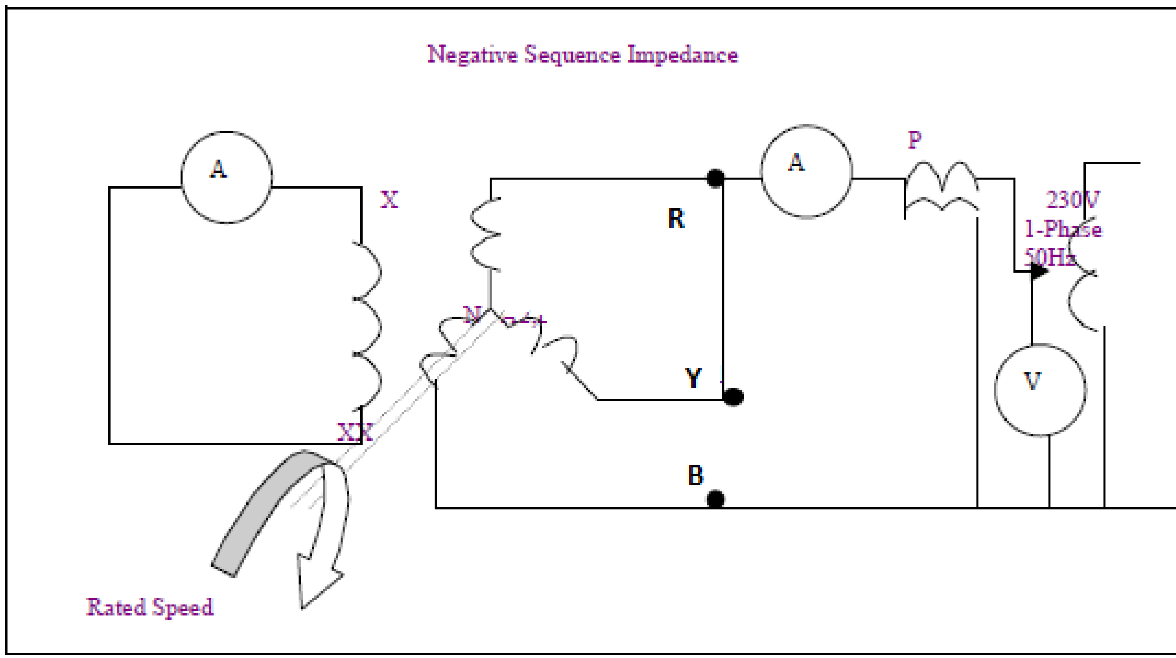
- The test is conducted when reduced symmetrical voltage (0.02-0.2) pu is applied to the machine driven at rated speed.
- and connected to an external source of supply with negative phase sequence i.e. operating as an electromagnetic brake with the slip equal to 2.
- The excitation winding is short circuited.

Negative phase sequence test

- If the residual voltage of the machine under test exceeds 0.30 times of the supply voltage, the rotor should be demagnetized before testing the machine.
- The voltage and current in all the three phases and power are noted.

Negative phase sequence test

- Negative sequence reactance and resistance are determined from the negative phase sequence test by the formulae.



- [Procedure for negative sequence reactance.docx]

Negative phase sequence test

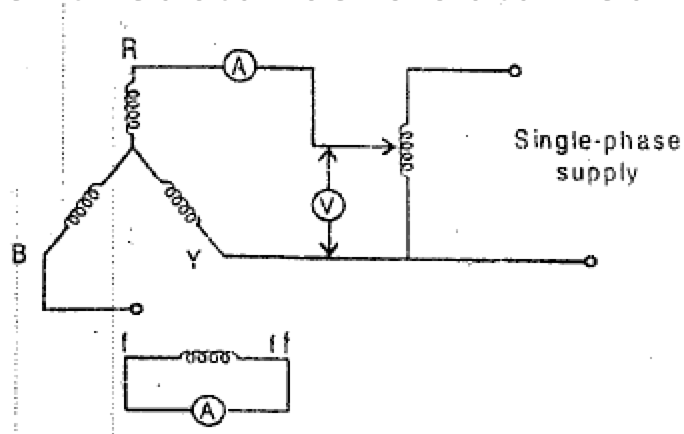
$$X_2 = \sqrt{Z_2^2 - R_2^2}\,\Omega,\quad Z_2 = \frac{V}{\sqrt{3}I}\,\Omega\quad R_2 = \frac{P}{3I^2}\,\Omega$$

$$[\,x_2 = \sqrt{z_2^2 - r_2^2}\,;\ z_2 = \frac{v}{i};\ r_2 = \frac{P}{i^2}\,]$$

•where P = input power, I = average current measured V = average voltage measured Lower case letters indicate per unit values

Measurement of sub transient reactance

1. The voltage is applied across any two terminals except neutral, with the rotor at rest and short circuited on itself through an ammeter.
2. The rotor is rotated by hand and it will be observed that for a fixed voltage applied, current in the field varies with the position of the rotor.
3. When the rotor is in the position of maximum induced field current direct axis sub transient reactance is obtained.
4. When the rotor is in a position of minimum induced field current quadrature axis sub transient reactance is obtained

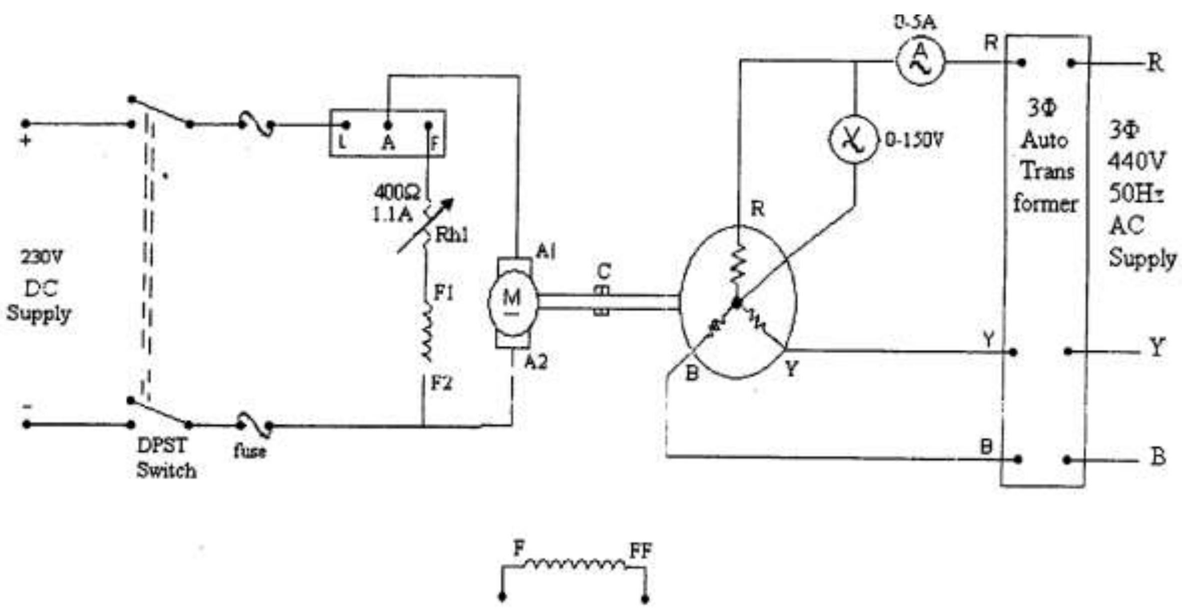


Slip test

1. Field terminals of the alternator is kept open.
2. With shunt field rheostat R_{h1} in minimum resistance position, the motor is started using 3-point starter.
3. By adjusting the field rheostat R_{h1} of the motor, the alternator is run at a speed slightly less than the synchronous speed.
4. Now 3- phase AC supply switch is closed, and then applied voltage of say **40 Volts** by varying the autotransformer a reduced A.C voltage is applied to 3Φ stator winding of the alternator. By using phase sequence indicator, check the phase sequence of the alternator.
5. If the phase sequence of the supply is found incorrect, interchange any two supply lines.

Slip test

1. Note down the readings I_{min}, I_{max}, V_{min}, V_{max} from ammeter and voltmeter respectively.
2. Reduce the autotransformer output to zero.
3. The motor field rheostat is brought to initial position, the DC supply is switched OFF.



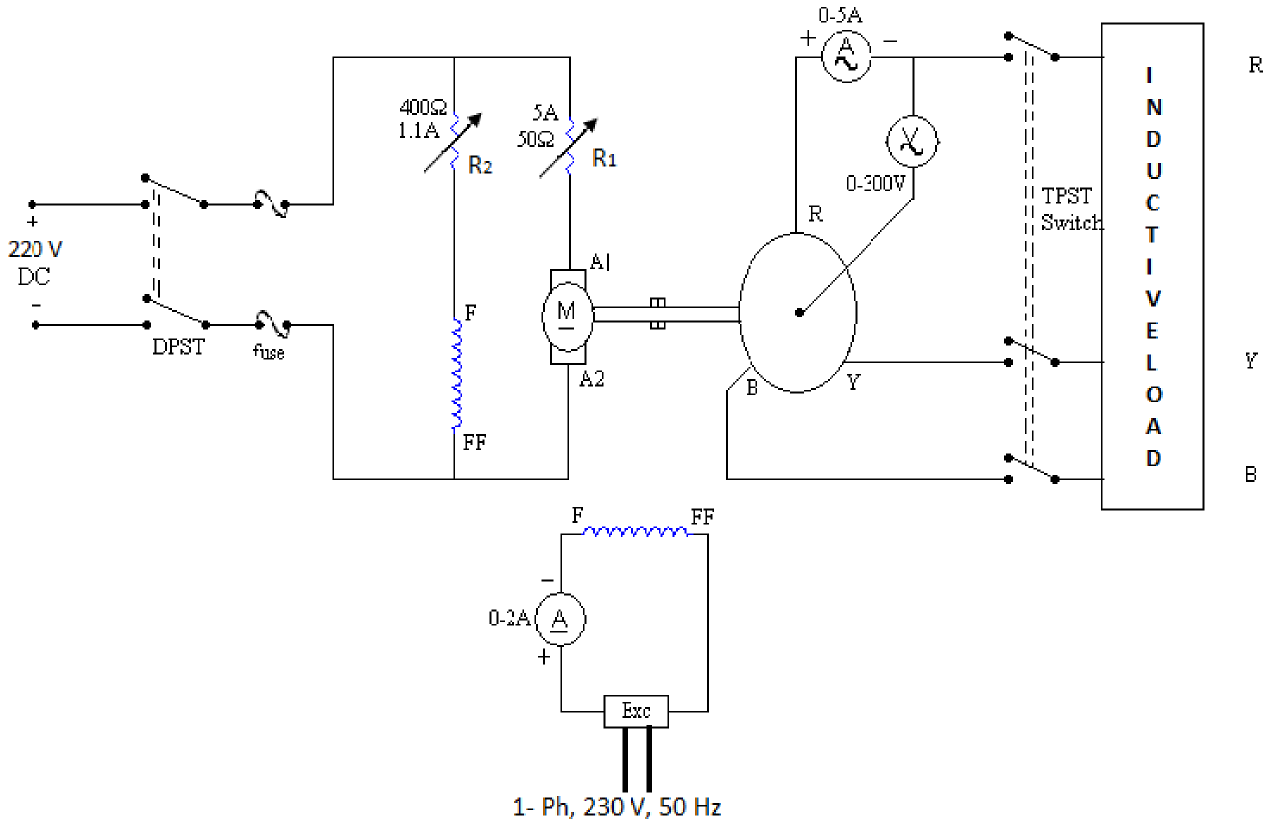
$$X_d = \frac{\text{Maximum voltage}}{\text{Minimum current}}$$

$$X_q = \frac{\text{Minimum voltage}}{\text{Maximum current}}$$

ZPF METHOD

1. The O.C and S.C procedures are followed as same in the EMF and MMF method.
2. By keeping armature rheostat R_1 in maximum resistance position, the field rheostat in R_2 minimum resistance position, the DC supply is switched ON and the motor speed is brought to the rated speed.
3. The open circuit and short circuit procedures are followed as mentioned in the EMF and MMF method.
4. Now exciter supply is switched ON and exciter current is increased such that rated voltage is build up across the alternator terminals by varying the knob of the exciter.
5. Now inductive load is applied across the terminals by using TPST switch. The ZPF load is slowly increased such that rated current flows through the ammeter of alternator. At this point readings of all the meters are noted.
6. By varying excitation and inductive load, other readings (for rated current flow through the ammeter of alternator) are obtained.
7. The plot of inductive load voltage v/s field current is drawn.
8. The Potier triangles are constructed, using which voltage regulation of alternator is found out for lagging, unity and leading power factor values.

ZPF METHOD



Procedure for ZPF characteristics:[REGULATION OF ALTERNATOR BY ZPF METHOD.docx]

Power frequency voltage withstand test

- This test is conducted on 3 phase ac windings of an ac generator with the specified values of power frequency test voltage.
- The test voltage of (2V+1) KV is applied for specified time (1 minute) between windings and earthed frame.
- The machine parts should not exhibit flash over, to consider it to have passed the test.

Over Speed Tests on Motors

- In certain applications over speed can occur occasionally.
- This test is an essential Type test and even may be a routine test.
- Eg: for traction motors, over speed test is conducted at speed of 120 to 150% of the rated speed for two minutes.

Over Speed Tests on Motors

- This test is carried out on hot motor.
- After the test, profile of rotor, end coils, air gaps and bearings can be observed visually.
- Minor repairs can be attended.
- If the serious damage occurs, the design/manufacture should be reviewed.

Over Speed Tests on Motors

The test is considered satisfactory if

- There are no evident deformation of the motor.
- The rotor winding passes the high voltage test.
- The vibrations of the test are within the prescribed limits as per IS 4729-1968.

Vibration test

- The vibration test is carried out on the complete machine after assembly and balancing of the machine.
- A set of three orthogonal accelerometers are fixed on each bearing.
- The vibrations are measured in two directions normal to the shaft.
- For vibration test the machine is run at no load without coupling to any machine

Vibration test

Measurement of audible noise:

- In applications where driven machine makes more noise, motor noise is ignored.
- In applications where audible noise levels are to be held within permissible limits, the audible noise test on motor may be an acceptance test in work or at site.

Vibration test

Measurement of audible noise:

- Motor design features including enclosure, degree of protection, power rating and speed influences audible noise directly.
- For example, 6 pole motor gives 76 dB(A) and 2 pole motor gives 84 dB(A) 1.1 KW motor gives 76 dB(A) and 1.1 MW motor gives 105 dB(A).

Vibration test

Sound measurement:

This requires sound meter fitted with filters to accept noise at set frequencies.

IEC A weightings of standardized curves of frequency (Hz) to relative sound pressure level (dB) are as

F Hz	20	50	100	200	500	1000	2000	5000
dB(A)	-50	-30	-20	-10	-2	0	2	1

Vibration test

Noise Reduction:

Noise is due to

1. Magneto striction
2. Aerodynamics
3. Bearing noise of rotating shaft

Speed and power affect aerodynamics and bearing noise of the rotating shaft.

1. Totally enclosed machine gives least sound, open ventilated machines give maximum sound.
2. Ventilation noise predominates in 2 pole machine
3. When bearing noise becomes audible, the other two are less significant.

Vibration test

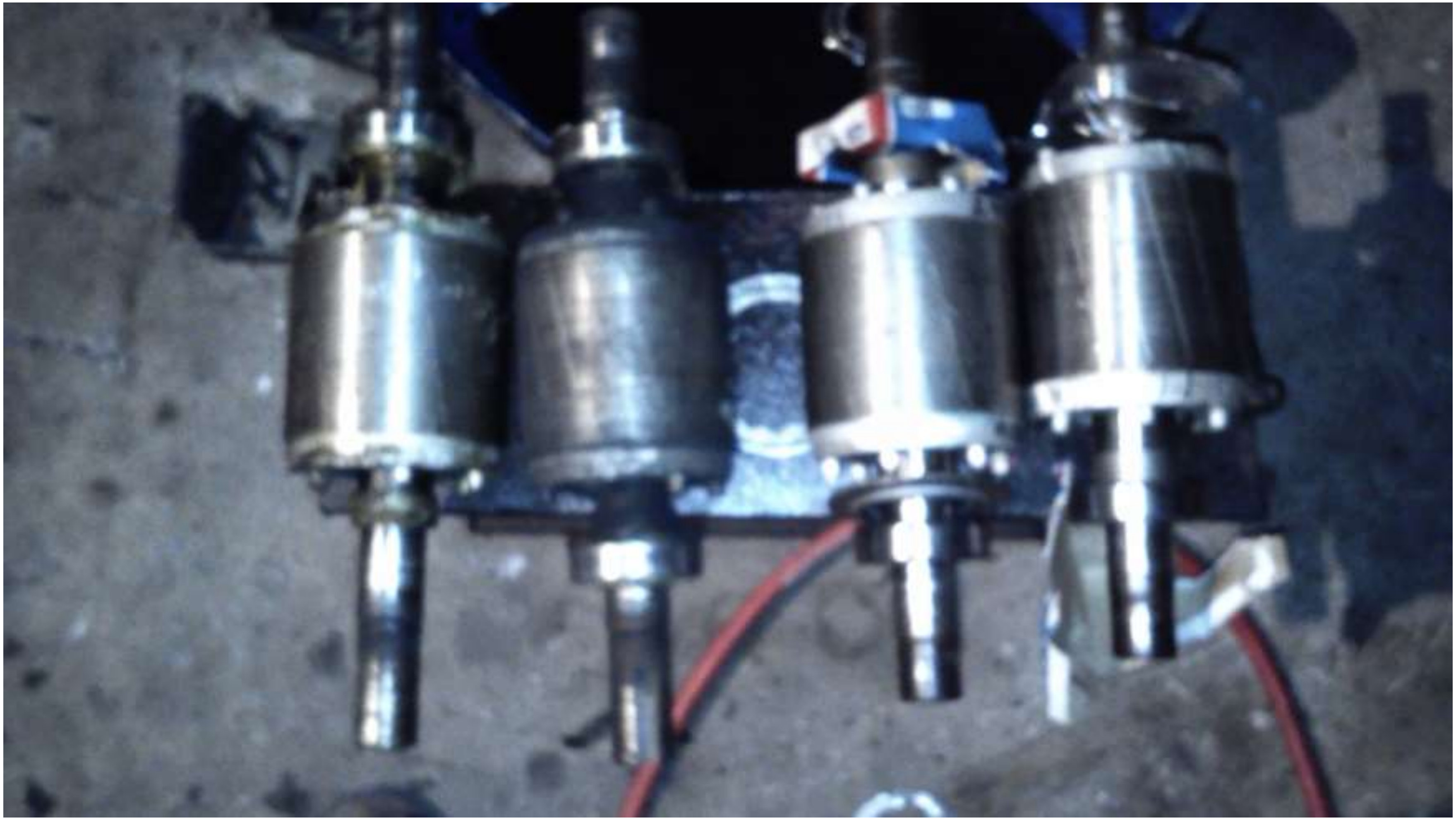
Methods to reduce noise:

1. By reducing magnetic loading
2. By increasing number of armature slots
3. By skewing slots
4. By continuously grading main pole gap
5. By increasing air gap length
6. By providing brace commutating poles against main poles
7. By using 12 pulse thyristor for speed control instead of 6 pulse converter
8. Semi enclosed slots or totally closed slots for compensating windings

Mechanical alignment

- When the rotor is supplied, without shaft assembled is to be fitted on to the shaft before installation.
- While fitting the rotor on to the shaft the difference b/w the rotor & shaft temp are to be taken into account.
- The rotor hub bore & shaft diameters are to be matched properly.
- Place the rotor in position such that the air gap b/w the rotor & rotor stocks is approximately uniform

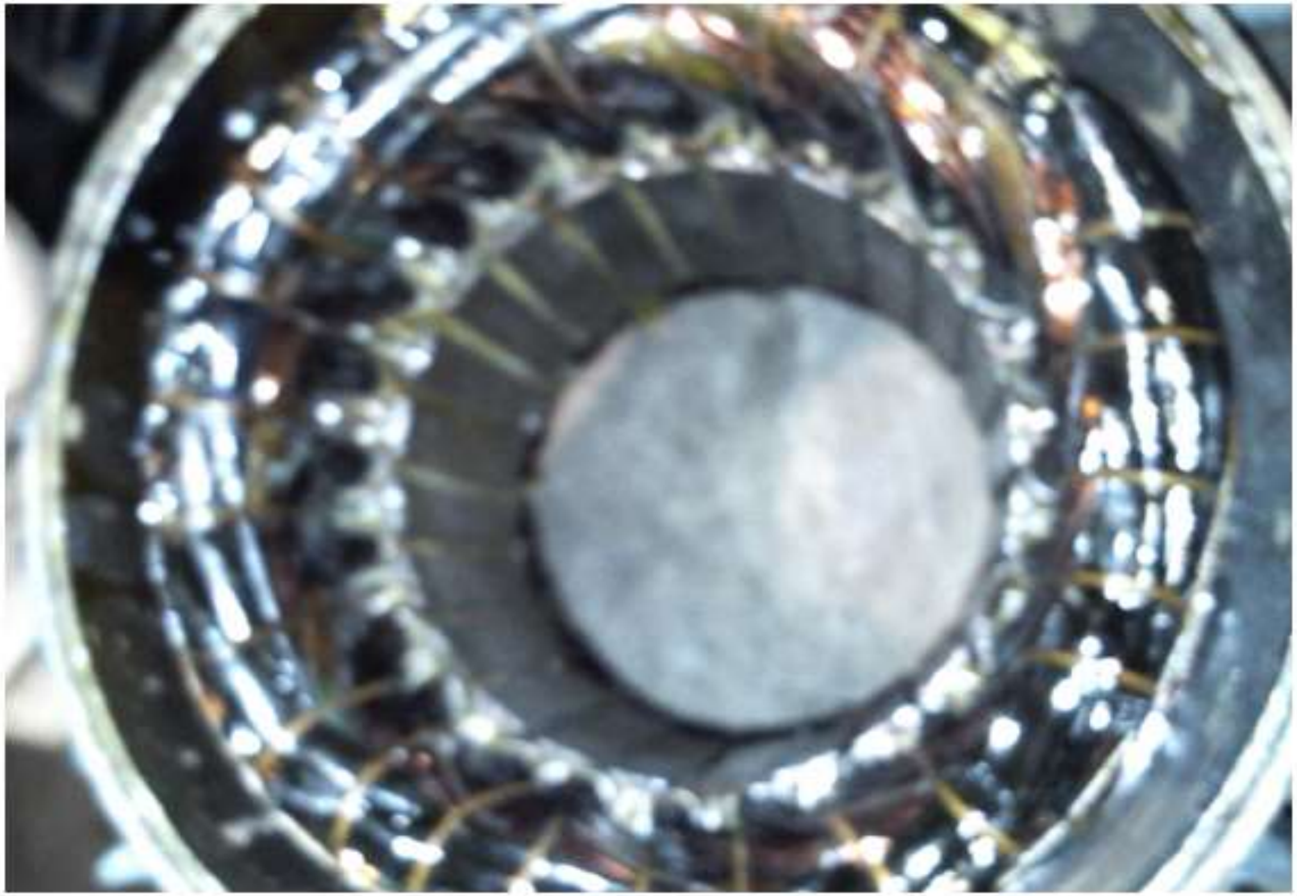
Mechanical alignment



Air gap symmetry

1. The air gap b/w the stator & the rotor are checked & adjusted after the shaft is fully aligned.
2. Set the air gap with the help of wedge type gauges on both sides of the rotor.
3. Permissible values of difference b/w max & min air gap for an induction motor is 10%

Air gap symmetry



Bearings

The selection of bearings depends upon the fallowing factors:

- Speed
- Temperature limit
- Load capacity
- Noise and vibrations
- End thrust
- Corrosion resistance
- Cost
- Space and weight limitation

Bearings

The different methods of lubricating are:

- **Oil bath:** In this rolling element will pass through the oil pool during each revolution.
- **Drop feed:** To avoid agitation & churning drop feed method in high speeds is used
- **Oil mist:** It is used for speeds of the order of 1,00,000 rpm.
- **Oil circulation system:** This is used for medium & large motor bearings for continuous use.

Measurement of temperature

The temperature of various parts of electrical machines can be measured by one of the following means.

1. **Thermometer:**
   - This gives the temperature of the surface at one point only.
   - It is used when it is not practicable to determine by the resistance method and single layer armature winding having less than 5MVA and core length less than 1m

Measurement of temperature

2. **Embedded temperature detector (thermo couple or resistance coil)**:

- This gives the temperature at one internal point.
- The temperature detectors are built into machines above 5MVA and core length more than 1m between layer of armature winding, in the slot portion & at various other points at which highest temperature is likely to develop.

Measurement of temperature

3. **Estimating the mean rise in temperature using the resistance temperature co-efficient.**

Resistance method:

This method is generally used for stator windings. Here temperature is determined by the increase in the resistance of the windings.

Measurement of temperature

The formula is alternative way to determine the temperature.

$$t_2 - t_a = ((R_2 - R_1)/ R_1)(235 + t_1) + t_1 - t_a$$

Where

t_a=temperature (C) of cooling air at the end of the test.

t_2=temperature (C) of the winding at the end of the test.

t_1=temperature (C) of the winding (cold) at the time of initial resistance measurement.

R_2=resistance of the winding at the end of test.

R_1=initial resistance of the winding.

Measurement of temperature

Direct method:

Load test: By loading the machine to the rated conditions of Armature current, Voltage, Power & Frequency.

Measurement of temperature

Indirect Method:

Separately by driving at its rated speed under

- Machine operating unexcited.
- Machine running as generator with armature winding shorted and current in the armature winding equal to the rated value(short circuit test).
- Machine running as generator on open circuit with its voltage equal to the rated voltage

Measurement of temperature

Heat Run Method(ZPF):

- Generator is run at rated speed with inductive load.

Measurement of temperature

- Loading of the machine should be within its specified limits as per duty.
- Over loading leads to temperature rise.
- Standard limits of temperature rise in electrical machines and the class of insulation temperature for different insulating materials are

Measurement of temperature

The class of insulation temperature and materials used

Insulation class	Max temp	Common materials of the Class Limit
Class Y	90	Cotton, silk, paper, wood, cellulose, fiber etc without impregnation.
Class A	105	The materials of class Y, impregnated with natural resins, cellulose, easter, insulating oil etc.
Class E	120	Synthetic resins, enamels, cotton & paper with formaldehyde bonding etc.
Class B	130	Mica, glass fiber, asbestos, etc with suitable bonding substances, built-up mica etc.
Class F	155	The materials of class B with more thermally resistant bonding materials etc.
Class H	180	Glass fiber and asbestos materials and built up mica with appropriate silicon resins etc.
Class C	>180	Mica, ceramics, glass, quartz and asbestos without binders etc.

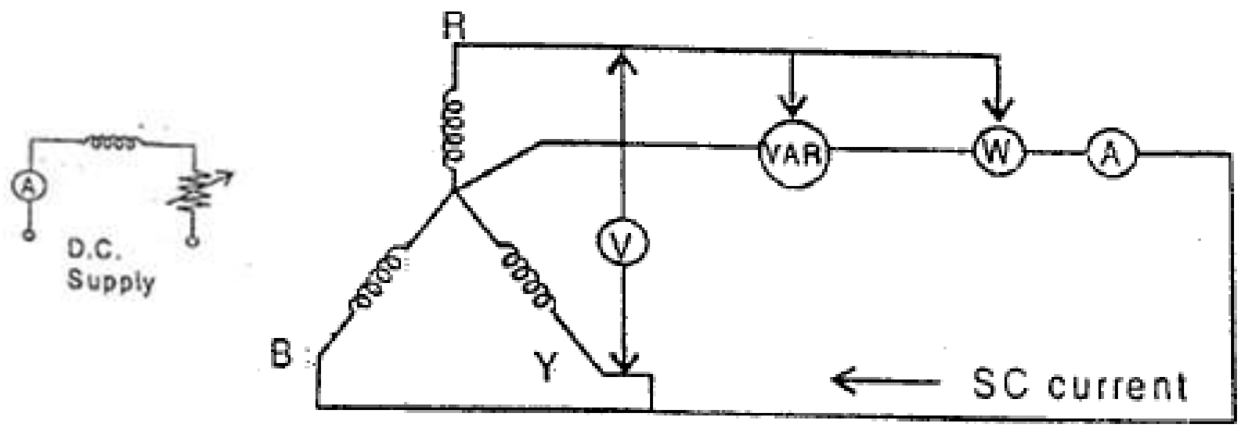
Double Line to Neutral Sustained Short Circuit Test

Purpose: To determine the zero sequence resistance of a synchronous machine.

Zero sequence resistance : The opposition offered by the conductor for the flow of zero sequence current due to the zero sequence voltage present across the conductor.

Double Line to Neutral Sustained Short Circuit Test

- Short circuit is applied to any two of the stator and the neutral of the stator winding.
- To conduct this test armature winding is star connected, two line terminals are short circuited to neutral.
- Machine is driven at rated speed and is then excited.



Double Line to Neutral Sustained Short Circuit Test

- Zero sequence resistance is given by,

$$R_0 = \frac{V_0^2}{P} \times \frac{P^2}{P^2 + Q^2}\ \Omega$$

"V" is the measured voltage

"P" is the active power measured

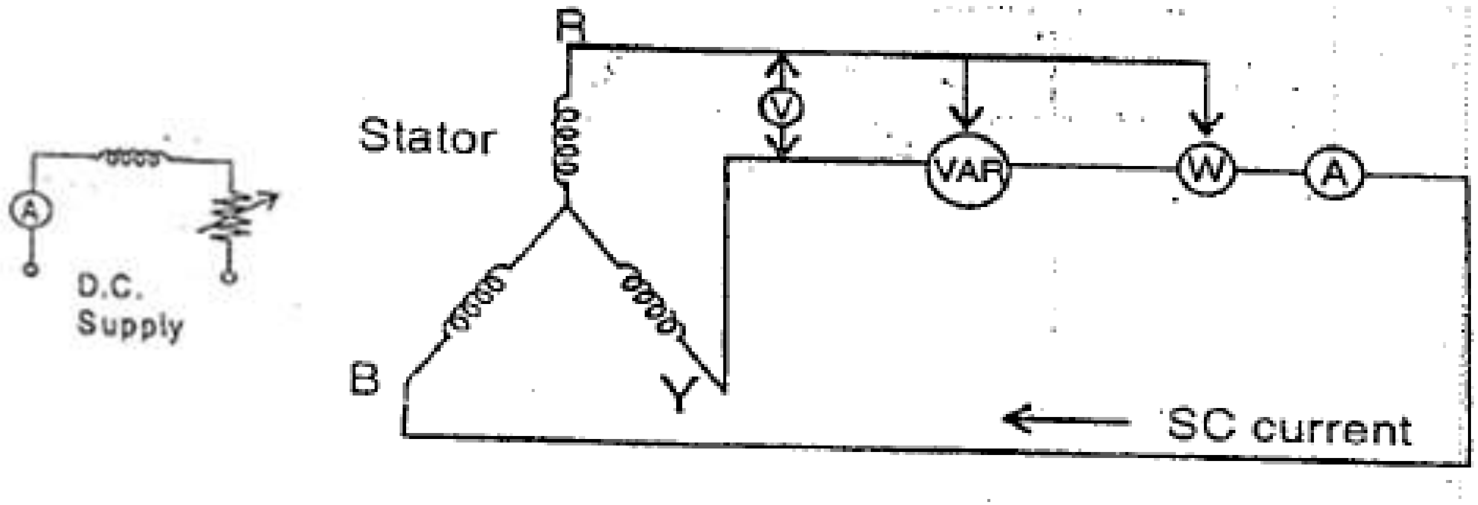
"Q" is the reactive power measured

Value of R_0 calculated when the neutral current equal to 3 times the phase current is taken as the rated value.

Line to Line Sustained Short Circuit Test

This test is to determine

1. Negative sequence(X2)
2. Negative sequence resistance(R2)



Line to Line Sustained Short Circuit Test

- Any two lines are shorted and the machine is driven at rated speed.
- The short circuit current, excitation current and the voltage between the open line terminals are noted.
- Negative sequence resistance is obtained from the test data.

Line to Line Sustained Short Circuit Test

- To avoid serious overheating of solid parts, the duration of the line-to-line sustained short-circuit test at currents above 30 percent.
- In should be limited to the time required for taking the readings of the instruments.
- For non-salient pole machines the armature current is usually limited to 50 percent of the rated value.

Line to Line Sustained Short Circuit Test

$$R_2 = \frac{P}{\sqrt{3} I_2^2} \Omega \left[r_2 = \frac{p}{\sqrt{3} i_2^2} \right]$$ neglecting voltage & current harmonics

$$R_2 = \frac{V^2}{P} \cdot \frac{P^2}{P^2 + Q^2} \cdot \frac{1}{\sqrt{3}} \left[r_2 = \frac{v^2}{p} \cdot \frac{p^2}{p^2 + q^2} \cdot \frac{1}{\sqrt{3}} \right]$$ with voltage current harmonics

Abnormal Conditions & Protection

SL.NO	ABNORMAL CONDITIONS	EFFECT	PROTECTION
1	Thermal overloading Continuous overloading Failure of cooling system	Overheating of stator winding and insulation failure.	Thermocouples or resistance thermometer embedded in stator slots and cooling system. Stators overload protection with over current relays.
2	External fault fed by generator,	Unbalanced loading stresses on windings	Negative phase sequence protection for large machines.
3	Unbalanced load.	And shaft,excessive heating for prolonged short-circuit.	Small generators.

Abnormal Conditions & Protection

4	Stator faults,phase to phase,phase to earth,inter-turn	Winding burn-out, welding of core laminations,shut down.	Biased differential protection,Sensitive earth fault protection and inter-turn fault protection.
5	Rotor earth faults	Fault causes unbalanced magnetic forces	Rotor earth fault protection.
6	Loss of field. Tripping of field circuit breaker.	Generator runs as induction generator deriving excitation currents from bus-bar. Speed increases slightly	'Loss of field' or 'Field failure' protection.

Abnormal Conditions & Protection

7	Motoring of generator. When input to prime mover stops, the generator draws power from bus-bars and runs as synchronous motor in the same direction.	Effect depends upon type of prime mover and the power drawn from the bus during motoring.	Reverse power protection by directional power relays.
8	Over voltage surges.	Insulation failure.	Lightning arrestor connected near generator terminals.
9	Over fluxing of transformers in generating stations.	Heating of core bolts,core bolt insulation.	Over fluxing protection by v/f relay for generator transformer unit.

Protection of Small Stand by Generator

Sl No	Abnormal condition	Protection
1	Over current(due to overloads)	Time lag over current relay set to open circuit breaker.
2	Sustained over voltages(due to system load shedding)	Time lag over voltage relay to trip stand by generator.
3	Under frequency & over frequency	Alarm & tripping arranged by frequency relay.
4	Forward power(over loading)	Control system & generator protection provide scheduled power.
5	Reverse power(failure of the prime-mover of standby generator)	Directional power relay set to trip the circuit breaker quickly.

Generator protection with reference to unit size

Sl No.	Protection	Below 1MW	Above 1MW	Above 10 MW	Above 100 MW
1	Differential				*
2	Restricted earth fault			*	
3	Stator turn to turn fault			*	
4	Time over current	*		*	
5	Temperature				
6	Negative sequence current		*	*	*
7	Loss of load			*	*

Sl No.	Protection	Below 1MW	Above 1MW	Above 10MW	Above 100MW
8	Loss of input		*	*	*
9	Loss of field			*	*
10	Loss of synchronism			*	*
11	Over speed	*	Only for	hydro	gen
12	Over voltage		Only for	hydro	gen
13	Rotor earth fault			*	*
14	Backup over current		*	*	*
15	Bearing temperature			*	*
16	Bearing insulation				*
17	Over fluxing		*	*	*