CMR INSTITUTE OF TECHNOLOGY	USN										

Internal Assesment Test - II

Sub:	Testing &Commissioning Of Electricla Equipments					Code:	10EE756
Date:	16/11/2016	Duration:	90 mins	Max Marks:	50	Sem: 7	Branch:	EEE

Answer any five full questions

	Note: **Sketch figures wherever necessary.**	Marks	OBE	
			CO	RBT
1	State and Explain Various type and routine test on synchronous machine	[10]	CO707.5	L4
2	Explain abnormal conditions that may be on synchronous machine with remedy	[10]	CO707.4	L4
3(a)	What do you mean by excitation? Explain Different types with respect to synchronous machines.	[5]	CO707.1	L1
(b)	Define Short Circuit Ratio (SCR) of a synchronous machine and Explain How it is Obtained.	[5]	CO707.1	L1
4	Explain about drying procedure of synchronous machine and state the polarizing index.	[10]	CO707.3	L3
5	Explain the procedure of low slip test and method of calculation of X_q from the same.	[10]	CO707.2	L2
6	Explain the commissioning test on the Automatic Voltage Regulator (AVR)	[10]	CO707.1	L1
7	State the various types of Enclosures for rotating electrical machine and type of cooling adopted in them.	[10]	CO707.4	L4
8	Explain the Sudden 3 – Phase short circuit test on a 3 – phase synchronous generator & Explain How to Calculate Xd, , Xd' and Xd''.	[10]	CO707.2	L2

Q. 1024. State the requirements of type-tests and routine tests on synchronous machines.

The synchronous machines include the following three types :

1. Synchronous generator. 2. Synchronous motors. 3. Synchronous compensators.

The tests performed include factory tests and field tests. The tests are conducted to demonstrate that the machine gives the required performance.

The following tests may be conducted :

1. Open-circuit test (no load test) 2. Short circuit test.

3. Zero-power-factor characteristic and loss measurement.

4. Temperature-rise (*i*) by full load z.p.f. over-excited run, or (*ii*) by equivalent heat run. The latter comprises a rise measurements on the stator with excitation but no stator current, followed by a test with rated stator current but minimum excitation. The total temperature rise is then obtained by combining the results.

5. Overspeed test *e.g.* 2.5 p.u. for turbo and 1.0 p.u. for hydro-generators, the latter in an enclosure ; as the windings loss varies as the cube of the speed, considerable drive power may be demanded.

6. High voltage tests.

7. Insulation-resistance tests, made before and after (6).

8. Waveforms, interference, gap, length, balance, vibration, bearing currents, magnetic symmetry, etc.

All the above test may not be necessarily on each machine. For small machines the testing is much simpler, and may be confined to (1), (2), (3), (4), (6), (7) apart from general machine construction verification. Excitation and control systems are subject to full testing schedules before assembly with the machine itself.

Q. 1028. State and explain the procedure of various tests on the synchronous machine and their significance.

Test	Description	Remarks
1. **Insulation Resistance** — Stator winding to earthed frame — Rotor winding to earthed shaft — Phase to phase winding insulation — Pedestal insulation — Bearing insulation	— Stator winding insulation resistance measured with motor driven Megger (Mega-ohm meter) of 1000 V or 2500 V D.C. rating — Rotor winding insulation resistance measured with 1000 V D.C. megger. The 15 sec. and 60 second readings are taken. The *polarisation index* is calculated by R_{60}/R_{15}	— During dryingout — Before h.v. tests — During periodic maintenance testing — Prior to commissioning — Reveals health of insulation — Value reduces with increased temperature R_{60} at working temperature should not be less than $I_nR_{60} = \frac{V_{rated} \text{ in volt}}{0.01P + 1000}$ P = kW rating I_nR_{60} = Megaohms
2. **D.C. Resistance** — Armature windings — Field winding — Field Discharge Resistance	D.C. resistance measured for *each winding* and compared with the original value. Difference should be within ± 2% for stator windings and ±5% for parallel circuits. Measured by one of the following three methods : 1. Voltmeter ammeter method. 2. Single bridge method. 3. Double bridge method.	— Resistance increases with increase in temperature Temperature of windings should be measured and noted Resistance of each winding is measured separately. — Three readings should be taken. — Low resistance (below 1 ohm) should be measured by double bridge method.
3. Di-electric test on stator winding (With AC voltage)	— Performed as per standard and the recommendation of the manufacturer. — These tests are necessary to prove the voltage withstand capability of insulations. — Power frequency voltage withstand test is performed by applying specified that voltage for a short duration between each phase and the frame the other phases are grounded.	— The stator winding should withstand the specified test voltage without failure. — The rotor winding should also withstand the specified test voltage without failure. — Test voltages *Stator winding* — $(2U + 1)$ kV rms for 1 minute Rotor winding 10 times rated field voltage but not less than 1500 V A.C. r.m.s. D.C. Test voltage 1.7 times rms rated voltage.
4. Di-electric test with D.C. voltage	— Stator winding tested with rectified (D.C.) voltage — Test voltage 1.7 times rated A.C. voltage and applied for 1 minute	Leakage current also measured.
5. Open circuit characteristic	This is the characteristic between field current and no load terminal voltage. — It is known as saturation characteristic Test conducted at rated speed. This test necessary for determining X_d reactance.	The O.C.C. relates terminal voltage at no load with field current, rated speed. At lower value of field current, the characteristic is linear. At higher field currents the characteristic becomes non-linear due to saturation.

Test	Description	Remarks
6. Short circuit characteristic of a synchronous machine (sustained)	This is a characteristic which relates the armature short circuit current with field current. The field current is gradually increased and the S.C. current is noted for various values.	The O.C.C. and S.C.C. are necessary to determine the synchronous reactance of the synchronous machine.
7. Sudden three phase short circuit test of a synchronous machine (Oscillographic test)	A three phase S.C. is suddenly applied by closing the main breaker. The excitation current armature line current and speed are recorded simultaneously. The oscillogram is obtained by u.v. recorder. The three phase short circuit test is useful for determining the time constant, transient and subtransient reactances. The oscillographic record should be for period more than $Td' + 0.2$s.	These tests are conducted as type tests under close supervision. U.V. recorder is used for obtaining the oscillogram of waveforms. The tests are three phase tests. The d.c. component the three phases is different in three phases. The symmetrical wave form is used for determining the following reactances. (1) Steady state (synchronous) reactance (2) Transient, and (3) Sub-transient reactance. The test is carried out at rated voltage if possible.
8. Slip test*	This test is performed to obtain values of X_d and X_q. Stator terminals are given voltage of the order of 0.2 p.u. Excitation winding left open circuited Rotor driven at a slip less than 0.01 V and I oscillate.	During switching on and off of supply to stator winding the rotor should be connected to field discharge resistor to avoid overvoltages $X_q = \frac{U_{min}}{\sqrt{3}I_{max}}$ ohms $X_d = \frac{U_{max}}{\sqrt{3}I_{min}}$ ohms
9. Voltage recovery test	Conducted immediately after sudden three phase short circuit test. Machine at rated speed. Excitation at 0.7 p.u. S.C. removed by opening main circuit breaker and oscillographic record of voltage recovery obtained.	X_d' and X_d'' can be calculated as follows $X_d' = \frac{U\infty - \Delta U'(0)}{\sqrt{3}I_k}$ $X_d'' = \frac{U\infty - [\Delta U'(0) + \Delta U''(0)]}{\sqrt{3}I_k}$
10. Line-to-line subtained short circuit test	This test is conducted. To determine X_2 and R_2. Sustained short circuit on any two line terminals, third terminal left open.	V, I, VAr, W measured from supply side by indicating instruments.
11. Negative phase sequence test	Test is conducted to determine X_2 Machine rotated at rated speed by prime mover Negative sequence 3Ph voltage applied tostator. Excitation to winding is short circuited.	$X_2 = \sqrt{Z_2^2 - R_2^2}$ where $Z_2 = \frac{U}{\sqrt{3}I}$ ohms $R_2 = \frac{P}{3I^2}$ ohms where P = Input power I = Measured current U = Measured applied voltage

*Note. X = Maximum ratio : Stator voltage/Stator current.
X_q = Minimum ratio : Stator voltage/Stator current.

Q. 1047. Why is the protection of large Synchronous generators very complex and elaborate?

State the various abnormal conditions in synchronous generators and the respective protections.

The Synchronous Generator Protection is complex, elaborate and important because.

— Generator is a large machine and is connected to busbars. It is accompanied by unit-transformers, auxiliary transformer and bus system.

— It is accompanied by excitation system, prime mover, voltage regulator, cooling system etc. Hence it is not a single equipment. The protection of generator should be coordinated with associated equipment.

— It is a costly and important equipment. It should not be shut off as far possible because that would result in power shortage and emergency.

Modern Turbo-generators have the following typical ratings :

60 MW	11.8 kV
200 MW	13.8 kV
500 MW	22 kV

Generator units upto 500 MW have been installed in India.

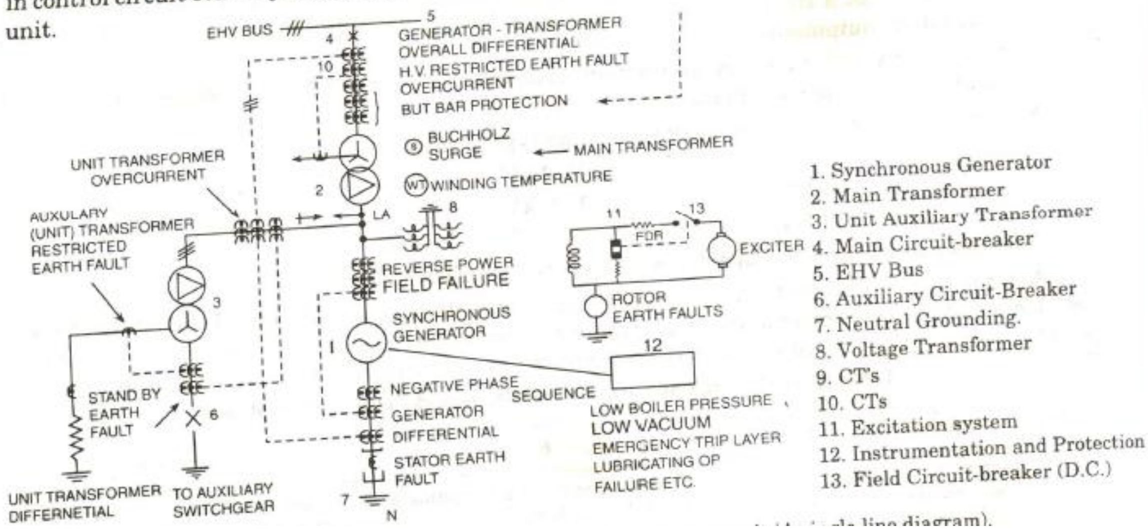
A generator is protected against several faults and abnormal conditions. Table Q. 1047 gives an idea about the present practice of alternator protection. Several other abnormal conditions give an alarm and indication. Static protection schemes are now preferred for generator protection.

Table Q. 1047. Some Abnormal Conditions and Protection Systems

S.N.	*Abnormal condition*	*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. Stator over-load protection with over-current relays.
2. 2.1.	External fault fed by generator. Unbalanced load.	Unbalanced loading stresses on windings and shaft, excessive heating for prolonged short- circuit.	Negative phase sequence protection for large machines. Overload protection for small generators.
3.	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, inter-turn fault protection.
4.	Rotor earth faults	Single fault does not harm second fault causes unbalanced magnetic forces causing damage to shaft, bearings.	Rotor earth-fault protection.
5.	Loss of field. — Tripping of field circuit-breaker. — Field discharged after tripping.	Generator runs as induction generator deriving excitation currents from bus-bar. Speed increases slightly.	'Loss of field' or 'Field failure' protection.

S.N.	Abnormal condition	Effect	Protection
6.	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 direct the reversal of power.
7.	Over-voltage surges	Insulation failure.	Lightning arresters connected near generator terminals.
8.	Over-fluxing of Transformers in Generating stations.	Heating of core, core bolts, core bolt insulation.	Overfluxing protection by volts/hertz relay for generator Transformer unit.

The abnormal operating conditions in boiler/boiler auxiliaries, turbine/turbine auxiliaries ; excitation system ; cooling system, lubrication system, external faults, faults in transformers, faults in control circuit etc. may need (1) and alarm/indication on control panels or (2) Tripping of the whole unit.



...le line diagram).

Abnormal Conditions in a Synchronous ...

1. External faults beyond Generator Protection Zone. During external faults with large short-circuit currents, severe mechanical stress will be imposed on the stator windings. If any mechanical defects already exist in the winding, these may be further aggravated. The temperature rise is however, relatively slow and a dangerous temperature level may be obtained after about 10 second. With asymmetrical faults, severe vibrations and overheating of the rotor may occur.

The external faults such as faults on bus-bars are not covered. Generator protection does not respond separate words respond to external faults.

The *over current and earthfault protection of generator* provides a back-up protection to external faults, while the primary protection is provided by the protective system of respective equipment (*e.g.* bus-bars, transmission lines).

2. Thermal overloading. Continued overloading may increase the winding temperature to such an extent that the insulation will be damaged and its useful life reduced.

Temperature rise can also be caused by failure of cooling system. In large machines thermal elements (thermo-couples or resistance thermometers) are embedded in the stator slots and cooling system.

The electrical overcurrent protection is generally set at higher value for responding the excessive overloads. Hence it cannot sense the continuous overloads of less value. Neither can sense the failure of cooling system.

3. **Unbalanced loading.** Continued unbalanced loads, equal to or more than 10 per cent of generated current cause dangerous heating of the cylindrical rotor in turbo-generators. Salient pole rotors in hydro-generators often include damper windings and are, therefore, much less affected by unbalance loading (negative phase-sequence currents).

Unbalanced loading on generator can be due to

— unsymmetrical faults in the system near the generating station.

— mal-operation of a circuit-breaker near generation, station, the three phases not being cleared.

Negative sequence protection senses unbalance loading of generators and gives alarm/tripping.

4. **Stator Winding Faults.** Stator winding faults involve armature winding and must therefore be cleared quickly by complete shutdown of the generator. Only opening the circuit does not help since the e.m.f. is induced in the stator winding itself. The field is opened and deenergized by "Field Suppression".

The stator faults include :

Phase-to-phase faults, Phase-to-earth faults, Stator inter-turn faults.

Phase to Earth faults. These faults normally occur in the armature slots. The damage at the point of fault is directly related to the selected neutral earthing resistor. With fault currents less than 20 A negligible burning of the iron core will result if the machine is tripped within some seconds. The repair work then amounts to changing the damaged coil without restacking of core laminations.

If however, the earthing resistor is selected to pass a much larger earth-fault current (> 200 A) severe burning of the stator core will take place, necessitating restacking of laminations. Even when a high speed earth-fault differential protection is used, severe damage may be caused owing to the large time constant of the field-circuit and the relatively long time required to completely suppress the field flux. In the case of high earth-fault currents it is therefore normal practice to install a circuit breaker in the neutral of the generator in order to reduce the total fault-clearance time.

Circulating current biased differential protection provides the earth fault protection. However the sensitivity of such a protection for earth faults depends upon the resistance in neutral to earth connection and the position of earth fault in the winding.

A separate and *sensitive earth fault protection* is generally necessary for generators with resistance earthing.

Phase to phase faults

Short circuits between the stator windings very rarely occur because the insulation between coils of different phases is at least twice as large as the insulation between one coil and the iron core. However a phase to earth fault may cause a phase-to-phase fault within the slots. If a phase-to-phase fault should occur, this is most likely to be located at the end connections of the armature windings, *i.e.* in the overhanging parts outside the slots. A fault of this nature causes severe arcing with high temperatures, melting of copper and risk of fire if the insulation is not made of fire resistant, non-flammable material. Since the short-circuit currents in this case do not pass *via* the stator core, the laminations will not be particularly damaged. The repair work may therefore be limited to replacing the affected coils and mechanical parts of the end structure.

Circulating current biased differential protection gives adequate and fast protection against phase-to-phase faults in the generator zone.

Stator Inter-turn faults. Short circuits between the turns of one coil may occur if the stator winding is made up of multiturn coils. Such faults may develop owing to incoming current stages with a steep wave-front which may cause a high voltage (Ldi/dt) across the turns at the entrance of the stator winding.

If, however, the stator winding is made up of single-turn coils, with only one coil per slot, it is, of course, impossible to have an inter-turn fault. If there are two coils per slot, the insulation between the coils is generally of such dimensions that an inter-turn fault is not likely to occur.

For large machines (> 50 MVA), it is the normal practice in some countries to use single-turn coils, whereas in the U.S.A. and Canada multi-turn coils are used. In the latter countries, therefore, the inter-turn, or split-phase, protection has become very popular.

Differential protection and overcurrent protection does not sense inter-turn faults. *Stator inter-turn fault protection detects the inter-turn faults.*

5. **Field Winding Faults.** Rotor faults include rotor inter-turn fault and conductor-to-earth faults. These are caused by mechanical and temperature stresses.

The field system is normally not connected to the earth so that a single earth fault does not give rise to any faults currents. A second earth fault will short circuit part of the winding and may thereby produce an unsymmetrical field system, giving unbalanced force on the rotor. Such a force will cause, excess pressure on bearing and shaft distortion, if not cleared quickly.

The unbalanced loading on generator gives rise to negative sequence currents which cause negative sequence component of magnetic field. The negative sequence field rotates in opposite direction of the main field and induce e.m.f's in rotor winding. Thus the unbalanced loading causes rotor heating.

Reduced excitation may occur due to short circuit or an open circuit in field or exciter circuits or a fault in automatic voltage regulator. If the field circuit breaker opens by mistake, the fully loaded generator falls out of step within 1 second, and continues to run as an induction generator drawing reactive power from the bus. To avoid this, a tripping scheme is so arranged that opening of field circuit breaker causes the tripping of generator unit breaker.

'Rotor earth fault protection' is provided for large generators.

Rotor temperature indicators are used with large sets for detecting rotor overheating due to unbalanced loading of generator.

6. **Overvoltages surges due to lightning and switching. Surge-voltages** are caused by direct lightning strokes to the aerial lines in the H.V. system. Induced and capacitively transferred voltages surges can reach the generator *via* the unit transformer. The amplitude and the duration of the surge on the generator side depends on the type of surge arresters used on the H.V. side and also on the actual configuration of the H.V. busbar and transformers.

Switching Surges. Switching operations may cause relatively high transient overvoltage if restriking occurs across the contacts of the circuit-breakers. These transients are similar to those obtained during intermittent earth faults (arcing grounds) and may be limited by using modern circuit-breakers, and Z_nO arresters.

Surge arresters installed between the generator circuit-breaker and the generator may also assist in reducing some of the highest switching surges.

Specially developed indoor type surge arresters are connected near generator terminals. These comprise three star connected units plus another unit between star point and earth and thus provide overvoltage protection for all phases and between phases. Capacitors rated about 0.1 μF to earth are fitted to absorb voltages surge.

Brushless excitation systems have no brushes/slip rings/commutators. The AC Exciter-rotor and, Rotating Diode Rectifier Bridge are mounted on the generator shaft without the need of brushes. Alternator field winding is connected to the two terminal plates of Rotating Diode Rectifier Bridge. The rotating rectifier bridge receives 3 phase input from AC Exciter Rotor and gives DC output to alternator field. The AC Exciter Stator has DC winding which receives DC power from Permanent Magnet Generator (PMG) through AVR Control.

The *flow of excitation power* is as follows :

Main field of Generator ⟵ Diode Bridge on Rotor Shaft of Gen. ⟵ Three phase rotor winding of AC Exciter on Gen shaft

↑

Field current for stator of AC exciter from PMG through AVR (PMG has rotating Poles and Stationary DC winding)

AVR the brushless excitation system is preferred for alternators where the control requirements are not very stringent or where sparking at brushes or commutators is not permissible due to chemically explosive environment (*e.g.* mines).

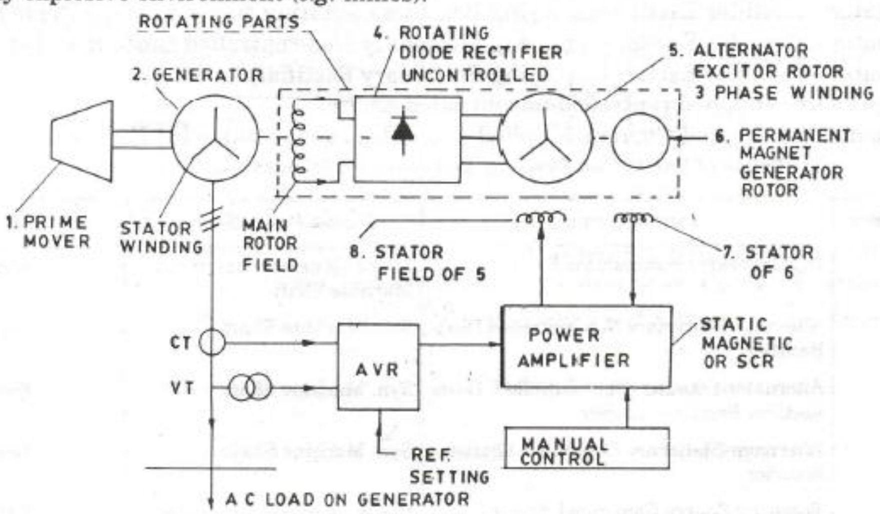


Fig. Q. 1080. Simplified schematic of brushless excitation system with rotating Noncontrolled diode rectifier.

Note : Design configurations may differ, the above figure illustrates a typical example.

Q. 1080. Explain the principle of operation and schematic of a Brushless Excitation System for Synchronous generators.

Brushless Excitation System

Fig. Q. 1080 gives a schematic of a Brushless Excitation System with Rotating Noncontrolled Diode Rectifier Excitation System.

It consists of an AC Exciter and a rotating diode bridge mounted on generator shaft. A small permanant magnet generator (PMG) provides excitation current to the stator AC exciter field. The excitation current supplied to stator of AC Exciter field is controlled by stationary AVR by manual control or Automatic control.

Q. 1033. Define short-circuit ratio SCR of a synchronous machine. What is its significance ? Explain the procedure of determining the SCR of a synchronous machine.

The short circuit ratio of a synchronous machine is defined as the ratio of the field current I_{fo} required for obtaining rated open circuit voltage to the field current I_{fsc} required for obtaining rated sustained short-circuit current under rated speed condition

$$SCR = \frac{I_{f-oc}}{I_{f-sc}} = K_s$$

$$= \frac{\text{Field current for rated o.c. voltage}}{\text{Field current for rated s.c. current}} \qquad (\text{at } N_s)$$

Short-circuit ratio is obtained from the graphs of o.c.c. and plotted with field current on common X-axis.

Short-circuit ratio K_s

It is the ratio of the field current for rated armature voltage on open circuit to the field current for rated armature current on sustained symmetrical short-circuit, both with the machine running at rated speed.

The short circuit ratio is determined from (1) the no-load saturation and (2) sustained three-phase short-circuit characteristics.

The three phase sustained short-circuit characteristic, is the relationship between the armature short-circuited winding current and the excitation current, drawn from the data of the three-phase sustained short-circuit test (Q. 1031).

The o.c.c. is drawn from no load open circuit test (Q. 1030) (saturation test). Short-circuit ratio is determined from the O.C.C. and S.C.C. plotted on the same graph. (Fig. Q. 1033).

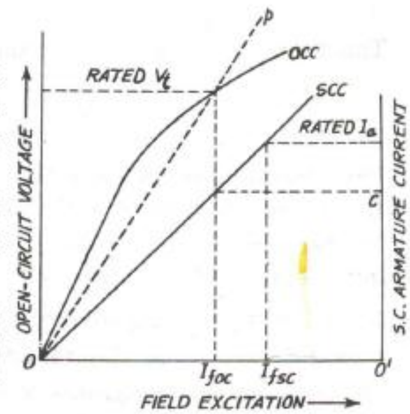


Fig. Q. 1033. S.C. Ratio from occ and scc.

...... L *max J

Q. 1041. Explain the purpose of drying-out of synchronous Machines and the rocedure of drying-out. What should be the values of Insulation Resistance and 'olarisation Index of Synchronous machines ?

The insulation of synchronous machine windings and current-carrying parts may contain excess ıoisture as a result of long storage. The moisture must be removed by drying till the insulation ɛsistance and polarization index reach the specified values before the machine is connected to ıltage supply.

In the course of drying, moisture is evaporated from the windings due to the thermal diffusion ıich causes a movement of moisture in the direction of the thermal flow, *i.e.*, from the hot spots towards cold spots. The factor causing this flow of moisture is a moisture gradient existing between different layers of insulation. As a result, moisture is released from moist parts of insulation to less moistened ones. Moisture gradient depends on temperature gradient within wet insulation.

The rate of insulation drying depends on the temperature gradient and is higher at a higher temperature gradient.

The desired temperature gradient can be obtained by heating the windings (for instance, with electric current passed through the winding) so that a temperature difference in the internal and external layers of insulation is obtained. The temperature gradient can be also obtained by periodically cooling down the external layers of insulation. To this end, the machine may be periodically blown down with cold dry air, which is followed by heating the windings. The method is most suitable for drying out wet windings.

The insulation resistance is measured by means of d.c. megaohm meter (Megger). For measuring the insulation resistance of windings rated at up to 1000 V a Megger of 500-V while 1000-V meggers should be used for machine-winding rated over 1000 V.

Use of Megger

Excitation Winding	:	500 V Megger
Control Winding	:	500 V Megger
Stator Winding	:	1000 V Megger

Values of Insulation Resistance

The phase to phase and phase-to-earth insulation resistance I_nR_{60}* (megohms) *at the working temperature* of the machine should not be lower than the value found from the equation

$$I_nR_{60} = \frac{V_{rated}}{1000 + 0.01\,P} \qquad ...(1)$$

where V_{rated} = rated voltage across the machine winding (in volts)

P = rated output of the machine (in kVA for ac machines and in kW for dc machines)

As a rule, however, the insulation resistance is not to be lower than 0.5 megohm.

The working temperature is assumed to be 70°C. If measurements were taken at a temperature other than 70°C, but not lower than 20°C, the data obtained can be referred to 70°C with the aid of Table Q. 1041.

The insulation resistance is approximately half for every 20°C temperature rise.

After drying the insulation, insulation resistance at a temperature of 70°C should not be lower than the following values.

Stators of ac machines :

at a working voltage above 1000 V	1 MΩ per every kilowatt
at a working voltage up to 1000 V	0.6 MΩ per every kilowatt
	1 MΩ per every kilowatt
Rotors of induction motors and synchronous machines (including the entire excitation circuit)	1 MΩ per every kilowatt

* I_nR_{60} : Insulation resistance measured 60 seconds after the megger is switched on, and the d.c. test voltage applied continuously. The megger reading goes on increasing as the absorption current of insulation goes on reducing $R_{60} > R_{15}$.

Table Q. 1041. Insulation Resistance of Synchronous Machines at Different Winding Temperatures

Winding temperature, °C	Insulation Resistance, Mega Ohms		
	3.3 kV	6.6 kV	11 kV
10	40	80	135
20	27	56	90
30	20	40	60
40	12	24	42
50	10	16	30
60	5	10	20
70*	3	6	10

Values of Polarisation Index

$$PI^{*} = \frac{I_nR_{60}}{I_nR_{15}} \quad \text{or} \quad PI^{\dagger} = \frac{I_nR_{10-m}}{I_n R_{1-m}} \qquad ...(2)$$

where $P.I.$ = Polarisation Index (see foot notes)

I_nR_{60} = 60 sec. Megger Reading

I_nR_{15} = 15 sec. Megger Reading.

I_nR_{10-m} = 10 minutes reading

I_nR_{1-m} = 1 minute reading

The polarisation index given by Eqn. (2) should be at least 1.5.

The temperature is controlled by controlling the short-circuit stator current. This is achieved by varying field current.

Periodic readings of following quantities are taken.

— Insulation Resistance I_nR_{60} and I_nR_{15}.

— Temperatures.

— Time in hours from starting.

Initially the insulation Resistance values drop. After several hours, a steady value is reached. The steady value of Insulation Resistance continues for several hours. Finally the value of I_nR starts rising. *When desired value of I_nR is reached during the rising mode and when the PI is above 1.2* the drying-out process is stopped.

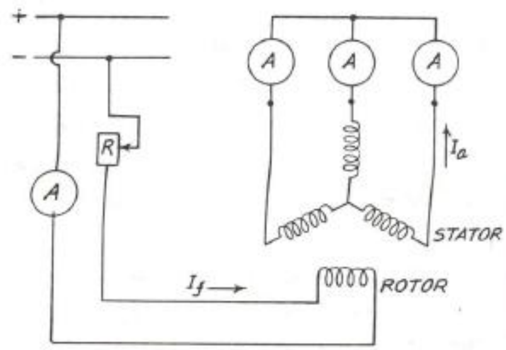


Fig. Q. 1041. Circuit for drying out of synchronous machines running as generators.

Q. 1040. Explain the procedure of low slip test and method of calculation of X_q from the same.

Low slip test

During the low slip test, subnormal symmetrical three-phase voltage ($0.01 - 0.2\ U_n$) is appl to the armature terminals of the machine under test. The voltage should be such that the mach does not pull in. The excitation winding should be open-circuited the rotor should be driven by a prime mover at a slip less than 0.01 p.u. and for solid rotor machines much less then 0.01 p.u., There by the currents induced in the damper circuits during synchronous operation will have negligible influence on the measurements. During switching on and off of the supply, the excitation winding should be closed (short-circuited or through a discharge resistance) to avoid possible damage. Armature current and voltage and the slip-ring voltage and slip are measured by indicating instruments or recorded by oscillograph. If the residual voltage measured before the test is larger than 0.3 of the supply test voltage, the rotor should be demagnetized. Demagnetizing might be done, for example, by connecting the field winding to a low-frequency source with current about 0.5 of the no-load rated voltage excitation current of the tested machine and gradually decreasing its amplitude and frequency (the latter if possible).

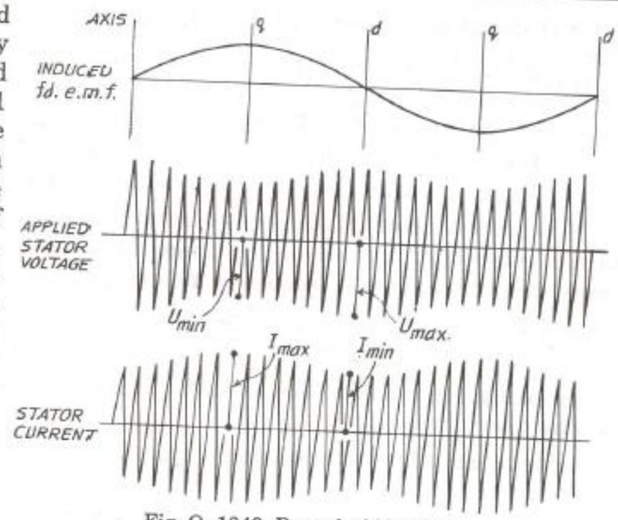


Fig. Q. 1040. Record of Slip-Test.
(The oscillograms of stator current and stator voltage indicate periodic variation due to the slip)

Determination of X_q from low slip test

To determine X_q from the low slip test, armature current and voltage are measured to maximum excitation winding voltage (U_{fo}), and X_q is calculated using the following formula :

$$X_q = \frac{U_{\min}}{\sqrt{3}\, I_{\max}}\,\Omega\,;\left[x_q = \frac{u_{\min}}{i_{\max}}\right]$$

Note. If I_{max} does not coincide with U_{min}, use in calculations I_{max} as a base and its corresponding voltage. Small letters are for p.u. values.

If during the test, the residual voltage of the machine (U_{res}) is in the limits of 0.1 – 0.3 of the supply test voltage, the value of the current is determined using the formula :

$$I_{max} = \sqrt{I_{av}^2 - \left(\frac{U_{res}}{\sqrt{3}\, X_d}\right)^2}\,\Omega\,;\;\left[i_{max} = \sqrt{i_{av}^2 - \left(\frac{u_{res}}{x_d}\right)^2}\right]$$

where I_{av} is the half sum of the two consecutive maxima of the current envelope curve (Fig. Q. 1042).

A check of the measured value may be made by calculating X_d from the same test, using the results of the voltage and current measurements at the time when the voltage of the open-circuit excitation winding is equal to zero comparing it with its real value. Then,

$$X_d = \frac{U_{max}}{\sqrt{3}\, I_{min}}\,\Omega\,;\;\left[X_q = \frac{u_{min}}{i_{max}}\right]$$

Q. 1041. Expl...

the turbine without causing instability. A typical trip level is 1%/s .

Q. 987. Explain the commissioning tests on the automatic voltage regulator (AVR)

The objectives of commissioning tests on AVR and Excitation systems are :

— To verify the performance of AVR and excitation system with reference to the Shop Tests and to confirm that the site test records tally with shop test rcords.

— To complete pre-commissioning checks to confirm that erection is satisfactory.

— To check polarity of AVR Current Transformers.

— To test AVR Control Systems.

— To obtain static characteristics of equipment and preset various control functions and the limitter-settings of AVR.

— To check various protective devices and their settings in AVR and excitation systems.

To check Field Suppression Circuit Breaker functioning.

The commissioning of the AVR and all its associated equipment is carried out in three distinct stages :

1. **Static Pre commissioning Tests.**

Some of the pre-commissioning tests are carried out by taking temporary supplies and dummy electrical loads. Some tests may be carried out before complete erection of the Unit. During Preliminary Tests of AVR, the cable connections between the main plant and AVR must be temporarily removed and insulated as the safety precaution. Instruction Book supplied by Manufacturer of generator and AVR must be followed.

Temporary Supplies and Special Equipment for Pre-commissioning are :

(*a*) Motor Generator Set (MG Set), frequency converter to provide : 220 V, 120 A.

(*b*) 3 Ph. 200 VA, 415 V/110 V phase shifting transformer.

(*c*) Zero to 300 V DC supply.

(*d*) Primary injection set for 200 A. Current Transformer (CT)

(*e*) Ultra Violet Recorder UV Recorder with 24 channels

(*f*) Insulation Tester (Megger)

(*g*) Continuity Tester

(*h*) Rectifier Set for DC voltage supply

(*i*) Low voltage DC Injection Source.

(*j*) Oscilloscopes, Digital Voltmeters, Multi-meters, Diode testers 400 Hz supply is used for simulating output of 400 Hz pilot exciter (in some Excitation Systems)

Preliminary Checks. These are performed to ensure that :

— Panel modules are connected correctly

— Components such as CTs, Relays, Rectifiers, Limiting Modules, Thyristors, Resistive circuits, potentiometers are connected correctly and function satisfactorily.

— Insulation resistance is satisfactory.

— Power supplies are within specified range.

— Fuses are of correct rating and healthy.

— Continuity is satisfactory

— Polarities of CTs and VTs are correct.

— Over-fluxing Relay Setting is correct.

[*Over-fluxing* of Power transformers causes damage to laminations in magnetic circuit due to saturation and higher losses when V/f exceeds 1.1 pu for longer time. Over-fluxing failure of Unit Auxiliary Transformer or main transformer can occur when full voltage is reached before attaining full speed. (Speed $< N_s$, $V = V_{-rated}$) Over-fluxing relay inhibits raising of voltage before attaining synchronous speed.]

Finally, the jumpers, shorts used during preliminary testing must be carefully removed and required connections must be restored.

— Preliminary Tests are carried out in Manual Mode.

— *Standard Check List must be filled and signed O.K. by Commissioning Engineers.*

2. **Commissioning tests with the link between the exciter and generator field removed, with the turbine at 3000 rpm.** The static testing used a motor generator set to provide the 400 Hz supply, but with the turbine at 3000 rpm the 400 Hz supply can be derived from its normal sources, the permanent magnet generator. With the link between the exciter and generator field removed, the AVR equipment can be energized from its permanent supply point without exciting the generator field.

3. **AVR testing including over-fluxing tests.** This testing is carried out with the link between the exciter and the generator in the service position, with the turbine at 3000 rpm on open circuit.

The following protective devices are provided for each channel.

— VT fuse failure

— Converter cooling failure

— Over excitation after a present time delay.

— Thyristor supply fuse failure

— DC voltage supply failure

General design features of AVR

The AVR should be capable of maintaining the generator terminal voltage to within deviation of 5% of the set voltage over the whole of the generator operating range. An *MVAr Limit* should be included to prevent the generator from operating beyond stability limits of 4% at full load to 110% at no load.

A manual follow up drive maintains the manual control at the setting taken up by the automatic control. This is inhibited when the generator operates beyond these limits. The 10% limit is chosen for this setting in preference to the manual stability limit of 20% at full load to 10% at no load, to avoid an excessive rise in the generator terminal voltage following an AVR trip. The operator is expected to increase the generator excitation until the machine is operating within the manual stability limit by tap changing on the generator transformer.

The MVAr limit settings are made during static pre-commissioning tests and checked with the generator on load.

Static Commissioning Tests

The static testing of the AVR and the excitation control equipment will have confirmed the following :

— The static characteristics of the equipment

— The correct preset of various control functions including the operating points of the MVAr limits.

— The correct operation of all relays and contractor

— Correct operation of all remote controls indication and alarm.

— Correct operation of all AVR and excitation system protective devices, including suppression of the generator excitation.

— An acceptance value of insulation resistance of the equipment.

The test to be carried out at 3000 rpm (for rated N_s = 3000 rpm) are as follows :

— Proving the output of the 400 Hz permanent magnet pilot exciter and its phase rotations.

— Measuring the 400 Hz permanent magnet pilot exciter output voltage and selecting the converter transformer tap position for both the A and B channels.

Independent channel checks

The following checks are carried out on each of the two channels independently.

— Check the supply available from the supply module of the thyristor converter.

— Check that the DC output from the thyristor bridge is smoothly controlled.

— Confirm that the voltage output collapses on tripping the thyristor bridge.

— Confirm that the firing angle of the converter bridge changes from 90° to 30° by adjusting the gain of the converter to produce a voltage change in the order of 3 V

The MCR excitation range should be set such that 95% of the computers converter output voltage is equivalent to that necessary for MCR excitation.r

The minimum voltage output is also set subject to the following :

— The minimum generator voltage in manual mode is not critical but must be less that the minimum voltage obtained in auto the converter gain control being set to obtain the correct voltages.

— Confirm that when set to MCR excitation in the auto control position the converter is driven into saturation after a predetermined time interval and that a trip to manual results. The permanent magnet generator and converter output voltage should be measured during this test.

— Having completed the checks on the selected channel, they should be repeated for the other channel, isolating the channel which has already been tested.

Dual channel checks

With both A and B converter isolator closed, adjust the voltage computer control to ensure that other AVR channel are sharing the load equally and that the converter output voltage is equivalent to that required for MCR operation. The AVR is then switched from manual to auto which should cause the converter output to rise rapidly to the saturation level and remain at his condition until the second channel trips to "manual" at which point it should not trip out completely, only tripping "manual".

The output voltage of the PMG (permanent magnet generator) and converter is recorded during this test.

Q. 816. State the various types of enclosures for Rotating Electrical Machines (Generators and Motors) and the types of cooling adopted in them.

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

1. *Open-pedestal*, in which the stator and rotor ends are open to the outside ambient air, the rotor being supported on pedestal bearings mounted on the bedplate.

2. *Open-end bracket*, in which the bearings form 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 type is common for small and medium size motors and generators.

3. *Protected* or end-cover types with guarded openings : the protection may be by *screen* or by *fine-mesh covers*.

4. *Drip-, Splash- or Hose-proof*, 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.

5. *Pipe* or *Duct-cooled*, with end-covers closed except for flanged openings for connection to cooling pipes.

6. *Totally-enclosed*, in which the enclosed air has no contact with the ambient air : the machine is almost airtight. Total enclosure may be associated with an internal rotor fan, an external fan, water cooling, or closed-air-circuit cooling, in which the air is circulated to a cooler and returned to the machine.

7. *Weatherproof, or watertight.*

8. *Flame-proof,* or *Explosion-proof* for use in hazardous locations such as mines, chemical factories, stores etc.

It may be noted that the ratings of machines are dependent on their respective cooling systems. For complex cooling systems, the machines may have to be derated.

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* The same designs exist in three cases : Inlet and outlet.

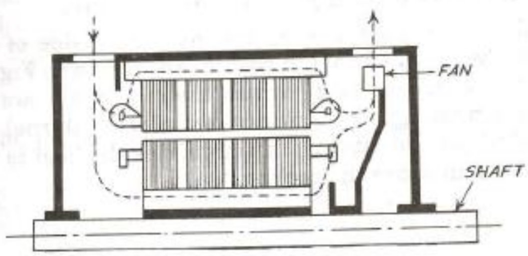


Fig. Q. 817(*a*). Combined axial and radial ventilation.

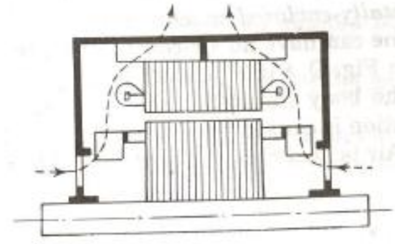


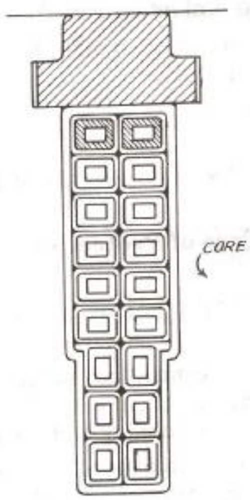
Fig. Q. 817(*b*). Radial ventilation.

Q. 817. Explain the path of cooling air flow inside the rotating machines.

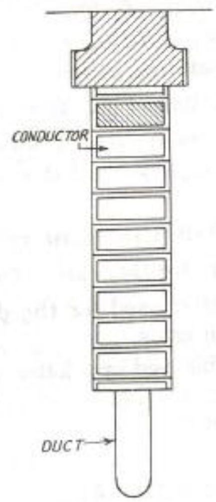
The choice path of the cooling air depends on the size and the type machine. A larger core requires more subdivisions and more complex ducting for gas flow.

1. *Radial flow* is preferred, because the rotor produces natural centrifugal movement of the air, which is modified by fans as shown in Fig. Q. 817(*a*). The end shields air shaped to guide air over the overhang and the back of the core, and baffles are fitted to improve the flow. For larger machines, subdivision of the core is necessary and the air paths through the radial ducts are in parallel with those across the overhang convectors.

2. *Axial flow* is suitable for high speed machines of medium output. The practically solid rotor construction and restricted spider, make it difficult to provide adequate air-paths to radial ventilating ducts. The increase in length of machine makes the axial flow more difficult. Fig. Q. 817(*b*) illustrates axial flow for a small machine with plain cores. To increase the cooling surface, holes may be punched in the core plates to form through-ducts where substantial heat-dissipation occurs. This improves the cooling, but requires a larger core diameter to obtain the higher core depth [Fig. 817(*c*)] conductors may be hollow with passage of cooling medium (hydrogen) through them.



Hollow-Conductors
Fig. Q. 817(c)



Cooling ducts
Fig. Q. 817(*d*)

3. *Combined radial and axial cooling* is employed for large machines. Fig. Q. 817 shows the arrangement of an induction motor for mixed ventilation. The air is drawn in at one end, and encouraged to pass through the ducts by baffling the fan end of the rotor spider. The shaft-mounted fan ejects the air.

4. *Multiple inlet-cooling.* With greater lengths of core, there is a tendency to starve the central radial ducts of air. With the multiple-inlet system it is possible to build machines with long cores and obtain effective centre cooling. The stator frame is divided into separate air circuits fed in parallel.

Q. 1036. (a) Explain the sudden three phase short-circuit test on a 3 phase generator.
(b) Explain how to calculate X_d' X_d'' and X_d or X_s from the sudden 3 ph. s.c. test.

When the alternator is short-circuited, the currents in all the three phases rise rapidly to a high value (10 to 8 times full load current), during the first quarter cycle. The flux crossing the airgap is large during a first couple of cycles. The reactance during these first two or three (there is no definite number, it depends on the machine) cycles is least and the short circuit current is high. This reactance is called *sub-transient reactance* and is denoted by X''. The first few cycles come under *subtransient state.*

After a first few cycles, the decrement in the r.m.s. value of short circuit current is less rapid than the decrement during the first few cycles. This state is called the *Transient State* the reactance in this state is called transient reactance X. The circuit-breaker contacts separate in the transient state.

Finally the transient dies out and the current reaches a steady sinusoidal state called the *Steady State*. The reactance in this state is called steady state reactance X_d.

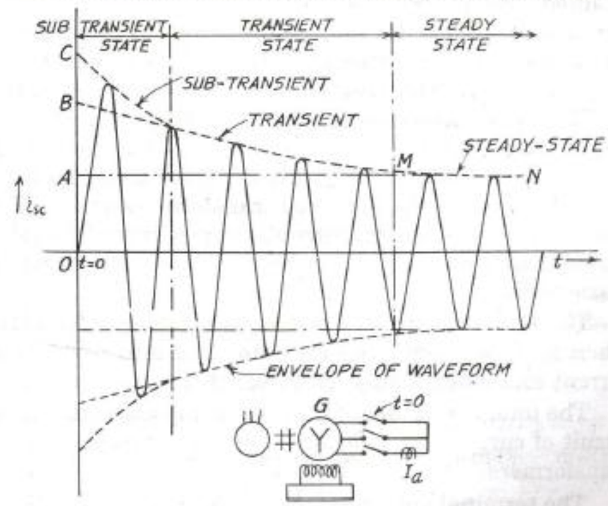


Fig. Q. 1036. Oscillogram of current in the phase having zero d.c. component in three phase sudden s.c. test.

Since the short circuit current of the alternator lags behind the voltage by 90°. The reactances involved are *direct axis reactances*.

Obtain a waveform of S.C. current with zero d.c. components in one of the three phases by trial tests. Draw the envelope curves.

Referring to Fig. Q. 1036 draw an envelope enclosing the Symmetrical waveform.

Extend the portions of the envelopes as shown in the figure. *NM* is extended to meet the zero time ordinate at point *A*. *ML* is extended to meet the ordinate at *B* and *LC* meets the ordinate of zero time at *C*. Measure *OC*, *OB* and *OA*.

NM is a portion of envelope in steady state, *LM* is a portion of envelope in transient state and *LC* is the portion of the envelope in sub-transient state.

The currents and reactances are given by the following expressions :

$$I = \frac{OA}{\sqrt{2}} = \frac{E_a}{X_d} \; ; X_d = \frac{E_a}{I} \qquad ...(1)$$

$$I' = \frac{OB}{\sqrt{2}} = \frac{E_a}{X_d'} \; ; X_d' = \frac{E_a}{I'} \qquad ...(2)$$

$$I'' = \frac{OC}{\sqrt{2}} = \frac{E_a}{X_d''} \; ; X_d'' = \frac{E_a}{I''} \qquad ...(3)$$

where, *OA*, *OB*, *OC* are intercepts of *X*-axis as shown. The emf induced by the generator

E_a = Positive sequence emf. per phase, rms. value.

I = Steady state s.c. current, rms value

I' = Transient s.c. current, rms. value

I'' = Sub-transient s.c. current, rms. value

X_d = Direct axis (synchronous) reactance

X_d' = Transient reactance (Direct axis)

X_d'' = Sub-transient reactance (Direct axis)

Procedure of the Sudden three-phase short-circuit test

The sudden three-phase short-circuit test for the determination of synchronous machine quantities is conducted at rated speed. The test is made by applying a short-circuit to the armature winding when operating at the desired voltage on no-load. Excitation of the machine is, as a rule, obtained from its own exciter which must be separately excited. If its own exciter cannot be used, then a separate exciter may be used, but its rated current value must be at least twice the no load field current of the tested machine and its armature resistance not greater than that of the main machine exciter. This exciter should be separately excited.

The three phase are to be short-circuited simultaneously. The circuit breaker poles of 3 phases should close within 15 electrical degrees of each other. This value can be exceeded on test when the armature d.c. component is not of importance. To measure short-circuit current, use is made of non-inductive shunts, air-cored transformers or suitable current transformers. The latter should be used in dealing with a.c. current components only, and should be chosen so that the initial value of the subtransient component of the short-circuit current is on the straight portion of the transformer characteristic.

The air-cored transformer is connected to the oscillograph through an integrating amplifier. When it is necessary to determine the maximum aperiodic and periodic values of short-circuit current components only, an integrating oscillographic galvanometer may be used.

The total resistance of the measuring instruments and their leads connected into the secondary circuit of current transformers should not exceed the rated values accepted for the given type of transformers.

The terminal voltage of the machine, the excitation current and the excitation current and the excitation winding temperature are measured immediately before the short-circuiting.

To obtain quantities corresponding to the unsaturated state of the machine, the test is performed at several armature voltages of 0.1 to 0.3 p.u., rated value. The quantities are obtained for each test and plotted against the initial value of a.c. transient or subtransient armature currents. From this relationship, the required quantities are obtained at the rated armature current value.

To obtain quantities corresponding to the saturated state of the machine, the test is performed with rated voltage at the terminals of the machine before short-circuit the armature winding.

If the sudden short-circuit test cannot be performed at rated armature voltage, it is recommended that the tests should be conducted at several armature voltages (for example, 0.3, 0.5 and 0.7 of rated armature voltage), and the quantities determined for each test. They are then plotted against open-circuit voltage before short-circulating and the approximate rated armature voltage quantity is found by the extrapolation method.

To determine the machine quantities, oscillograms are taken of the armature current in each phase and of the current in the excitation circuit.

Oscillograph recording should continue for a time interval not less than $\tau_d + 0.2$ s after the short-circuit. The steady values should also be recorded by restarting the oscillogram following the establishment of steady conditions. The final values for a check shall be measured by instruments. Shorter oscillographic records may be taken if it is known from tests on similar machines that the current value decay at an exponential.

Short-circuit is initiated by closing the circuit-breaker and the removed by opening the circuit-breaker. The three phases on down side of c.b. are shorted.