Prof. Waghmode.

* Back to Back Test (Hopkinson's test):-

- This test is also called as regenerative method of testing as second machines & hence saving in power for testing the machines.
- Generally for this type of test, two identical machines are required. Both machine's are mechanically coupled together as well as electrically connected together.
- One machine is started as a motor. It's mechanical o/p drives the second machine as a generator.
- The electric o/p of the generator is supplied back to motor. If there were no losses then this combination would run without any external power.
- But in actual case both machines have losses & hence power taken from supply is only to supply these losses.

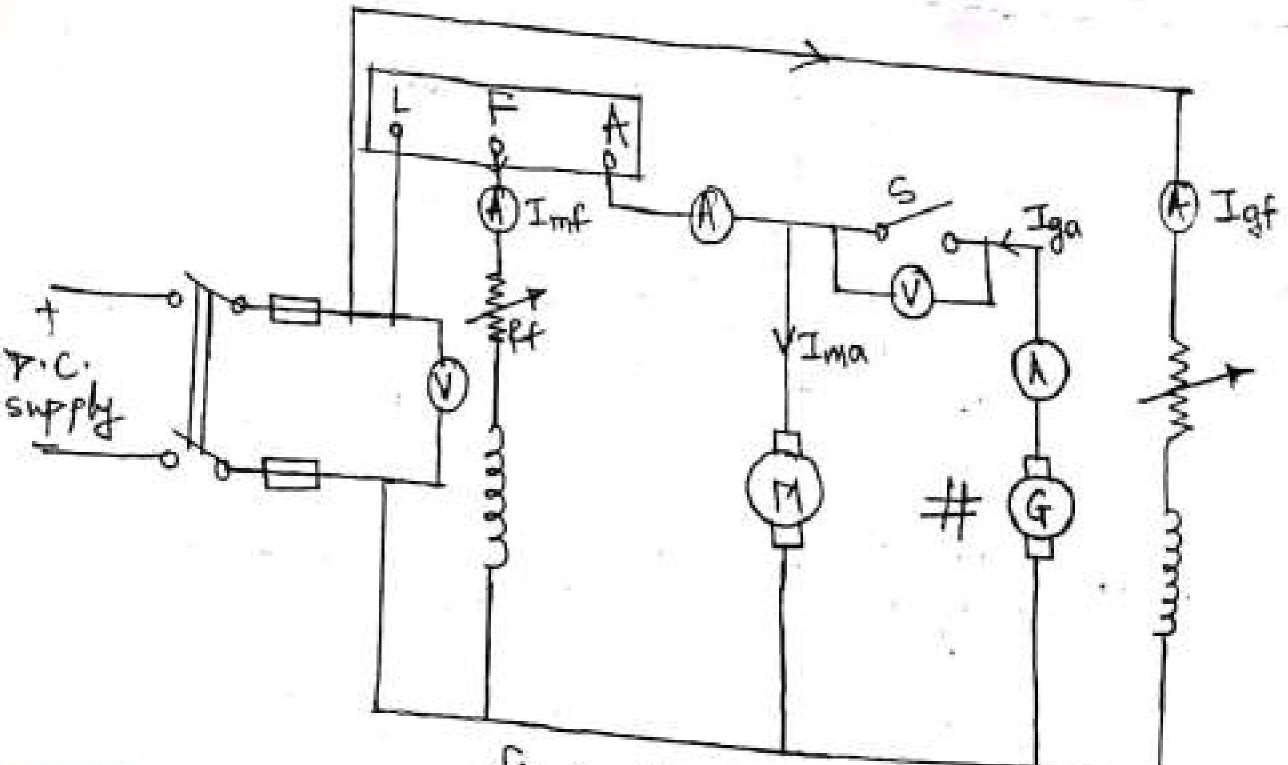

fig :- Circuit diagram

- The two identical machines are connected as shown in fig.
- Initially switch 'S' is kept open & machine no. 1 is started as the motor & it's speed is adjusted to it's rated speed by it's field regulator Rf.
- The machine no. 2 acts as a generator driven by the motor. It's excitation is adjusted by it's field regulator in such a way that the voltmeter shows zero readings.
- This shows that the voltage generated by generator is equal to supply voltage. At this stage generator floats on the busbar when switch 'S' is closed.
- The generator will not supply any power. The power taken from the supply is used to meet with the no load losses of both the machines.
- To load the machines the excitation of generator is increased, which increases it's generated EMF which becomes more than supply voltage & the generator gives out the current (I_g) & gets loaded.
- As the generator is loaded, the motor is also loaded. It's speed decreases.
- The speed can be adjusted to rated speed by it's regulator.
- The motor draws ~~are~~ more current. Adjusting properly the excitations of both the machines full load condition of machine can be adjusted. All the readings are taken. The losses and efficiencies of the machines can be worked out as follows:-

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Both Machines are separately excited.

As seen from diagrams;

I_{gf} = Generator field current

I_{ga} = —||— Armature —||—

R_{ga} = —||— Armature resistance

I_{mf} = Motor field current.

I_{ma} = —||— armature —||—.

R_{ma} = —||— armature resistance.

∴ Generator field cu loss $= V \cdot I_{gf}$

Generator armature cu loss $= [I_{ga}]^2 \times R_{ga}$.

Motor field cu loss $= V \cdot I_{mf}$

Motor armature cu loss $= [I_{ma}]^2 \times R_{ma}$.

I/P from supply to the set =

$$V.I + V.I_{gf} + VI_{mf}.$$

- Losses in the set is the sum of field cu loss, armature cu loss & stray losses of both generator & motor.

Equating I/P to the set = Losses of both machines.

$$VI + VI_{gf} + VI_{mf} = VI_{gf} + I_{ga}^2 R_{ga} + VI_{mf} + I_{ma}^2 R_{ma} + 2\,[\text{stray losses}]$$

$\therefore$ Stray [constant loss] of each machine $= \frac{VI - I_{ga}^2 R_a - I_{ma}^2 R_m}{2}$

$= W_c$

- 'Wc' is stray losses of each machine. Stray loss means mechanical loss & iron loss together. This loss is assumed to be constant for the machine at all the loads.
- The efficiency of each machine can be found as follows :-

* For generator :-

Generator o/p $= VI_{ga}$.

Generator losses $= W_c + I_{ga}^2 R_{ga} + VI_{gf}$

Generator I/P = o/p + losses

$= VI_{ga} + W_c + I_{ga}^2 R_{ga} + VI_{gf}$

Efficiency $= \frac{\text{output}}{\text{input}}$

$= \frac{VI_{ga}}{VI_{ga} + W_c + I_{ga}^2 R_{ga} + VI_{gf}}$

* For motor :-

Motor I/P $= VI_{ma} + VI_{mf}$

Motor losses $= W_c + I_{ma}^2 R_{ma} + VI_{mf}$

(But $I_{ma} = I + I_{ga}$)

Motor o/p = Input − losses

$= VI_{ma} + VI_{mf} - W_c - I_{ma}^2 R_{ma} - VI_{mf}$

$= VI_{ma} - W_c - I_{ma}^2 R_{ma}$

$$\text{Efficiency of motor} = \frac{\text{output}}{\text{input}}$$

$$= \frac{VI_{ma} - W_c - I_{ma}^2 R_{ma}}{VI_{ma} + VI_{mf}}$$

* Advantages :-

- Power required for test is small (because one machine supplies power to the other machine).
- suitable for small as well as large machines
- calculation of 'η' & losses are accurate because full load current can be circulated in both machines.
- Commutation can be observed.
- full load temp. can be measured.

* Disadvantages :-

- Two identical machines are required.
- If machines are not identical then results are not accurate.

* Comparison of Tests :-

Sr. No.	Point of Comparison	Swinburne's Test	Brake Test	Hopkinson's Test
1.	Loading Method	It is no load indirect test	It is direct load test	It is indirect back to back or regenerative test.
2.	Power required	Small (Equal to no load losses)	More [Equal to output + losses]	Medium [Some power is fed back from generator]
3.	Suitability	shunt m/c & large capacity m/c	small m/c upto 5 kW capacity	two identical m/c [small/medium/large]
4.	Commutation	Can not be observed as machine runs on no-load	Can be observed as machine is fully loaded	Can be observed as machine carries full load currents
5.	Temperature rise	Can not be observed as m/c on no load	Can be observed as m/c is fully loaded	can be observed as machines carry full currents.
6.	Limitations	Suitable for only shunt m/c & level compound m/c	suitable for any type of m/c	suitable for two identical machines.
7.	Accuracy in results	Results are approximate	Results are most accurate	Results are nearly accurate

* Direct & Indirect Testing of 3φ Induction Motor:-

** 1) Routine Tests:-

- These are carried out on each & every motor manufactured in the industries. As per I.S. 325-1970 and 327-1974 following tests shall be carried out, on each motor.

i) Insulation resistance test.
ii) Measurement of D.C. resistance.
iii) High voltage test.
iv) No-load running of motor & reading of current in 3 phases & voltage.
v) open circuit voltage ratio test (for slip-ring motor only).
vi) Locked-rotor readings of voltage, current & power i/p at a suitable reduced voltage.
vii) Reduced voltage running up test.
viii) Measurement of slip.

* 1) Insulation Resistance test:-

- The insulation resistance is measured by megger. The voltage, developed by megger should not be less than 500 volt (D.C.). The insulation resistance when high ~~high~~ this high voltage is applied should not be less than 1 MΩ
- Two terminals of megger are connected to the respective points betn which insulation resistance is to be measured. As shown in fig.⑧ the insulation resistance is measured, betn R & Y, Y & B, B & R & then betn each phase winding & earth (frame).
- Note that, finishing ends of winding are

kept open during test.

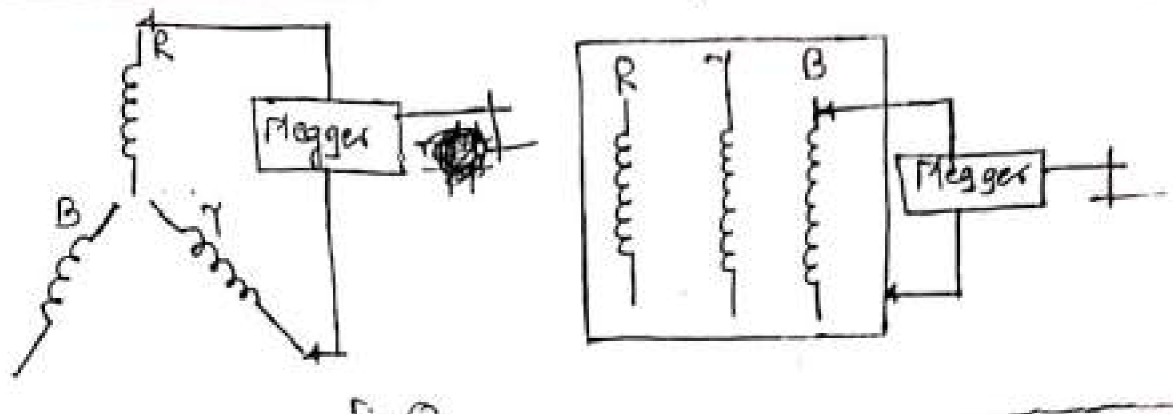

Fig (a)

* ii) Measurement of D.C. Resistance of 3Φ I.M. :-

- The stator of the 3Φ I.M. may be star connected or delta connected. The terminals are available on the terminal box.
- Simple test to measure D.C. resistance of motor is voltmeter - Ammeter method.
- The winding terminals of stator or rotor can be connected to a low voltage D.C. supply as shown in fig. (b).
- The stator or rotor winding is internally star connected. Hence any 2 terminals are taken say A & B whereas 3rd terminal 'C' is kept open.

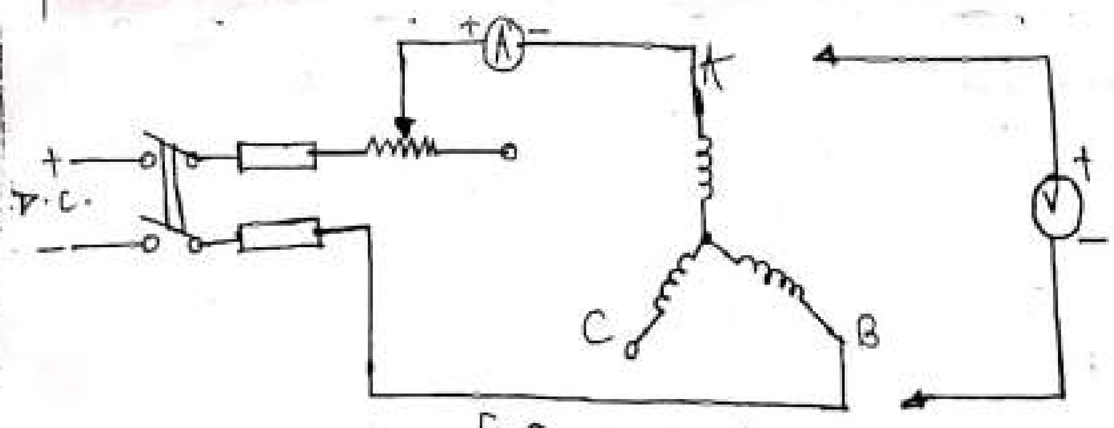

fig (b) Circuit diagram

- D.C. supply is switched 'ON' & current is adjusted to a suitable value of varying rheostat.
- Ammeter & voltmeter readings are noted at room temp. (t_1).
- Resistance at room temp. t_1 is found as $R = \frac{V}{I}$
This value is the combined value of two windings in series. Hence, resistance per phase is equal to $R_1 = \frac{R}{2}\ \Omega$
- When motor works, temp. increases & resistance also increases.
- If at a working temp. t_2 the resistance is to be found, use the following relation,

$$R_2 = R_1\left[\frac{234.5 + t_2}{234.5 + t_1}\right]$$

- This method gives moderate results.
- For small value of resistances, the most accurate method would be wheatstone-bridge or kelvin's double bridge method.
- A.C. resistance ≈ 1.25 D.C. resistance.
- Same procedure is followed for delta connected stator.

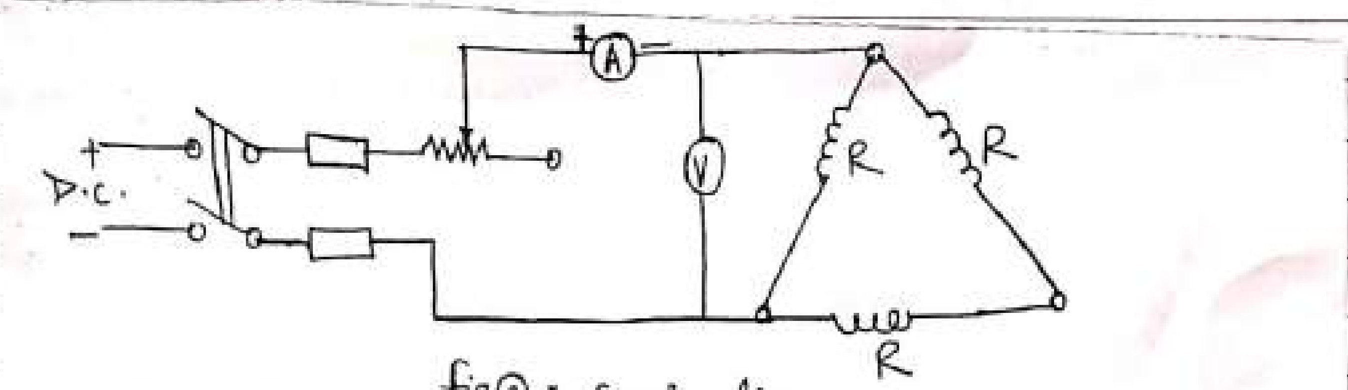

fig © :- Circuit diagram

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Equivalent resistance $= \frac{2R \times R}{2R + R} = \frac{2}{3} R$

$$\therefore \frac{2R}{3} = \frac{V}{I}$$

$$\therefore R = \frac{3V}{2I}$$

This is R_1 at temp. t_1

$$R_2 = R_1 \left[\frac{234.5 + t_2}{234.5 + t_1}\right]$$

* iii) High voltage test :-

- In this test specified voltages is applied betn various winding & earth. This test should be carried out together with the insulation resistance test at manufacturer's works. Generally high voltage test is applied only if insulation resistance is less than the specified limit.

- Method of testing :-
- The test shall be made with alternating voltage of any convenient frequency betn 40 Hz to 60 Hz. The test voltage should be of sine waveform (approximately).

- Duration :-
- The test is started by applying 1/3rd of the test voltage & then voltage is increased to full test voltage in accordance with the table 1.

Table 1.

Sr.No	part of Motor	Test voltage (r.m.s)
1.	stator winding (primary)	(1000 V) + (Twice rated voltage) with minimum of 2000V.
2.	Rotor winding (Secondary) not permanently short circuited.	(1000V) + (Twice open circuit standard vtg. as measured between sliprings.
a)	for non-reversing motors or undirectional motors.	With rated vtg. applied to primary or a minimum of 2000 volts.
b)	for motors to be reversed or brake by reversing the primary while motor is running.	(1000V) + (Four times open circuit voltage defined in a).

- This test checks weakness of insulation, damaged insulation etc.

*iv) No load Running of Motor & Reading of current in 3 phases & voltage :-

& voltage :-

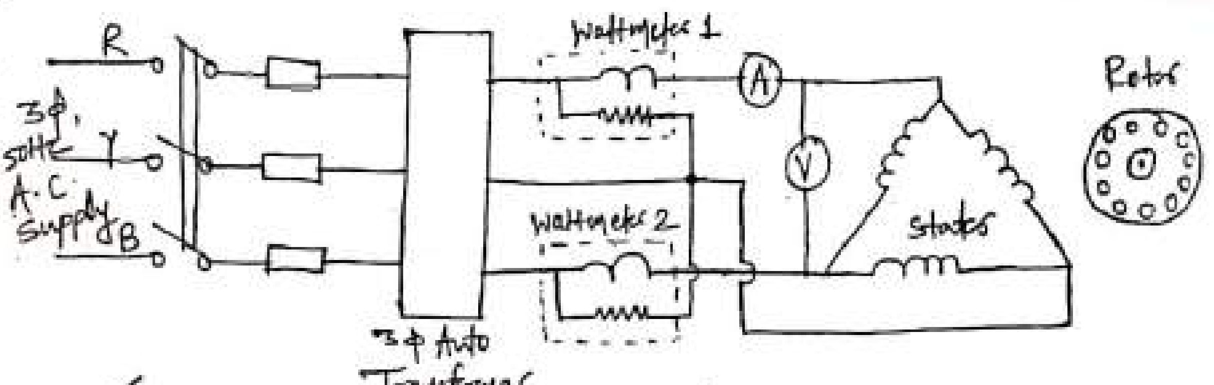


fig :

- This test is carried out to find out no load current, core loss & friction & windage losses.
- The arrangement for this test is shown in fig. The motor is supplied with rated voltage, rated freq^n & is run on no load. The readings of wattmeter, ammeter & voltmeter are recorded. Generally, this test should be performed immediately after temp. rise test.
- The wattmeter readings (W_1+W_2) indicates total i/p power which is sum of core loss, friction & windage loss & no load primary cu loss (I^2R).
- The readings are tabulated as follows:-

Rated voltage (V_0) (volts)	No load current I_0 (Amp)	W_1 (watt)	W_2 (watt)	No load I/P $W_0=W_1+W_2$ (watt).

- From these readings the magnetic circuit constants (R_0 & X_0) components of no load current (I_μ & I_W) are found as follows:-

$$W_0 = \sqrt{3}\, V_0 I_0 \cos\phi_0$$

$$\therefore \cos\phi_0 = \frac{W_0}{\sqrt{3}\, V_0 I_0}$$

Now; $I_W = I_0\cos\phi_0$ & $I_\mu = I_0 \sin\phi_0$

$$R_0 = \frac{V}{I_W} \quad \& \quad X_0 = \frac{V}{I_\mu}$$

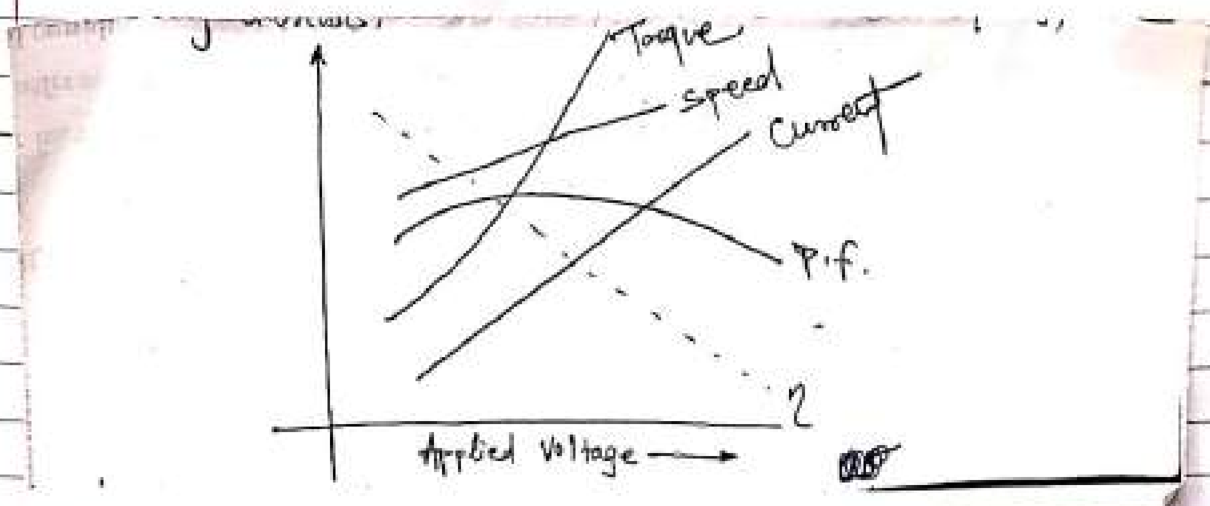
- Effect on torque:-
- The torque of I.M. is proportional to square of supply voltage $T \propto V^2$. The variation is hyperbolic.

- Effect on speed:-
- Since, torque of I.M., $T \propto V^2$. The slip at maximum torque is independant of supply vtg ($S_{MT} = \frac{R_2}{X_2}$). A large change in supply vtg produces a very small change in speed.

- Effect on Power factor:-
- The iron losses depend on vtg. The iron losses increase with increase in vtg. hence power factor becomes poor.

- Effect on current:-
- The current drawn by motor increases with applied voltage.

- Effect on Efficiency:-
- Since, losses increase with increase in vtg the efficiency decreases.



* v) Open circuit Voltage Ratio Test :-

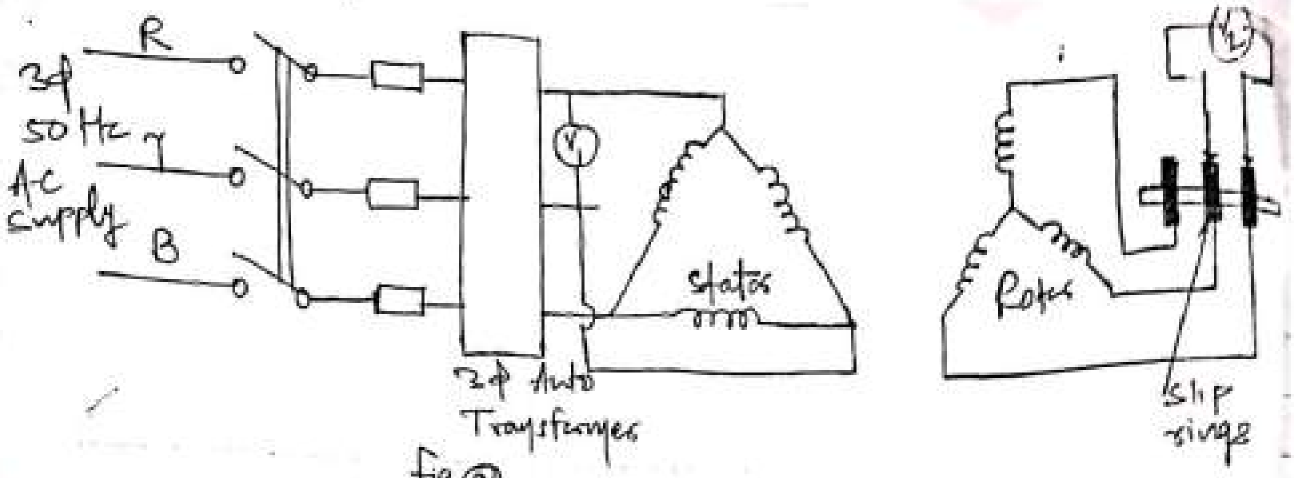


fig (a)

- The test is carried out to find out the voltage ratio or turns ratio. As shown in fig (a), the rotor resistance starter is disconnected from sliprings & voltmeter is connected across slip rings. Rated voltage is given to starter windings through auto transformer, it's value is V_1.

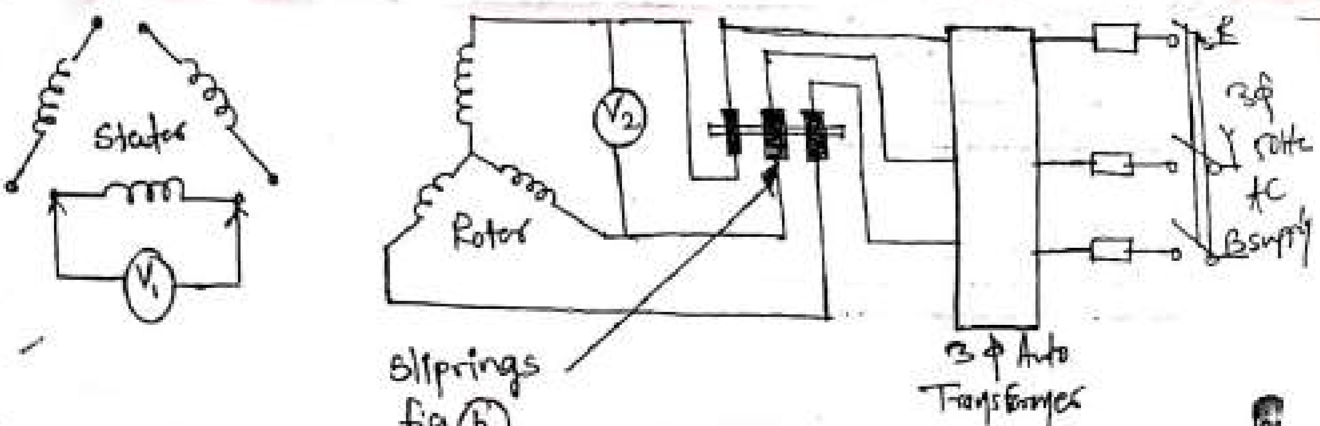


fig (b)

- The vtg. across sliprings = V_2 & it is line vtg. which should be divided by $\sqrt{3}$ i.e. $\frac{V_2}{\sqrt{3}}$ to get Vphase. Thus, readings of V_2 are taken across different sliprings & in different sliprings & in different positions of rotor &

average of these value is taken.
- The voltage ratio should be equal to turns ratio but it is not so because of leakage of stator flux. To obtain true ratio, the arrangement is made as shown in fig ⑥
- And above procedure is repeated from rotor side i.e. V2 is applied to rotor through auto transformer & V1 is measured.

Turns ratio $= \frac{\text{I}^{\text{st}} \text{ turns or stator turns } T_1 \text{ per phase}}{\text{II}^{\text{nd}} \text{ turns or rotor turns } T_2 \text{ per phase}}$

$= \frac{V_1 + V_1}{V_2 + V_2}$

*VI) Locked Rotor readings of voltage, current & Power input at suitable reduced voltage.-
- This test is also called 'Blocked rotor test' or 'short circuit test'. In this test the rotor is not allowed to rotate. The rotor can be held by hand in case of small motors for big motors,
following arrangements are used:-
i. Dynamometer
ii. Rope & Pulley
iii. Beam clamped rigidly to motor shaft
(with these arrangement the torque can also be measured.)

- Low voltage is applied across stator terminals through 3phase auto-transformer. The respective motors are connected in circuit as shown in fig. ⑧. The Vtg. is gradually increased to a value so that full load current flows

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through the windings. The test is similar to short ckt. test of transformer.

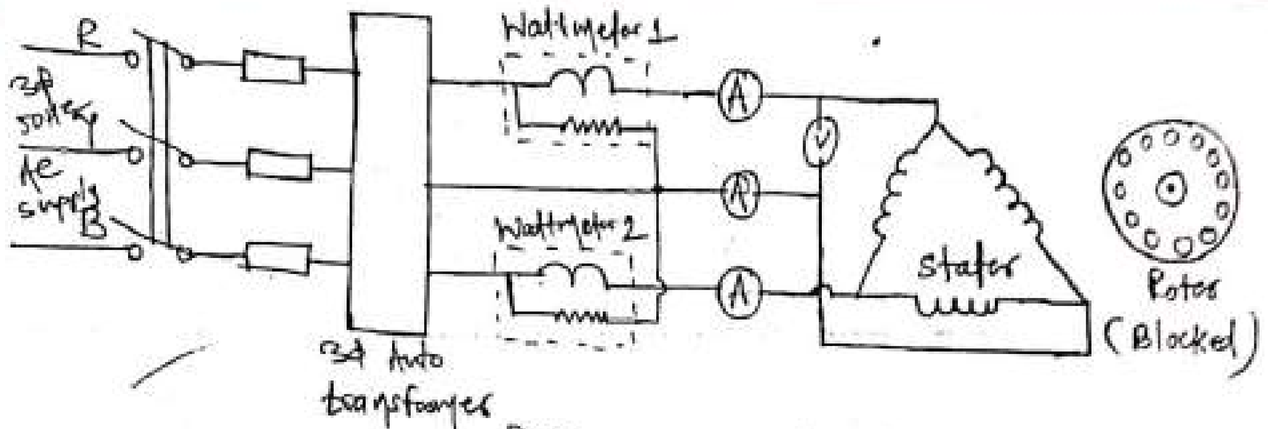


fig (a)

- The voltage required to circulate rated current is low. The power input to stator is wasted as I^2R loss in stator & rotor windings. The core loss is negligibly small. The sum of two wattmeter readings give total I/P power (i.e. W_1+W_2). The average of 3 ammeter readings give short circuit current (I_{sc}) & voltmeter give short circuiting voltage (V_{sc}). It should be noted that testing of I.M. under locked condition with poly phase power involves unusual mechanical stresses & high rates of heatings, therefore it is necessary that :-

1. The mechanical limits of locking the rotor should be of adequate strength to prevent possible injury to personnel or damage to the equipment.
2. The direction of rotation be established prior

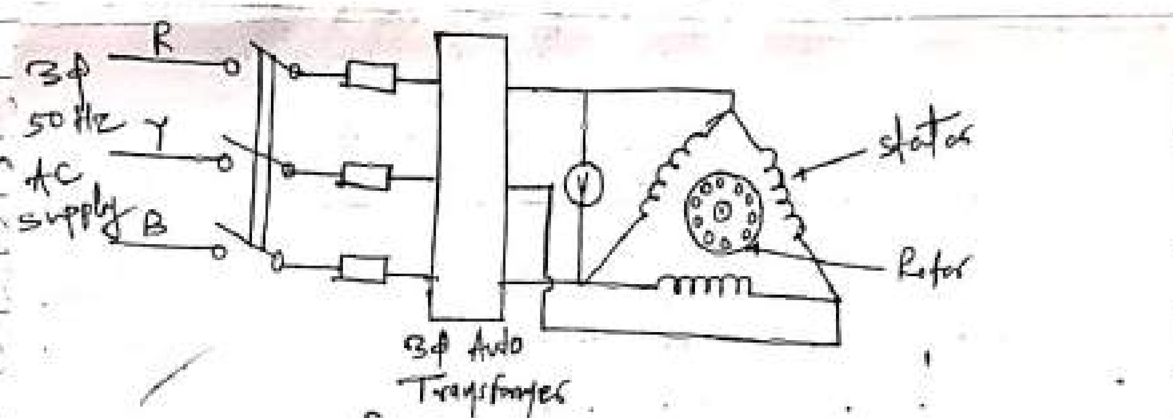
to test.

3) The winding get heated up so the test should be carried out as rapidly as possible.

- The readings are tabulated as follows:-

Short ckt. voltage (Volt)	Short ckt. current (AMP)	W1 (watt)	W2 (watt)	Short ckt I/P $W_{sc} = W_1 + W_2$ (watt)
V_{sc}	I_{sc}	W_1	W_2	W_{sc}

*vii) Reduced voltage Running up test -



fig@ :-

- Many I.M. are started with star-delta starter where applied voltage at starting is $1/\sqrt{3}$ times rated voltage. To ascertain the ability of motor to run at rated speed in both directions satisfactorily (when connected in star) this test is carried out.
- Also the rotor of squirrel cage motor sometimes refuses to start at all, particularly when voltage is low. This happens due to magnetic locking betn stator & rotor teeth.

This phenomenon is called cogging. The cage motors are also liable to harmonic torques & result is crawling. This test also reveals if the tendancy of crawling is present as well as noisy running & presence of loose bars.

- The arrangement for carring out this test is shown in Fig. ⓐ. The respective motors are connected as shown in circuit diagram & no load speed is measured with tachometer. Then motor is run in reverse direction by changing phase sequence & speed is noted down.
- The motor is again started with the help of auto T/F applying $1/\sqrt{3}$ times rated vtg. & speed is noted. Again direction of rotation is reversed & by applying $1/\sqrt{3}$ times rated vtg. speed is measured.
- The observations are tabulated as follows.

Normal voltage (V) (volts)	speed with normal Phase seq. (rpm)	Speed with reversed phase seq. (rpm)
Voltage $= \frac{1}{\sqrt{3}} V$ (volts)	speed with normal phase seq. (rpm)	speed with reversed seq. (rpm).

- The speed in both the case should be equal as nearly equal to rated speed of motor.

viii) Measurement of slip:-

- It is important to measure slip for range of loads for which efficiency is to be determined. The slip of 3φ I.M. is defined as -

$$\% \, s = \frac{N_s - N}{N_s} \times 100$$

where, N_s = synchronous speed $= \frac{120 f}{P}$

N = Rotor speed on load.

- The synchronous speed varies as frequency & inversly as (P) no. of poles. The slip goes on increasing on load. The normal variation from no load to full load is betn (0.5-1%) to (5-12%). The accurate estimation of slip is quite important. Following methods are employed.

① Direct measurement of speed by tachometer:-

- In this method rotor speed is directly measured using a mechanical analogue device like a TACHOMETER. The frequency is monitored on stator side to ascertain synchronous speed. The slip is then calculated using relation given above.
- This method is not accurate & in case of small motors, the speed is affected on connecting tachometer to shaft.

Table :- Observation table for 4 pole motor

Sr.No	f	NS	N	$\% S = \frac{NS - N}{NS} \times 100$
1.	50	1500	1470	2%
2.	50	1500	1455	3%

② Stroboscopic method :-

- The method involves no physical contact with shaft of motor & shaft is not loaded. This method is quite accurate if precise time measurement is mode.
- A disc is mounted on the shaft of motor having equal no. of block & white sectors equal to no. of poles of motor & are identical in shape. A neon lamp illuminates dis & is connected to supply. The neon lamp emits ~~lamp~~ light pulses twice in a cycle of stator supply. Thus, it becomes bright 100 times in a second (assuming f = 50 Hz). If disc rotates at synchronous speed. The time of 1/4 revolution will be same as interval between 2 light pulses. The disc appears stationary.
- At a speed less than synchronous speed, the time for 1/4 revolution of disc becomes greater than interval of light flickers. Therefore, sectors appear to move in opposite direction & rate of their rotation is the slip speed in r.p.m.. The speed of any one sector is measured. The time taken for fixed no. of revolutions of disc is measured from which slip- speed is found.

& slip is calculated.

calculated.

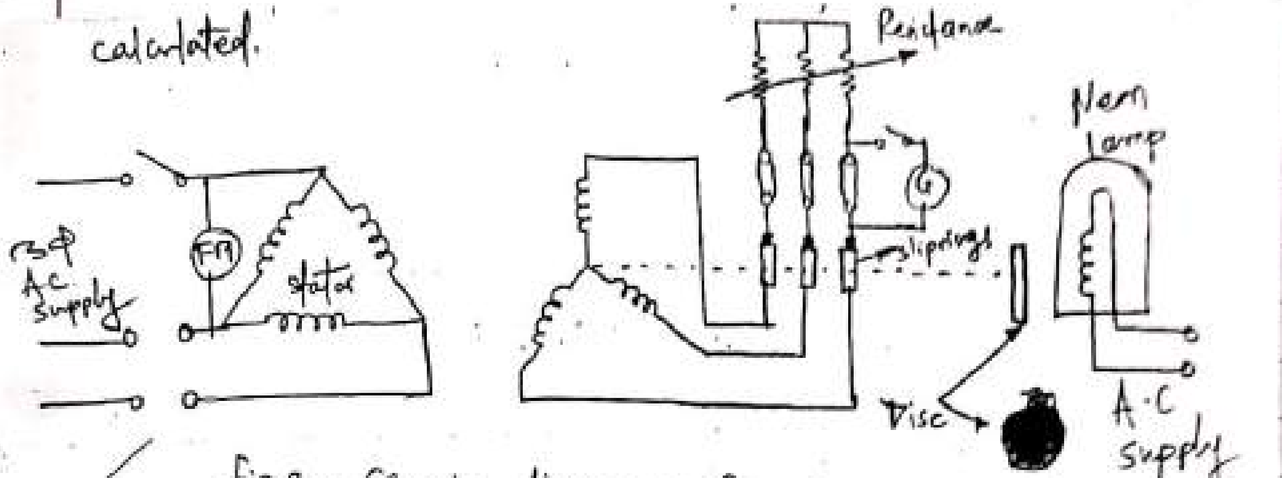


fig:- Circuit diagram for measurement of slip

* procedure :-
- Measure the time for 5 revolution of disc sector is second & calculate slip as follows:
  - observation table :-

Sr. No	f	Time for 5 revolution of sector
1	50	10 seconds
2	50	6.66 seconds

- Calculation :-
- For Sr. No. 1

for 10 sec = 5 revolution

for 60 sec = 30 revolution

$$= \frac{5}{1} \times \frac{60}{10} = 30$$

$\therefore$ slip speed = 30 rpm.

$$\%\ \text{slip} = \frac{\text{slip speed}}{N_S} \times 100$$

$= \frac{30}{1500} \times 100$

$= 2\%$.

for Sr. No. 2

for 6.66 sec = 5 revolution

for 60 sec = 45 revolution = $\left[\frac{5}{1} \times \frac{60}{6.66} = 45 \text{ rpm}\right]$

$\therefore$ slip speed = 45 rpm

$\%$ slip $= \frac{45}{1500} \times 100$

$= 3\%$.

② Galvanometer method :-

- The frequency of rotor emf is slip times stator frequency. In case of slip ring motors, a galvanometer connected betn slip rings gives oscillations per second corresponding to rotor emf frequency. If motor is of 'P' no. of poles, the rotor emf undergoes P/2 electrical cycles for every revolution.

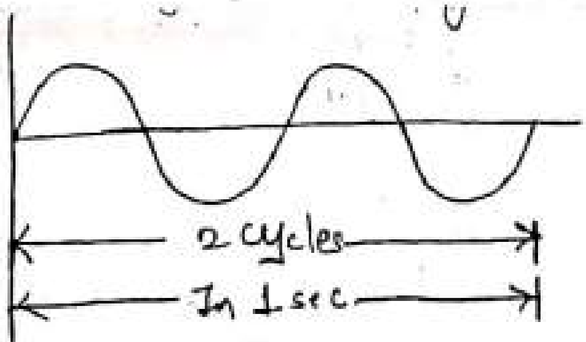


fig ②