جامعة الأنبار – كلية الهندسة

قسم الهندسة الكهربائية

Efficiency, current and power factor
Of a three – phase induction motor

Object: The object of this experiment is to determine the characteristics for efficiency, current and power factor of a three – phase induction motor with squirrel – cage rotor.

Theory: As explained in the previous experiment and from Figure (23) which shows the running characteristic curve, torque – speed characteristics, of a 3 – phase induction motor, the torque is usually dependent on the speed. It can be seen that ($M = 0$) when the motor is operated on no – load. If a load is applied to the motor, the speed drops and the torque increases. The maximum torque which a motor can produce is known as the pull-out torque (Mk). If the motor turns at its lowest possible speed, you get the starting torque (Ma).
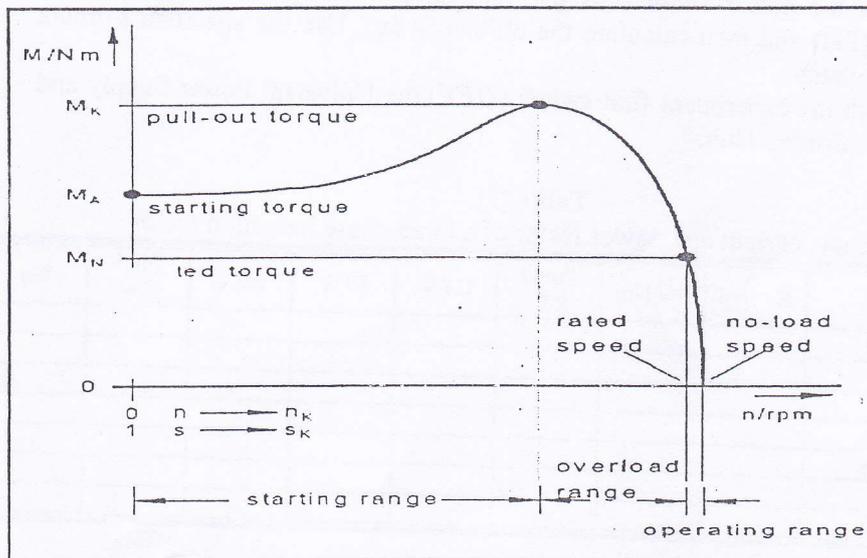

Figure (23)
Torque – speed characteristics of a 3 – phase induction motor

From these characteristics the motor efficiency can be obtained as follows:

Mechanical output power:

$$Pout = (2 \times p \times M \times n) / 60 \ \text{watts}$$

Electrical input active power:

$$Pin = \sqrt{3} \times U \times I \times \cos \varphi$$

% efficiency (η) = Pout / Pin

Such that the motor efficiency at any load can be determined.

Necessary equipments:

1. Three – phase induction motor (Type 2707).
2. Brake Unit (Type 2719).
3. Control Unit (Type 2730).
4. Universal Power Supply (Type 2740).
5. Power factor meter (10 A).
6. Ammeter, range (1 – 10 A).
7. Voltmeter, range (0 – 500) V.

Procedure:

1. Connect the circuit as shown in Figure (24).
2. Start up the system as already described in experiment 1. The motor stator windings are delta connected and the motor must rotates clock wise.
3. Record the characteristic points asked for in Table (7). For each point, read the speed (n) and the torque (M) from the displays on the Control Unit and calculate the output power (Pout). Measure the input current (I), the voltage (U) and the power factor ($cos \varphi$). With these readings calculate the input power (Pin) and then calculate the efficiency (η). Use the specified formula for calculation.
4. To finish the experiment first switch (OFF) the Universal Power Supply and then the Control Unit.

Table (7)

Efficiency, current and power factor of a three-phase induction motor

Characteristics points	N / rpm	M / Nm	Pout / KW	U / V	I / A	cos φ	Pin / KW	%η
No – load speed								
1st sub - value								
Rated speed								
2nd sub – value								
Pull – out torque								
3rd sub – value								
Minimum speed								

Notes:

- Carry out the measurements without delays if possible. If the motor heats up too much, the measuring results deviate and the motor must cool down.
- Record the characteristic points first on no – load, then for rated speed, then for the pull – out torque and finally for the minimum achievable speed.
- Determine the sub – values in the tables yourself. Make sure that the characteristic points are meaningful.
- Observe the setting of the torque attenuator.

Report & Discussion:

1. Draw the efficiency – speed characteristics listed in Table (7).
2. Draw the power factor – speed characteristics listed in Table (7).
3. Draw the input current – speed characteristics listed in Table (7).
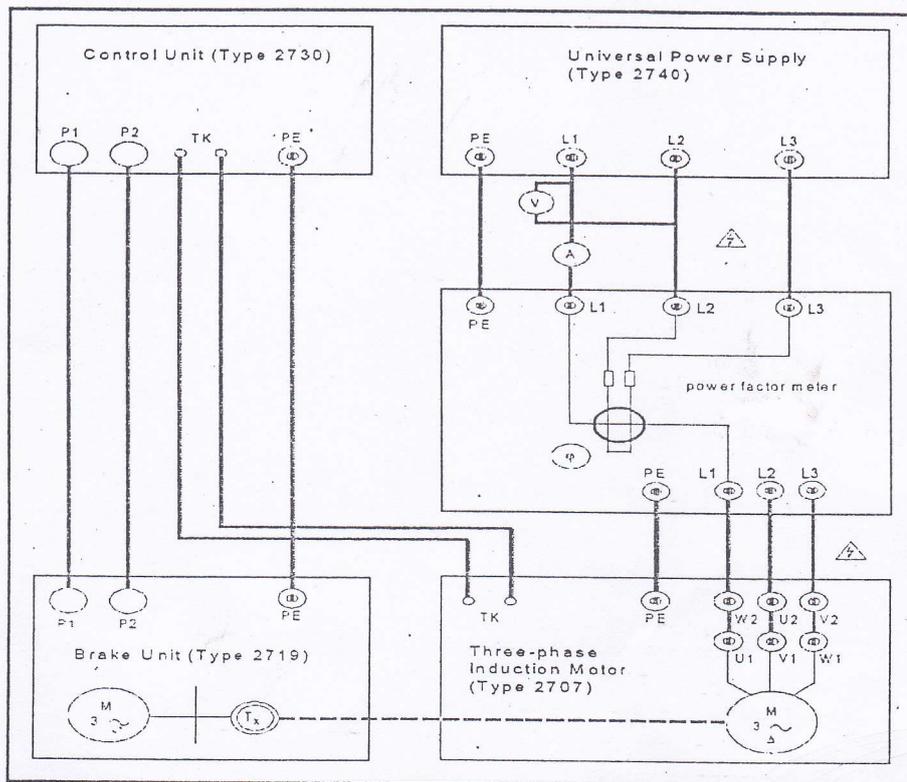4. What do you learn from these characteristic?

Figure (24)
Connection circuit diagram of a 3 – phase induction motor to obtain its efficiency

*Connection & Rotational direction and optimum starting resistance test
of 3 – phase induction motor fitted with slip ring rotor*

<u>Object:</u> The object of this experiment is to connect, check the direction of rotation
and to measure the rotor standstill voltage (*U20*) and the rotor current (*I2*). Also, to
calculate the optimum starting resistance for 3 – phase induction motor fitted with slip
ring rotor with these values (MA = MK, p = 2).

<u>Theory:</u> The 3 – phase induction motor fitted with slip ring rotor unlike the 3 – phase
induction motor with squirrel – cage rotor in that the rotor winding in the slip ring
rotor is not short – circuited. Series resistors can be connected to the rotor circuit to
improve the starting properties. The stator of the slip ring motor has the same
structure as that of the 3 – phase induction motor with squirrel – cage rotor. The rotor
is usually designed as a three – phase winding in star circuit. The rotor and stator
winding have the same number of poles. The rotor winding is embedded in a sheet –
iron casing. The ends of the rotor winding are connected with three "slip rings" sitting
on the shaft which lead to the terminals in the terminal box via carbon brushes.
Figure (8) shows the cutaway view of a slip ring rotor. The connections of the rotor
are designated K, L and M. Via these the rotor terminals can be short – circuited or
starting resistors circuited in the rotor circuit to improve the starting properties.
The Universal Resistor (Type 2750) is used for simple realization of these starting
resistors. Figure (9) shows the connection of the Universal Resistor to the rotor
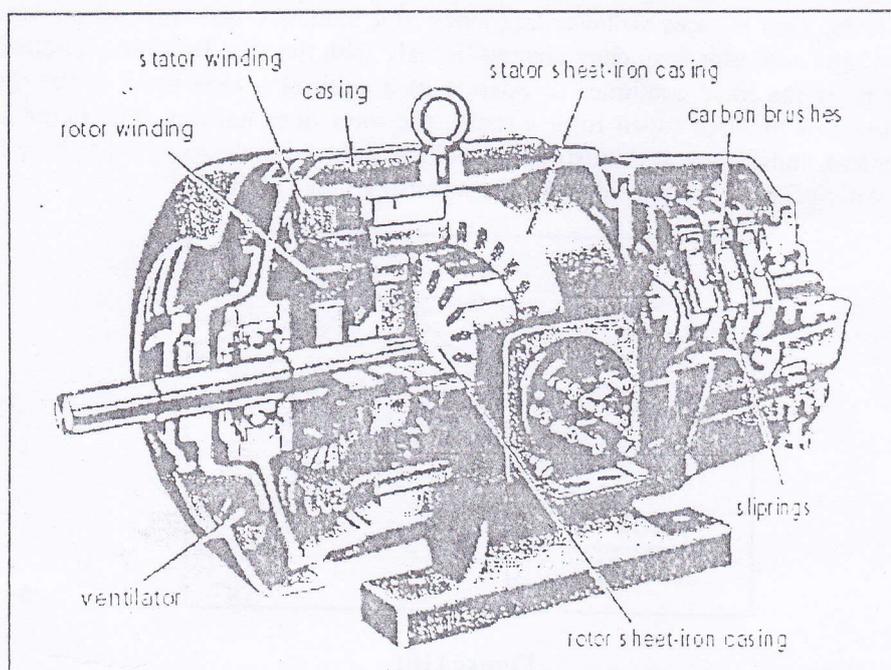winding.

Figure (8)
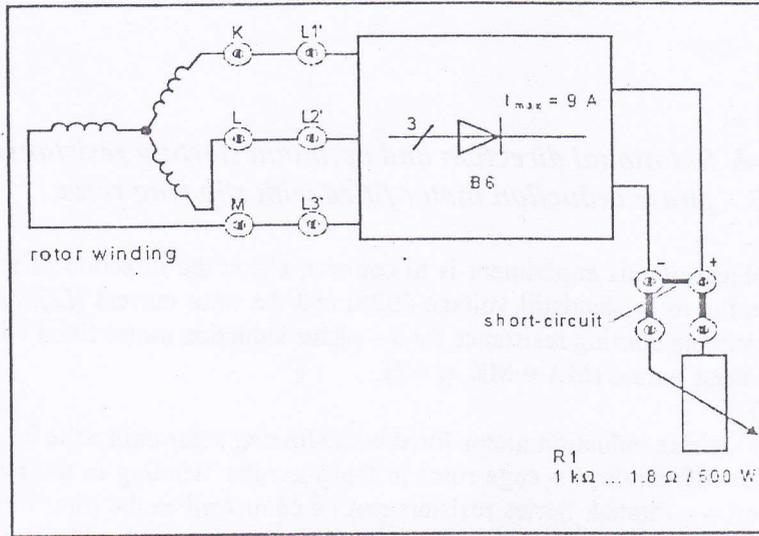Cutaway view of a 3 – phase induction motor fitted with slip ring rotor

Figure (9)
The connection of the Universal Resistor to the rotor winding

By connecting resistors in the rotor circuit the following can be obtained:
1. Reduction of the starting current.
2. Reduction of the phase shift between rotor current and voltage.
3. Increase of the starting torque.

The slip ring rotor develops a relatively high starting torque at moderate starting current. It is therefore particularly suitable for heavy startup on lifting equipment. Slip and cut speed of the rotating field are reduced when running up from standstill to the loaded state. This reduces voltage, frequency and inductive resistance of the rotor. Rotor voltage and rotor frequency change linearly with the slip. By short – circuiting the slip rings the rotor continues to operate as a squirrel – cage rotor. If the rotor circuit remains unwired (open rotor circuit), the rotor does not turn. The stator and rotor act as a transformer at standstill. The voltage induced in the rotor winding by the stator rotating field is designated as rotor standstill voltage ($U20$).
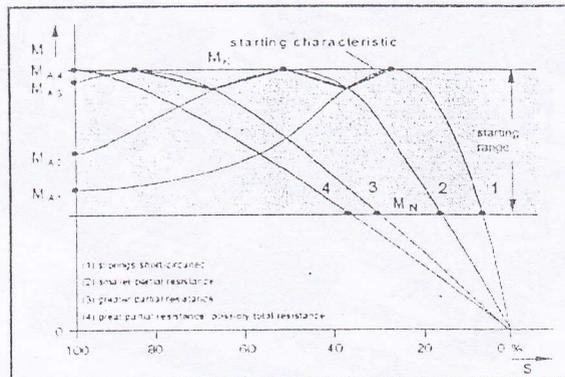

Figure (10)
Torque – speed characteristics of 3 – phase induction motor
Fitted with slip ring rotor

From the torque characteristics shown in Figure (10) it can be seen that the characteristic curve gets flatter when starting resistors are connected and the pull – out torque (Mk) is moved further into the starting range. The starting torque (Ma) is relatively high due to the resistors, which means that the motor starts up well. You get the optimum starting resistance when $Ma = Mk$.

Connection of the motor: Figure (11) shows the connection of the motor. It shows that the stator windings U1, V1, W1 and U2, V2, W2 of the motor with slip ring rotor in star or delta connection circuits can be connected. The connections K, L, M of the rotor winding are fed out separately.
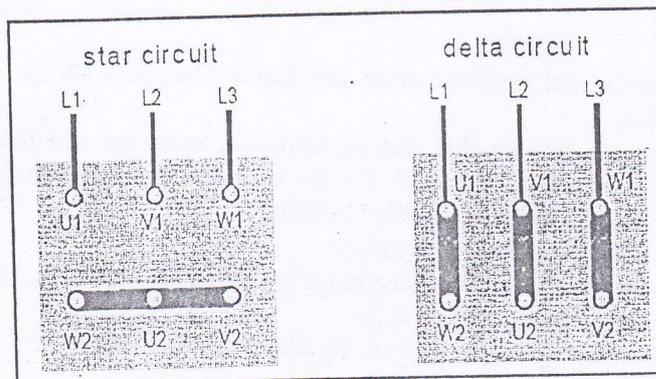
Figure (11)
Star connection and delta connection of stator windings

Figure (12) shows the Name Plate Data of the 3 – phase Induction Motor fitted with slip ring rotor (Type 2708). You can see Y/D 400/230 V which means that the motor on the 400 V three – phase mains supply is only to be operated in star circuit or in delta circuit on 230 V. Since the windings in this motor are designed for 230 V, they would heat up too much on 400 V in delta circuit.
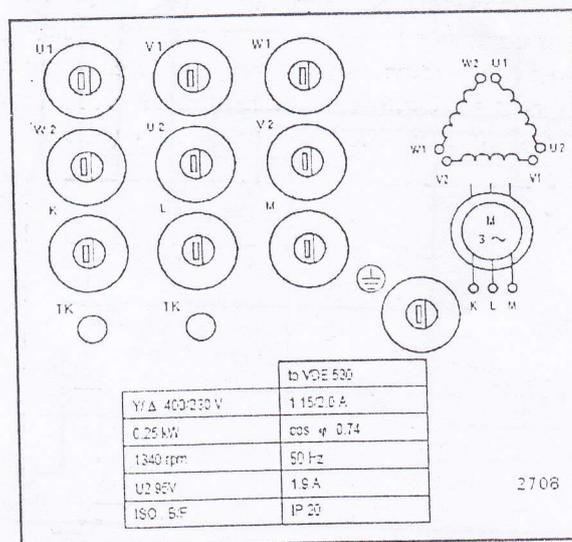
to VDE 530	
Y/Δ 400/230 V	1.15/2.0 A
0.25 kW	cos φ 0.74
1340 rpm	50 Hz
U2 95V	1.9 A
ISO 5/F	IP 20

2708

Figure (12)
Name plate data of 3 – phase induction motor fitted
With slip ring rotor(Type2708)

Necessary equipments:

1. 3 – phase induction motor with slip ring rotor (Type 2708).
2. Brake Unit (Type 2719).
3. Control Unit (Type 2730).
4. Universal Power Supply (Type 2740).
5. Ammeter, range (0 – 10) A.
6. Voltmeter, range (0 – 500) V.

Procedure:
Run I:

1. Push the experimental machine onto the Brake Unit and couple it to the braking machine.
2. Adjust the adapter feet so that the experimental machine and the braking machine are collinear (on one axis). Fix the experimental machine by pulling the clamping lever towards the braking machine.
3. Connect the circuit shown in Figure (13).
4. Connect the motor stator winding in star circuit to the 400 V mains supply.
5. Switch *ON* the Universal Power Supply.
6. Measure the rotor standstill voltage ($U20$) and record the value.
   $$U20 = \ldots \ldots \ldots$$
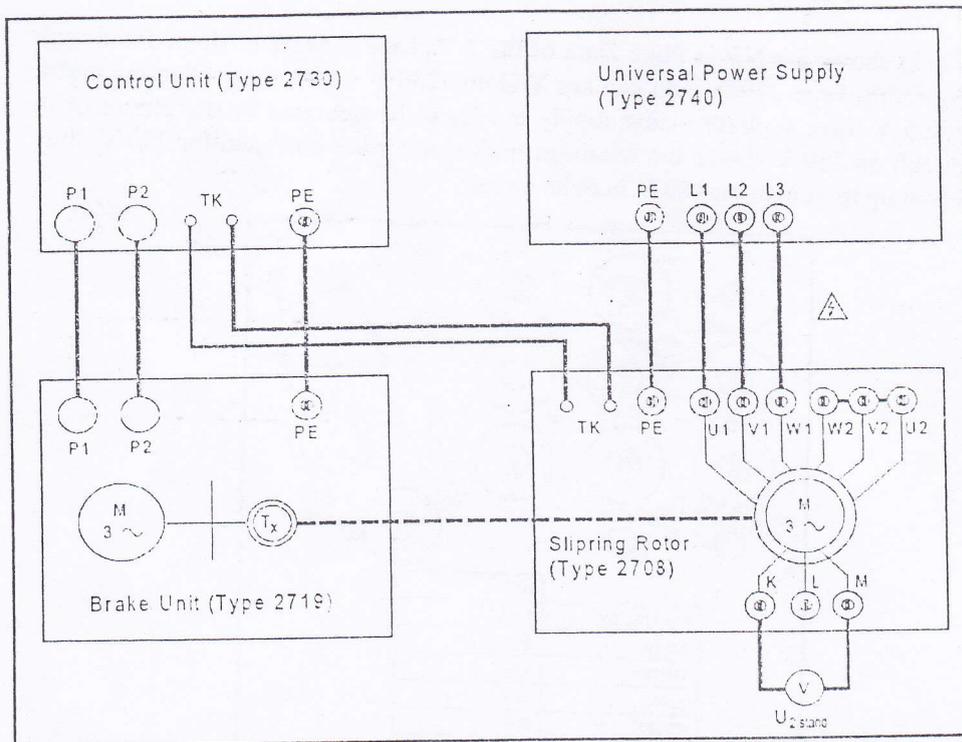7. Switch *OFF* the Universal Power Supply.

Figure (13)
Connection circuit diagram of 3 – phase slip ring motor
To determine standstill rotor voltage

Run II:

1. Connect the circuit shown in Figure (14), assure that the rotor terminals (K, L and M) are short circuited.
2. Switch *ON* the Control Unit.
3. Switch *ON* the Universal Power Supply: speed, torque and direction of rotation are displayed.
4. The direction – of – rotation display. The motor should turn to the right (CW); Otherwise switch *OFF* the Universal Power Supply and interchange two of the three mains leads and Switch *ON* the Universal Power Supply again.
5. Record the speed (no – load speed) and the direction of rotation in the following table:

Speed (*no*) / rpm	Direction of Rotation	CW(Clock Wise)	CCW(Counter Clock Wise)

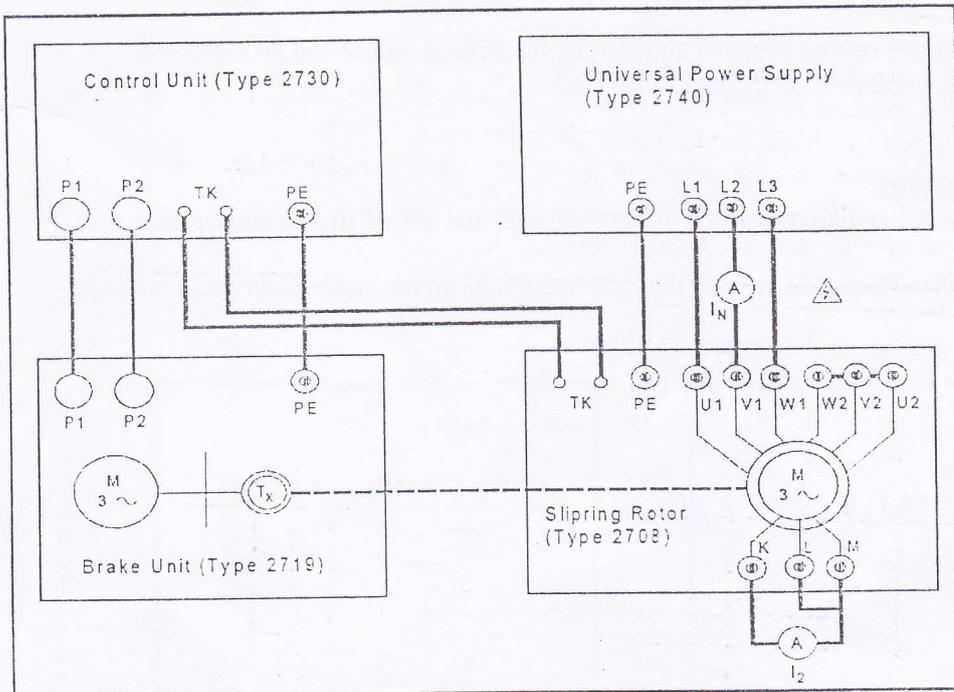6. Switch *OFF* the Universal Power Supply.

Figure (14)
Connection circuit diagram of 3 – phase slip ring motor
To determine rotor current and rated current

Run III:
Make the following settings on the Control Unit:

1. Switch the operation – mode switch to MANUAL.
2. Note the setting of the torque attenuator.
3. Set the speed – preselection switch to range of previously recorded speed (1800 or 3600 rpm).
4. Set the set point switch INT/EXT to "internal" position.

5. Set the direction – of – rotation switch to previously recorded direction of rotation.
6. Start the braking machine by briefly pressing the START/STOP key.
7. Compare the displayed speed with the previously recorded one and adjust it if necessary with the set point potentiometer.
8. Switch *ON* the Universal Power Supply. The torque should now be zero. Correct the speed with the set point potentiometer if necessary.
9. Brake the motor by reducing the speed so that it consumes the rated current (*IN*) specified on the rating plate. Record the value, *IN* = ... A.
10. Measure the rotor current (*I2*) and record the value, *I2* = ... A.
11. Measure the speed (*nk*) at the pull – out torque and record the value, *nk* = ... rpm.
12. To finish the experiment first switch *OFF* the Universal Power Supply and then the Control Unit.

<u>Note:</u> For an accurate setting of speed and torque, the voltage values can be measured additionally with a voltmeter at the jacks provided.

Report & Discussion:

1. Calculate the optimum starting resistance with the aid of the formula given below.
2. Explain the effect of increasing the rotor resistance on the motor bahaviour.

speed of rotary field: $\quad n_0 = \dfrac{f_1}{p} \cdot 60\,s$	$n_0 = \ldots \ldots \ldots \ldots$
f_1 mains frequency p number of pole pairs	
at $M_A = M_K$ (maximum torque):	$s_K = \ldots \ldots \ldots \ldots$
pull-out slip: $\quad s_K = \dfrac{n_0 - n_K}{n_0}$	$U_2 = \ldots \ldots \ldots \ldots$
rotor voltage: $\quad U_2 = s_K \cdot U_{2\,stand}$	$R_2 = \ldots \ldots \ldots \ldots$
rotor resistance for 1st phase: $\quad R_2 = 1/2 \cdot \dfrac{U_2}{I_2}$	
opt. starting resistance: $\quad R_{a\,max} = R_2 \cdot \left(\dfrac{1}{s_K} - 1\right)$	$R_{a\,max} = \ldots \ldots \ldots$

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قسم الهندسة الكهربائية

Characteristics of 3 – phase induction motor fitted with slip ring rotor

<u>Object:</u> The object of this experiment is to determine the characteristics for torque, efficiency, current and power factor of the slip ring motor at different starting resistances (short – circuit of the rotor terminals, smallest possible resistance, Ra max/3, Ra max). Use the optimum starting resistance (Ra max) calculated from previous experiment.

<u>Theory:</u> From the torque characteristics shown in Figure (15) it can be seen that the characteristic curve gets flatter when starting resistors are connected in series with the rotor and the pull – out torque (*Mk*) is moved further into the starting range. The starting torque (*Ma*) is relatively high due to the resistors, which means that the motor starts up well. You get the optimum starting resistance when *Ma = Mk*, as explained in the previous experiment.
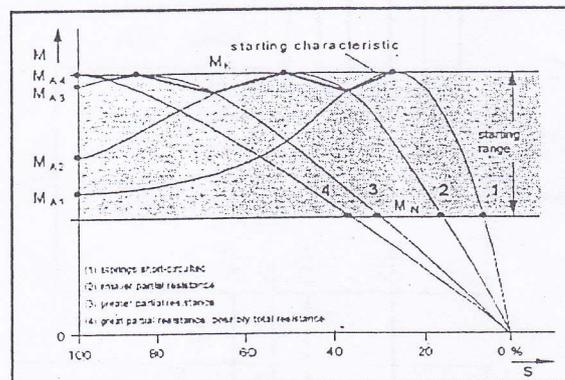

Figure (15)

Torque – speed characteristics of 3 – phase induction motor fitted with slip ring rotor

<u>Necessary equipments:</u>

    1. 3 – phase induction motor with slip ring rotor (Type 2708).
    2. Brake Unit (Type 2719).
    3. Control Unit (Type 2730).
    4. Universal Power Supply (Type 2740).
    5. Universal Resistor (Type 2750).
    6. Power Factor Meter (10 A).
    7. Voltmeter, range (0 – 500) V.
    8. Ammeter, range (0 – 10) A.