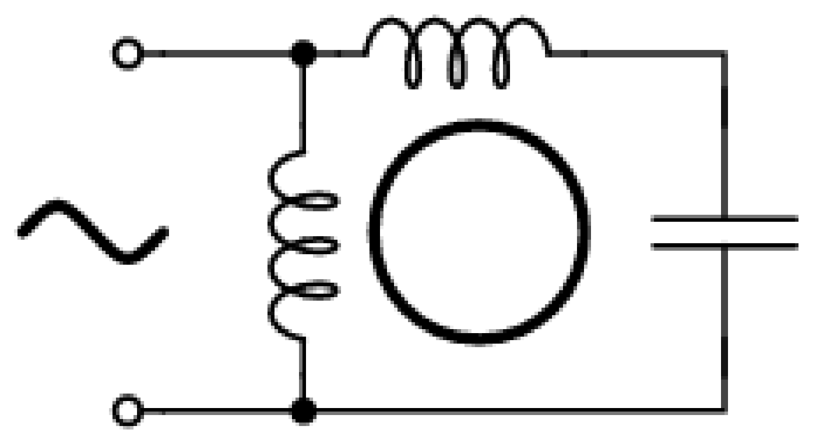
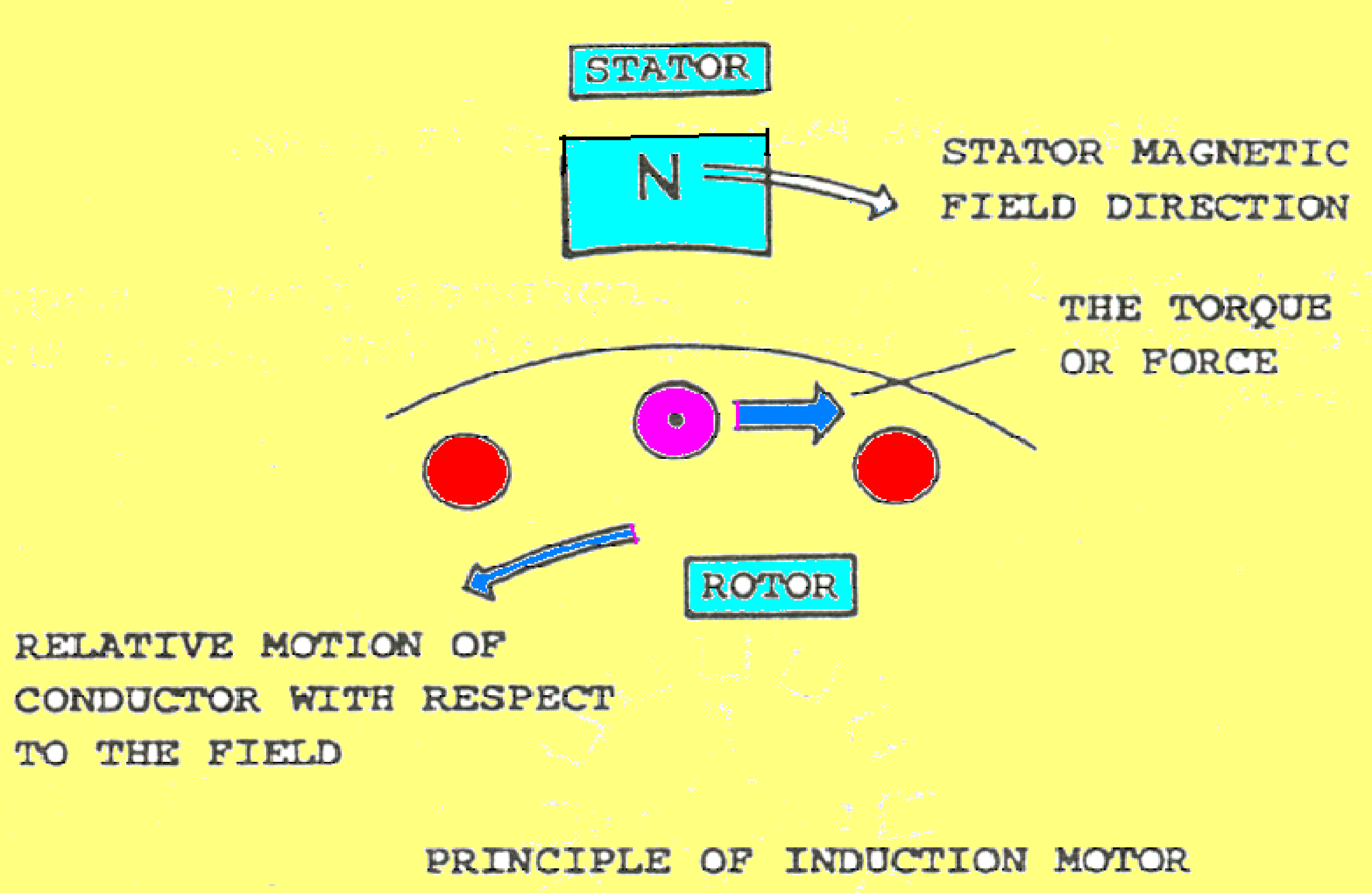
Single Phase Induction

Permanent-split capacitor motor

One way to solve the single phase problem is to build a 2-phase motor, deriving 2-phase power from single phase. This requires a motor with two windings spaced apart 90º electrical, fed with two phases of current displaced 90º in time. This is called a permanent-split capacitor motor in Figure



Principle of Induction Motor



PRINCIPLE OF INDUCTION MOTOR

Slip in Induction Motor

slip speed = synchronous speed - rotor speed
measured in RPM

Slip = (synchronous speed - rotor speed) /synchronous speed
expressed as a percentage

The greater the slip speed, the greater is the force on each conductor and the torque exerted by the whole.

Main and Auxiliary windings

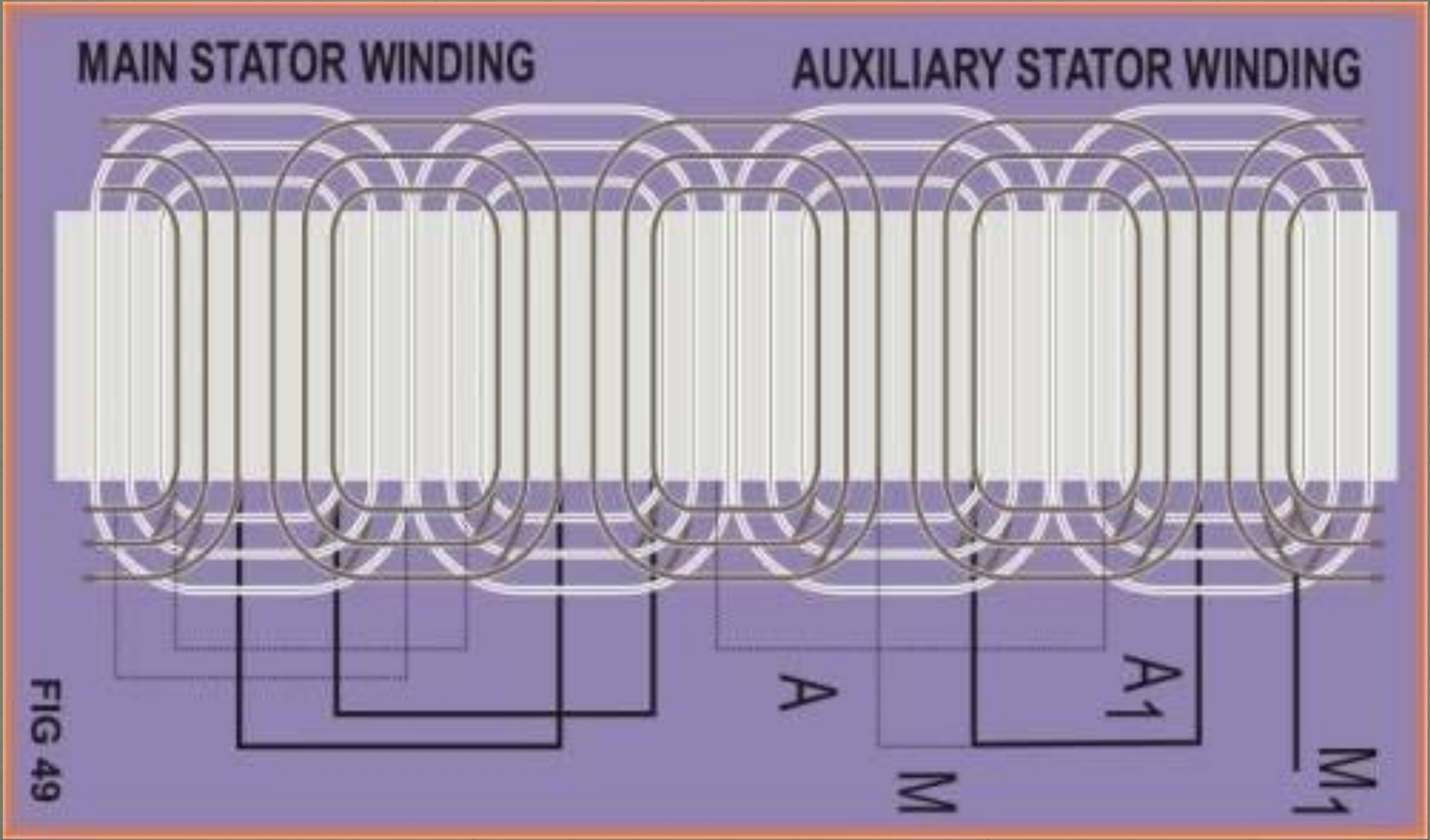


FIG 49

1-Phase Induction Motor

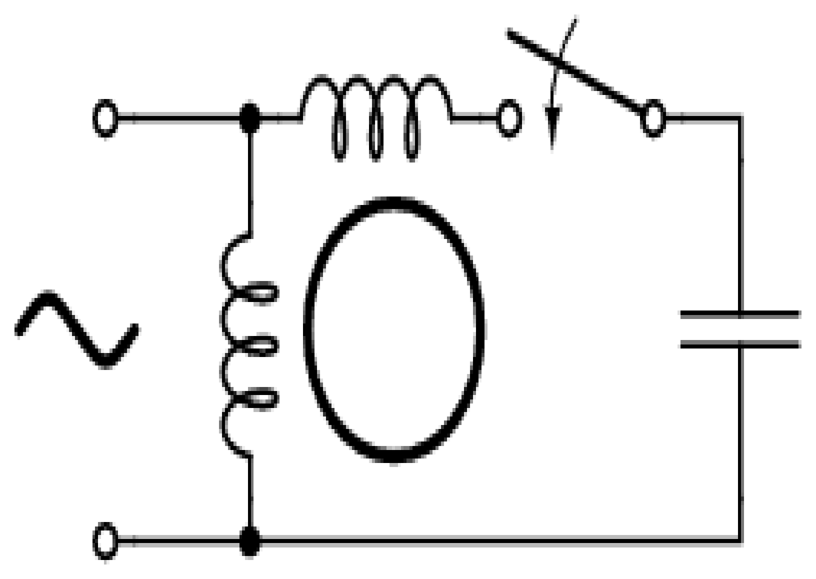
- This type of motor suffers increased current magnitude and backward time shift as the motor comes up to speed, with torque pulsations at full speed. The solution is to keep the capacitor (impedance) small to minimize losses. The losses are less than for a shaded pole motor.

1-Phase Induction Motor

- This motor configuration works well up to 1/4 horsepower (200watt), though, usually applied to smaller motors. The direction of the motor is easily reversed by switching the capacitor in series with the other winding. This type of motor can be adapted for use as a servo motor, described elsewhere is this chapter

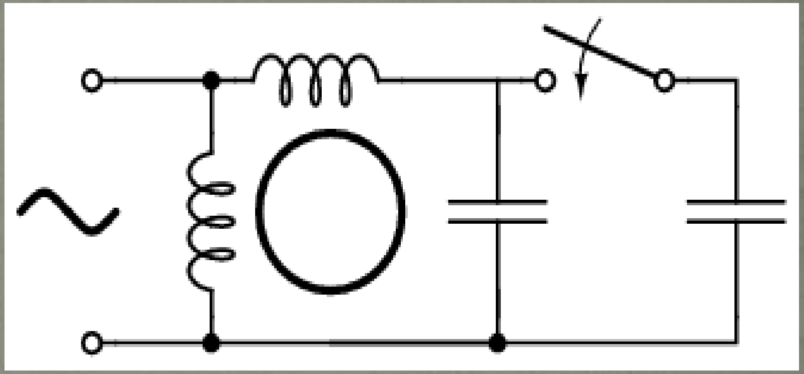
Capacitor-start induction motor

In Figure a larger capacitor may be used to start a single phase induction motor via the auxiliary winding if it is switched out by a centrifugal switch once the motor i up to speed. Moreover, the auxiliar winding may be many more turns o heavier wire than used in a resistance split-phase motor to mitigate excessive temperature ris The result is that more starting torque is available for heavy loads like air conditioning compressors. This motor configuration works so well that it is available in multi-horsepower (multi-kilowatt) sizes.



Capacitor-run motor induction motor

A variation of the capacitor-start motor Figure is to start the motor with a relatively large capacitor for high starting torque, but leave a smaller value capacitor in place after starting to improve running characteristics while not drawing excessive current. The additional complexity of the capacitor-run motor is justified for larger size motors.



1-phase Capacitor start

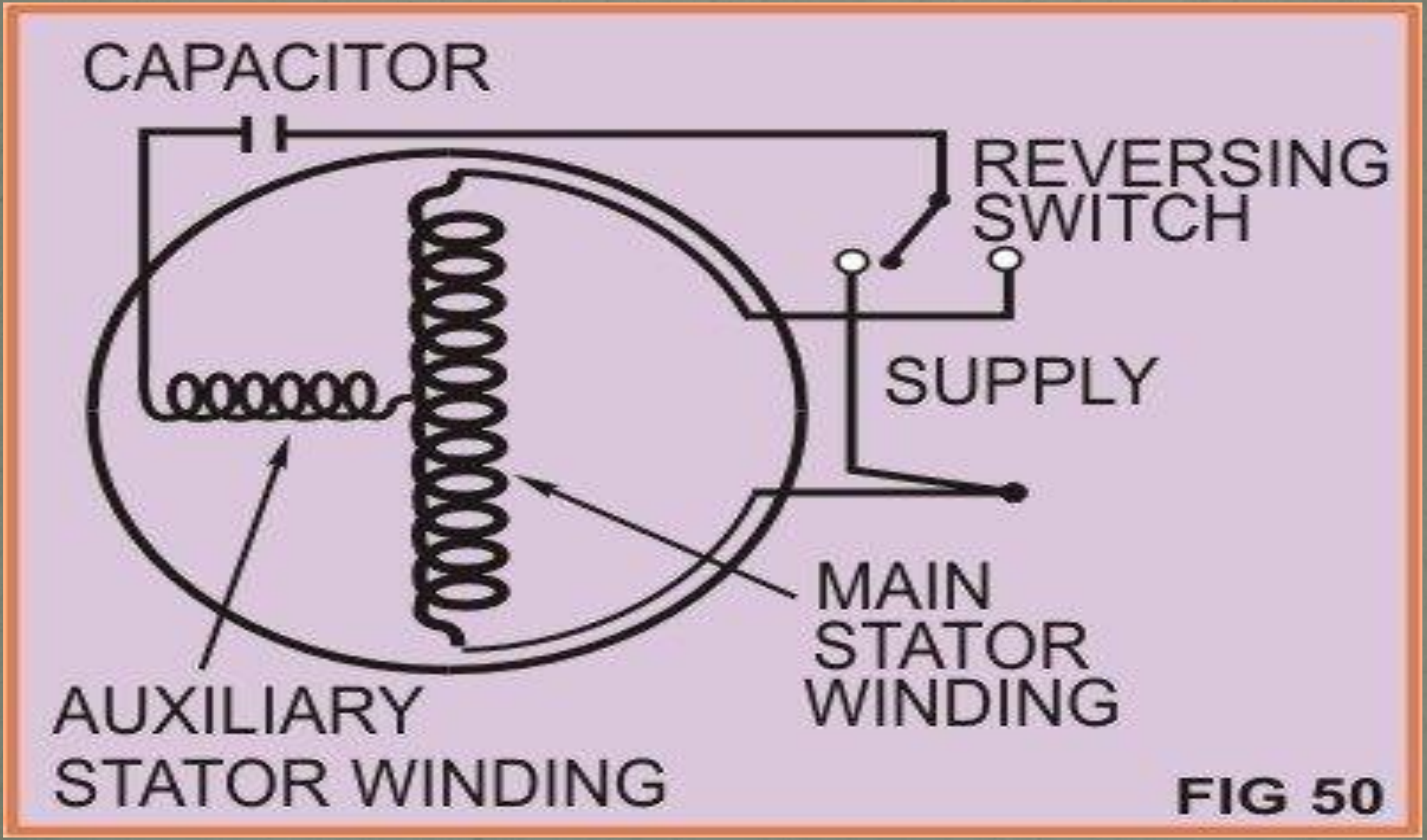


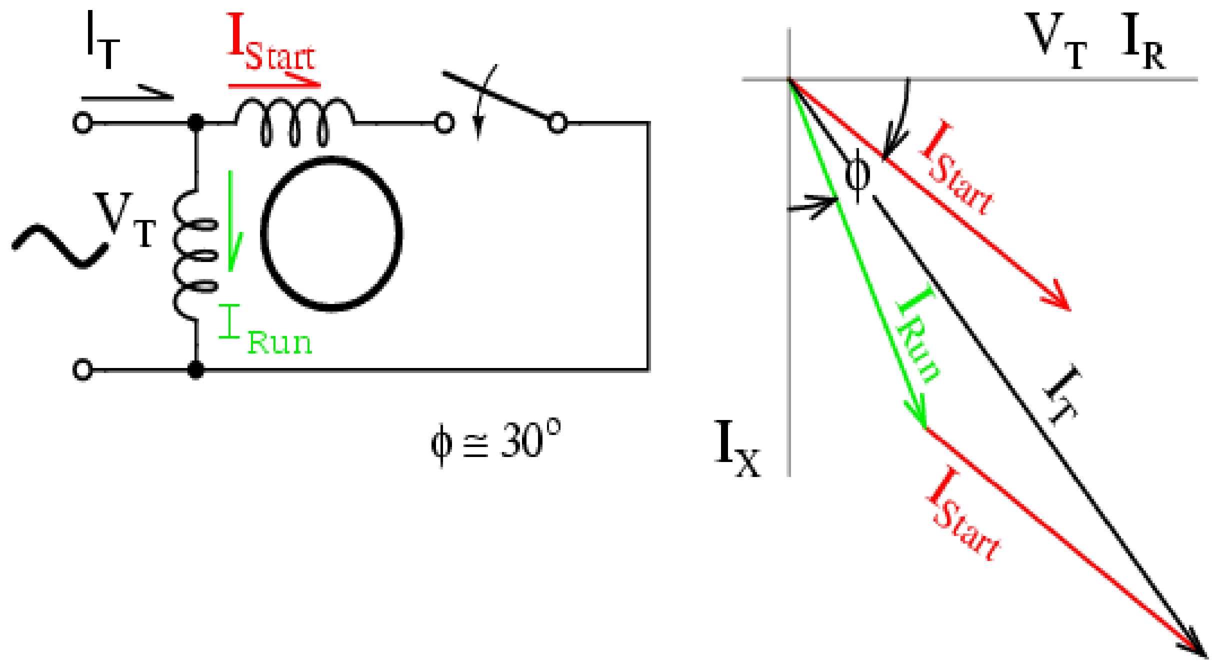
FIG 50

Capacitor Start-Run Induction Motor

- A motor starting capacitor may be a double-anode non-polar electrolytic capacitor which could be two + to + (or - to -) series connected polarized electrolytic capacitors. Such AC rated electrolytic capacitors have such high losses that they can only be used for intermittent duty (1 second on, 60 seconds off) like motor starting. A capacitor for motor running must not be of electrolytic construction, but a lower loss polymer type.

Resistance split-phase motor induction motor

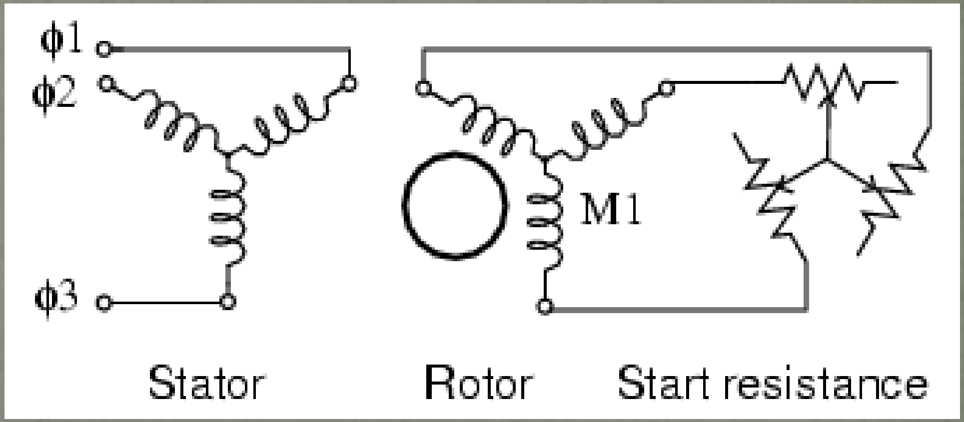
If an auxiliary winding of much fewer turns of smaller wire is placed at 90° electrical to the main winding, it can start a single phase induction motor. With lower inductance and higher resistance, the current will experience less phase shift than the main winding. About 30° of phase difference may be obtained. This coil produces a moderate starting torque, which is disconnected by a centrifugal switch at 3/4 of synchronous speed. This simple (no capacitor) arrangement serves well for motors up to 1/3 horsepower (250 watts) driving easily started loads.



Wound rotor induction motors

A *wound rotor* induction motor has a stator like the squirrel cage induction motor, but a rotor with insulated windings brought out via slip rings and brushes. However, no power is applied to the slip rings. Their sole purpose is to allow resistance to be placed in series with the rotor windings while starting.

This resistance is shorted out once the motor is started to make the rotor look electrically like the squirrel cage counterpart.



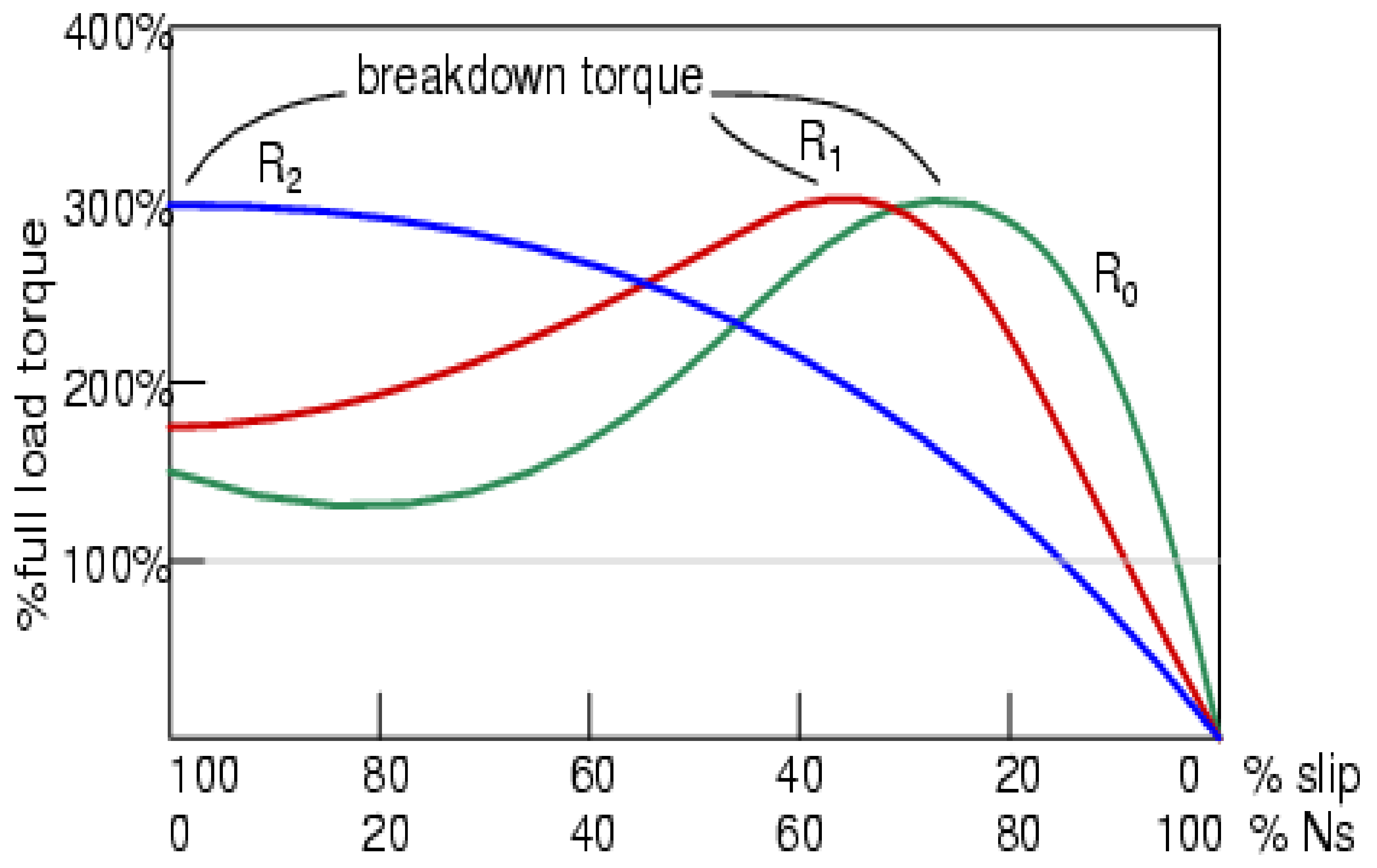
Wound Rotor Induction M/C

- Why put resistance in series with the rotor? Squirrel cage induction motors draw 500% to over 1000% of full load current (FLC) during starting. While this is not a severe problem for small motors, it is for large (10's of kW) motors. Placing resistance in series with the rotor windings not only decreases start current, locked rotor current (LRC), but also increases the starting torque, locked rotor torque (LRT).

Wound Rotor Induction M/C

- Figure shows that by increasing the rotor resistance from R_0 to R_1 to R_2, the breakdown torque peak is shifted left to zero speed. Note that this torque peak is much higher than the starting torque available with no rotor resistance (R_0) Slip is proportional to rotor resistance, and pullout torque is proportional to slip. Thus, high torque is produced while starting.

Wound Rotor Induction M/C



Wound Rotor Induction M/C

- The resistance decreases the torque available at full running speed. But that resistance is shorted out by the time the rotor is started. A shorted rotor operates like a squirrel cage rotor. Heat generated during starting is mostly dissipated external to the motor in the starting resistance. The complication and maintenance associated with brushes and slip rings is a disadvantage of the wound rotor as compared to the simple squirrel cage rotor.

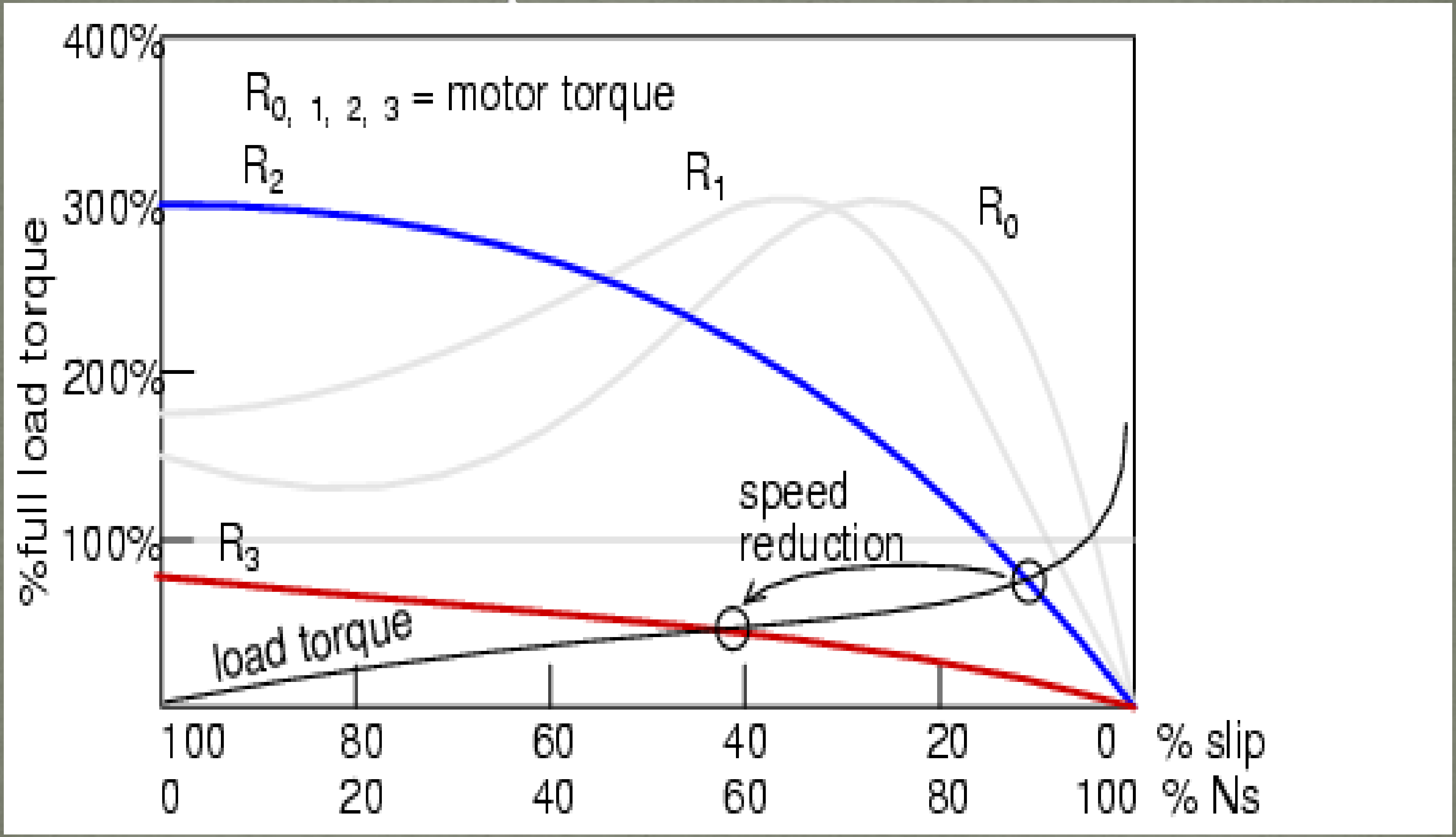
Wound Rotor Induction

- This motor is suited for starting high inertial loads. A high starting resistance makes the high pull out torque available at zero speed. For comparison, a squirrel cage rotor only exhibits pull out (peak) torque at 80% of its' synchronous speed

Speed Control

- Motor speed may be varied by putting variable resistance back into the rotor circuit. This reduces rotor current and speed. The high starting torque available at zero speed, the down shifted break down torque, is not available at high speed. See R_2 curve at 90% Ns, Resistors $R_0R_1R_2R_3$ increase in value from zero. A higher resistance at R_3 reduces the speed further. Speed regulation is poor with respect to changing torque loads. This speed control technique is only useful over a range of 50% to 100% of full speed. Speed control works well with variable speed loads like elevators and printing presses.

Speed Control



Induction motor speed

- At what speed will the IM run?
  - Can the IM run at the synchronous speed, why?
  - If rotor runs at the synchronous speed, which is the same speed of the rotating magnetic field, then the rotor will appear stationary to the rotating magnetic field and the rotating magnetic field will not cut the rotor. So, no induced current will flow in the rotor and no rotor magnetic flux will be produced so no torque is generated and the rotor speed will fall below the synchronous speed
  - When the speed falls, the rotating magnetic field will cut the rotor windings and a torque is produced

Induction motor speed

- So, the IM will always run at a speed lower than the synchronous speed
- The difference between the motor speed and the synchronous speed is called the *Slip*

$$\boxed{n_{slip} = n_{sync} - n_m}$$

Where n_{slip}= slip speed

n_{sync}= speed of the magnetic field

n_m = mechanical shaft speed of the motor

Torque

- While the input to the induction motor is electrical power, its output is mechanical power and for that we should know some terms and quantities related to mechanical power
- Any mechanical load applied to the motor shaft will introduce a Torque on the motor shaft. This torque is related to the motor output power and the rotor speed

$$\boxed{\tau_{load} = \frac{P_{out}}{\omega_m} \quad N.m}$$

and

$$\boxed{\omega_m = \frac{2\pi n_m}{60} \quad rad / s}$$