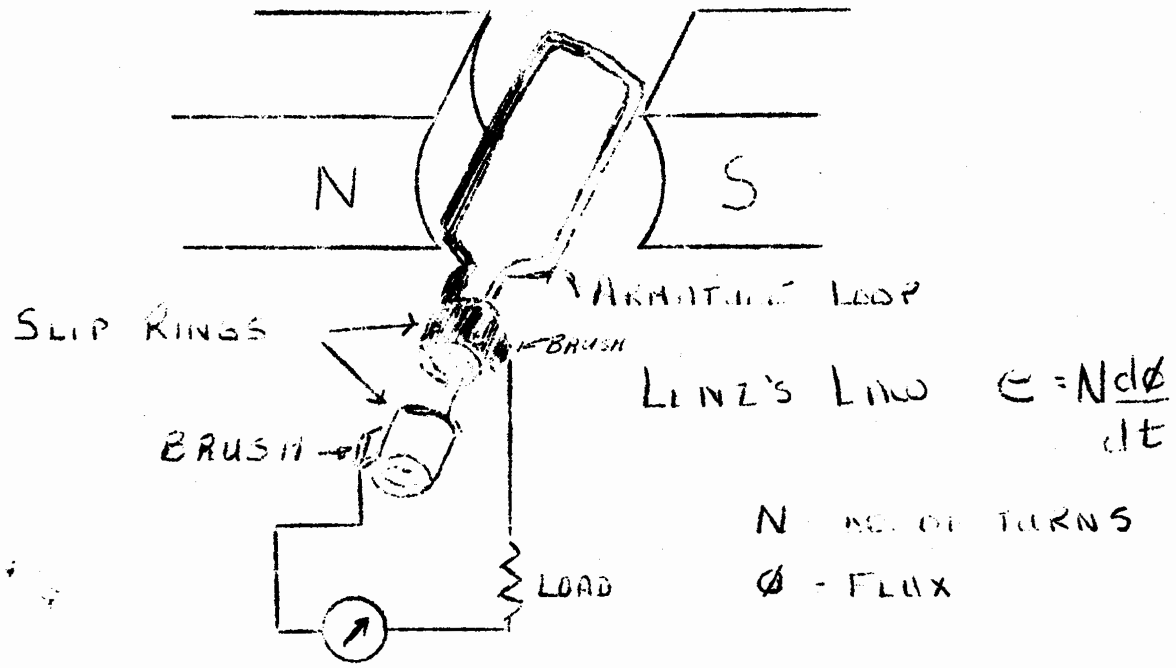
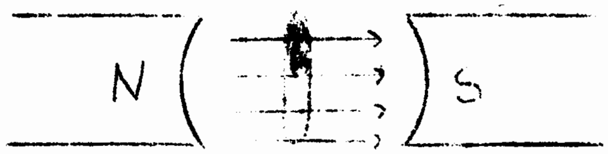
D.C. MACHINES

Elementary Generator

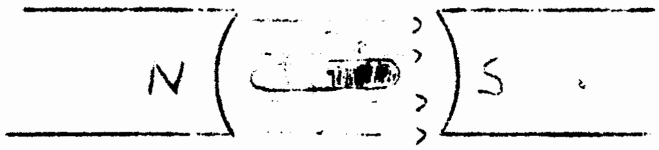
- Consists of a loop of wire which rotates in a stationary magnetic field.
- As the loop of wire cuts the magnetic field a current is induced in the loop.



- Max. voltage is generated when the loop cuts the magnetic field at right angles, and min. voltage is generated when the loop moves parallel to the lines of force.



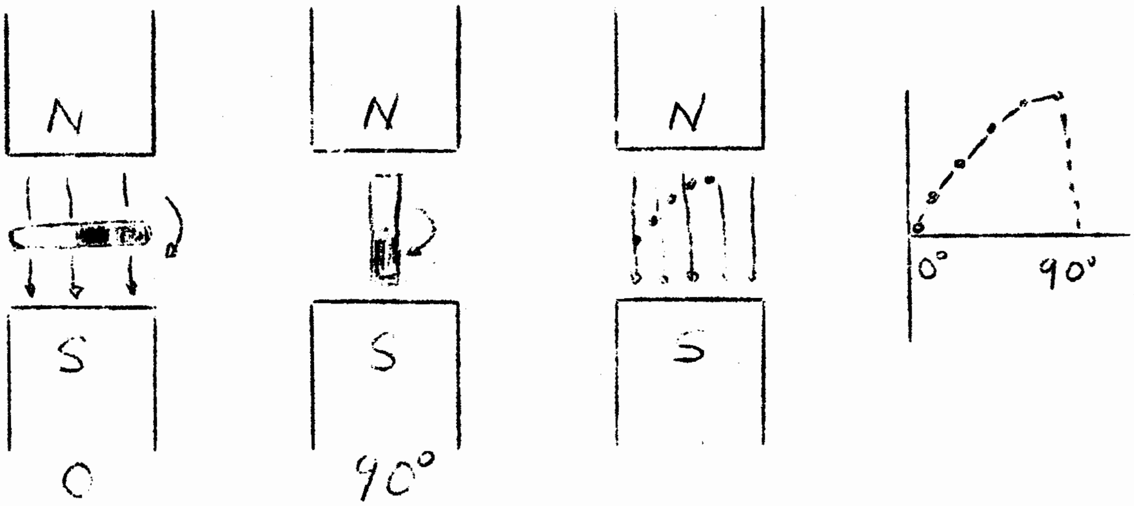
Min. voltage generated

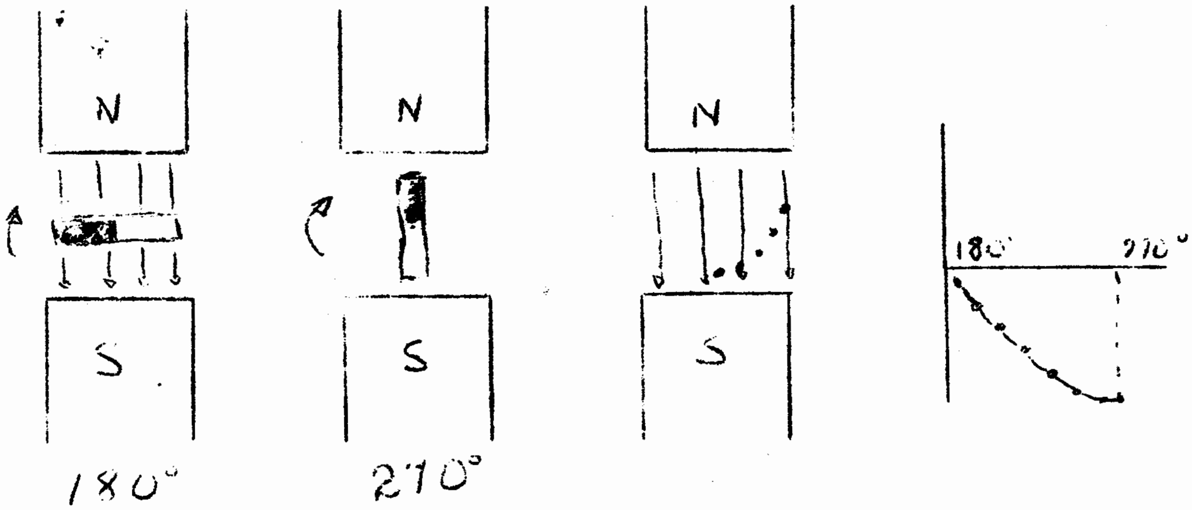


Max. voltage generated

Right Hand Rule - Generator

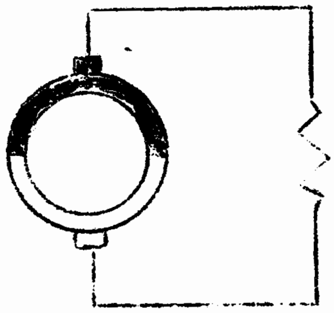
Thumb - direction of motion.
Index finger - direction of magnetic flux.
Middle finger - direction of current flow (conventional).



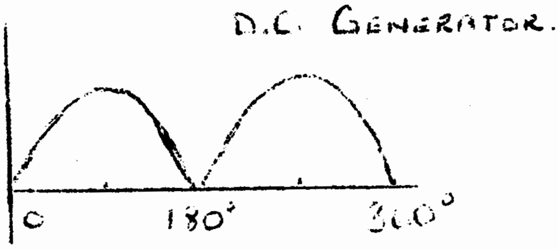


Commutation

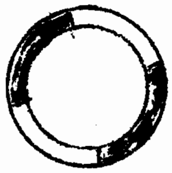
It can be seen that as long as the white slipring is the reference, the voltage developed across the resistor is positive for half a cycle and negative for the other half. If the white slip ring is taken as the reference for one half cycle, and the black slipring for the other half cycle, positive voltage can be induced in the load.



Current will always flow in the same direction.



Two coil armature
i.e. four section commutator



Factors Affecting Generator Voltage

1. Number of turns in coil - increased no. gives higher output.
2. Strength of magnetic field - increased mag. field results in a higher output voltage.
3. Speed of rotation - increased speed gives increased output.

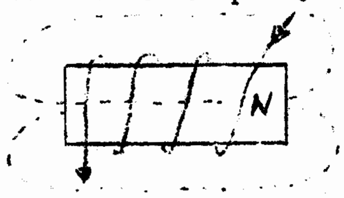
To increase the magnetic field strength, field coils (electromagnets) are used.

Right Hand Rule for Conductors

If thumb points in direction of current, fingers are in direction of magnetic field lines.

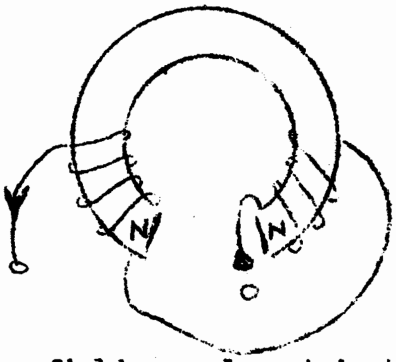
Right Hand Rule for Coils

If fingers are wrapped around coil in direction of current flow (conventional), the thumb will point towards the north pole.



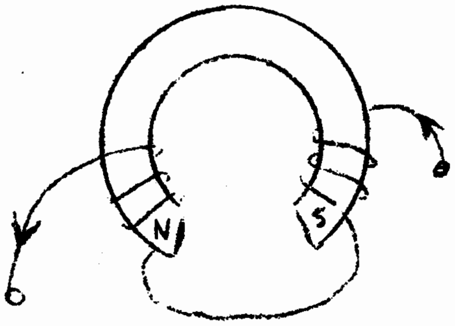
Electromagnets

Opposing Fields

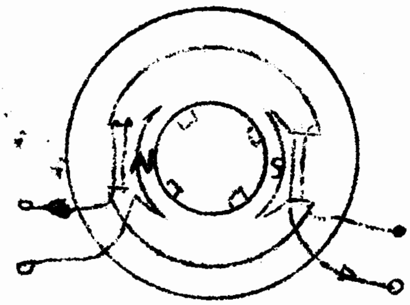


- field cancels out in the air gap.

Aiding Fields



- very strong field exists in the air gap.



Iron Rotor - reduced the air gap
- armature coils are mounted on the rotor.

D.C. Generator Construction

Armature coil is usually mounted on the rotating part. Field coils are usually mounted on the stationary part.

A.C. generators - usually the opposite is true.

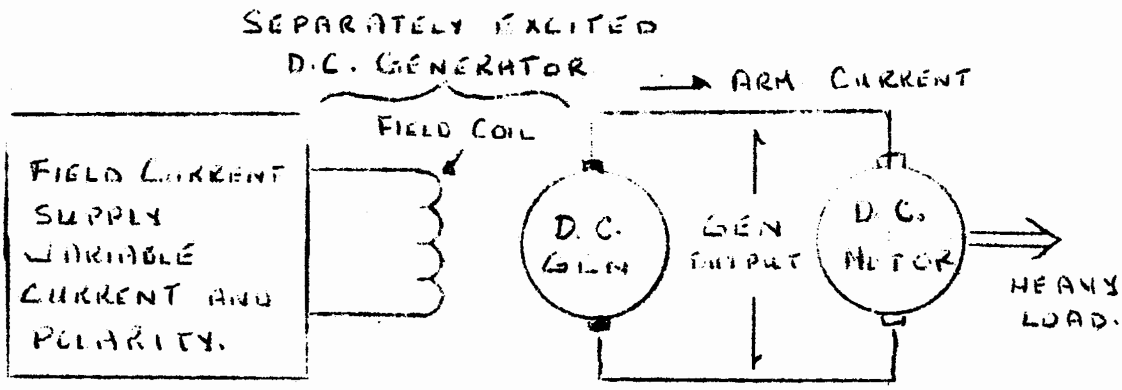
Some means of turning the rotor must exist so that generator action takes place (steam engines, steam turbines, electric motors, gasoline engines, etc.)

Direct Current Generators

Classified according to the manner in which the field is supplied with excitation current.

1. Separately Excited

- very sensitive control since field current is independent of load current.
- slight change in field current ⇒ large change in load current.



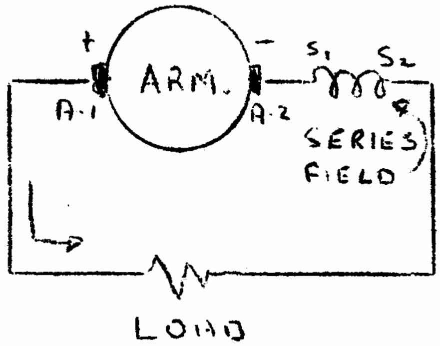
Uses: elevators, door openers, locomotives.

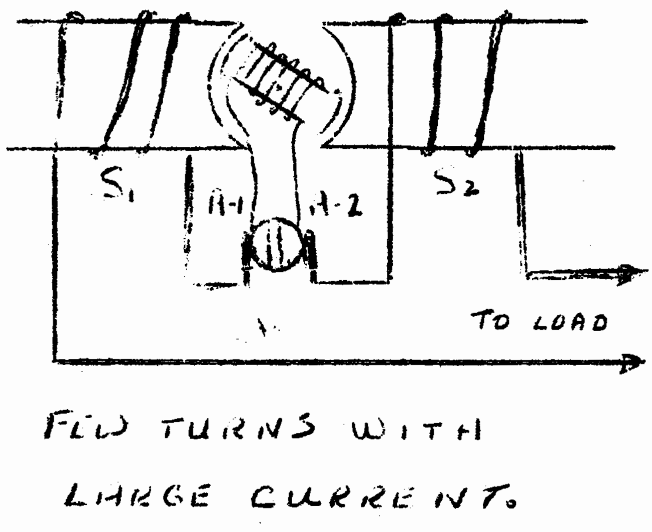
2. Self-excited D.C. generators

a. Series generator.
b. Shunt generator.
c. Compound generator

- Long shunt.
- Short shunt.

a. <u>Series Generator</u>





No load current → no field current → little emf in armature

As current increases ⇒ field strength ↑ & terminal voltage ↑

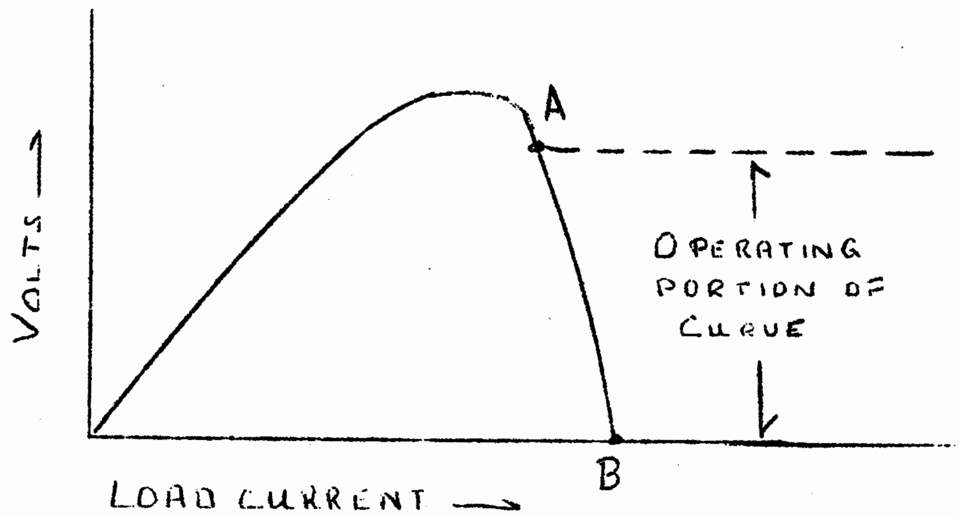
As current increases ⇒ field saturates.

Beyond point A, increasing load current decreases voltage output due to the increasing voltage drop across the resistance of the field and armature. Series generator always operated between A + B ⇒ load current ≅ constant with changes in load resistance.

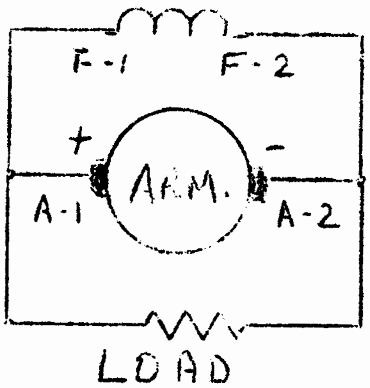
Called constant current generators. Use: to operate arc lamps.

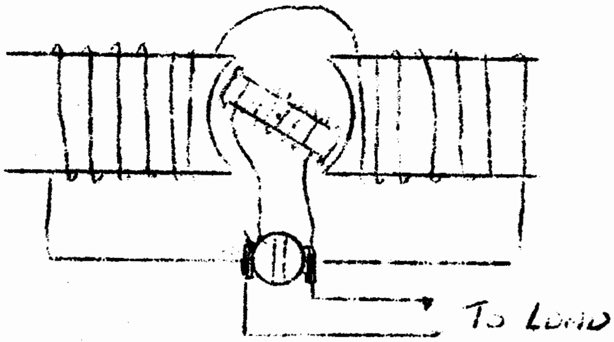
Characteristic

Curve



B. Shunt Generator





Field coil in parallel (or shunt) with armature circuit.

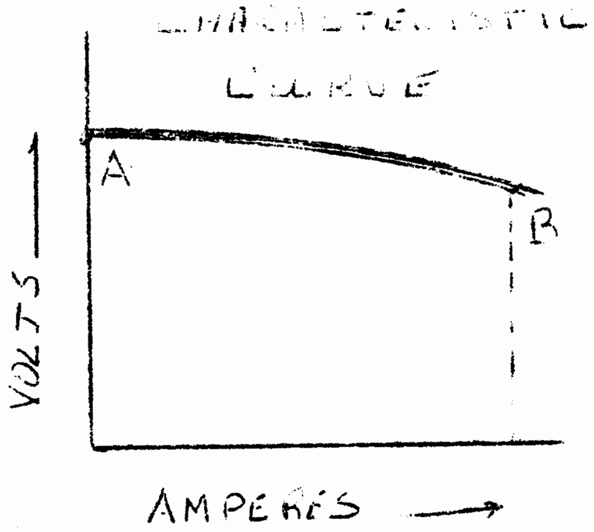
Current through field coils is determined by terminal voltage and resistance of field. Shunt windings have large no. of turns of fine wire and therefore require little current to produce necessary flux.

Buildup to rated voltage very rapid. As load draws more current from the armature, the terminal voltage decreases because the increased armature drop subtracts from the generated voltage. Over no load to full load (A to B), the drop in terminal voltage, as load current increases, is relatively small.

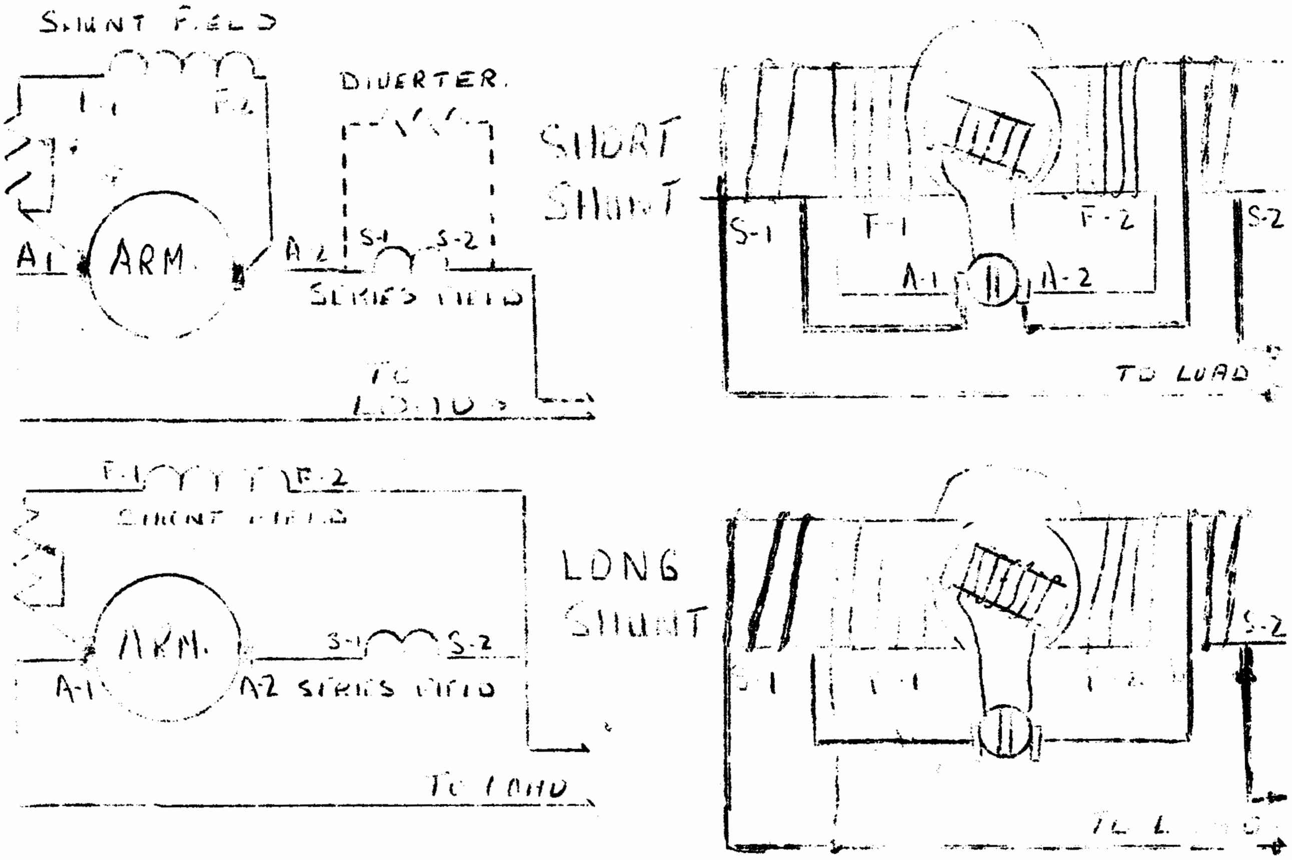
- Is operated between A-B & used as constant voltage generator.

  Never run beyond B.

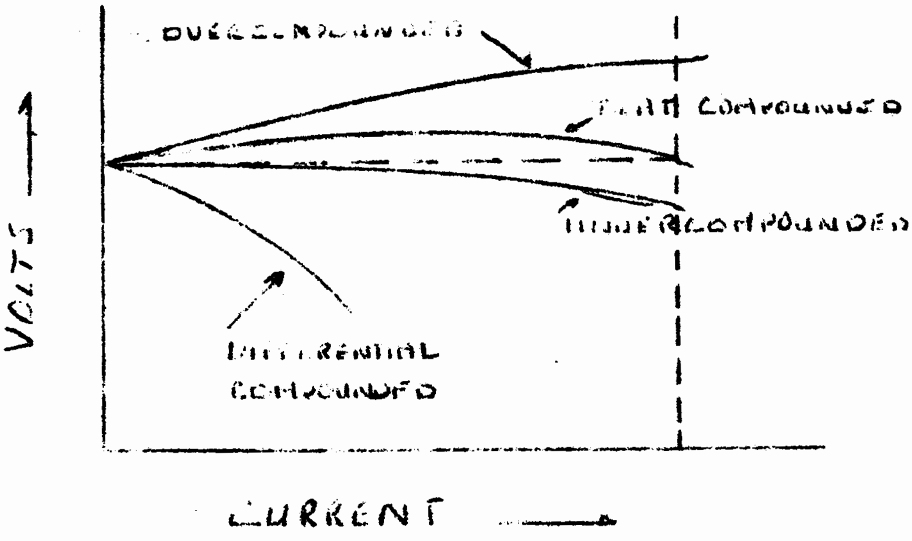
Terminal voltage controlled by varying rheostat in series with the field coils.



C. <u>Compound Generators</u>



Operating characteristics for both types of shunt connections are practically the same.



CHARACTERISTIC CURVES OF COMPOUND GENERATORS

Compound generators were designed to overcome the drop in terminal voltage which occurs in a shunt generator when the load is increased. This voltage drop is undesirable where constant voltage loads, such as lighting systems, are used. By adding the series field, which increases the strength of the total magnetic field when the load current flowing through the armature resistance is overcome, and constant voltage output is practically attained.

The voltage characteristics of the cumulative compound generator depend on the ratio of the turns in the shunt and series field winding. If the series windings are so proportioned that the terminal voltage is practically constant at all loads within its range, it is "flat-compounded". Usually in these machines the full-load voltage is the same as the no-load voltage, and the voltage at intermediate points is somewhat higher. Flat-compounded generators are used to provide a constant voltage to loads a short distance away from the generator. An "over-compounded" generator has its series turns so selected that the full-load voltage is greater than the no-load voltage. These generators are used where the load is some distance away. The increase in terminal voltage compensates for the drop in the long feeder lines, thus maintaining a constant voltage at the load. When the rated voltage is less than the no-load voltage, the machine is said to be "under-compounded". These generators are seldom used. Most cumulative compound generators are over-compound. The degree of compounding is regulated by placing a low resistance shunt called a "diverter" across the series field terminal as shown. The terminal voltage can be controlled by varying the field rheostat in series with the shunt field. In a differentially compounded generator, the shunt and series fields are in opposition. Therefore the difference, or resultant field, becomes weaker and the terminal voltage drops very rapidly with increase in load current.

Generator Voltage Buildup

In self-excited d.c. generators the armature voltage is used to excite the field. This may be a problem when the generator is first started up. The field excitation depends on the armature voltage which is induced in the armature coil when it moves through the magnetic field. How can voltage be induced if there is no initial magnetic field?

The field poles retain a certain amount of magnetism called "residual magnetism". A weak magnetic field exists which induces a small voltage and the resultant magnetic field is strengthened. This action increases until the magnetic field is saturated. The buildup time is normally 20-30 seconds.

Reasons for Generators Failing to Buildup

1. Insufficient residual magnetism → the initial magnetic field may be too weak. The initial field can be provided by using an external d.c. source - "flashing the field." (Correct polarity must be observed.)

2. Reversed shunt field connections → the induced magnetic field will oppose the residual magnetic field.

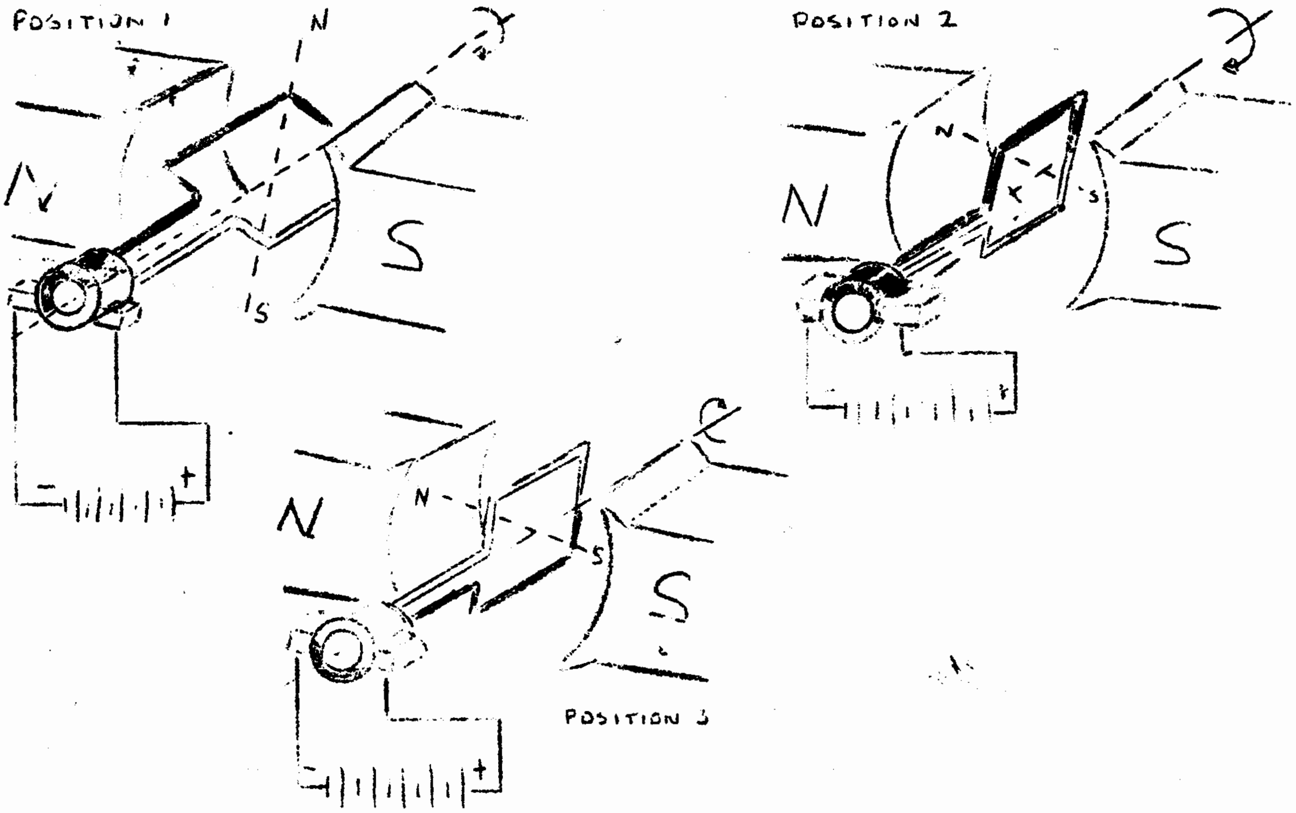
3. High shunt field resistance → the field rheostat is set at too high a resistance; must be reduced so that voltage can build up.

4. Open field circuit.

Direct Current Motors

Electrical power forces armature to turn ⇒ mechanical power out.

Uses same principle as basic galvanometer. Current in suspended coil forms magnet and is deflected by horse shoe magnet.



Commutation takes place and load continues rotating.

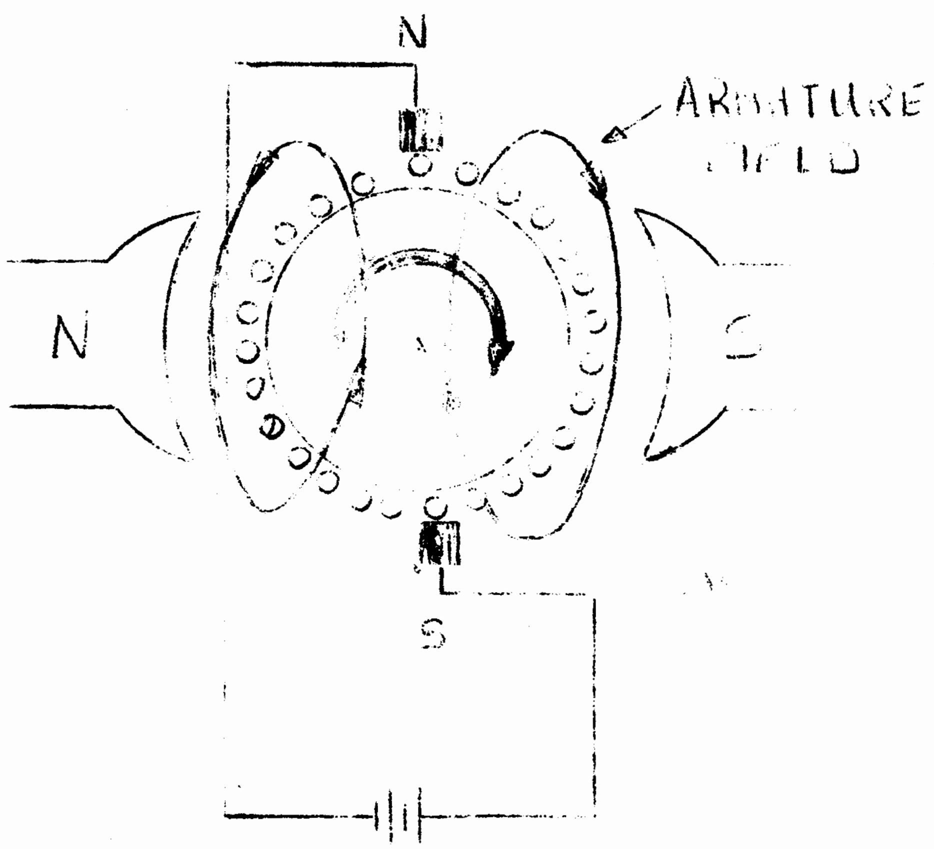
Commutator Action in a D.C. Motor

It is obvious that the commutator plays a very important part in the operation of the DC motor. The commutator causes the current through the loop to reverse at the instant unlike poles are facing each other. This causes a reversal in the polarity of the field; repulsion exists instead of attraction, and the loop continues rotating.

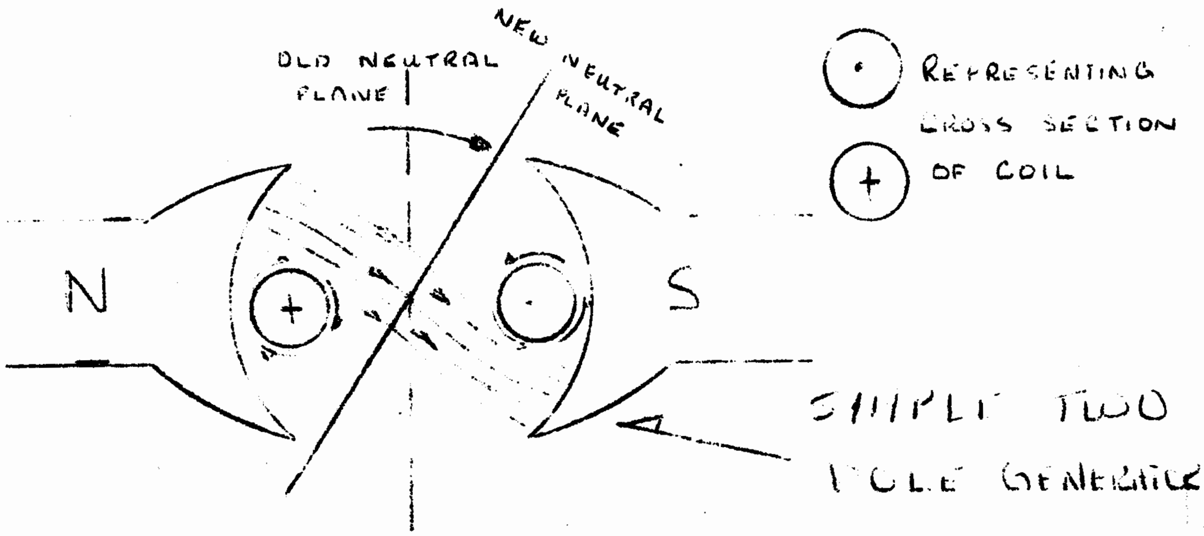
In a multi-coil armature, the armature winding acts like a coil whose axis is perpendicular to the main magnetic field and has the polarity shown below. The north pole of the armature field is attracted to the south pole of the main field. This attraction exerts a turning force on the armature, which moves in a clockwise direction. Thus a smooth and continuous torque or turning force is maintained on the armature due to the large number of coils. Since there are so many coils close to one another, a resultant armature field is produced that appears to be stationary.

Armature field re[illegible]ins
fixed as armature moves.

D.C. MOTOR



Armature Reaction



For proper commutation, the coil short-circuited by the brushes should be in the neutral plane.

Field around armature distorts **stator** field.

Shift of plane is dependent on load current ⇒ shifting brushes will not eliminate the problem, but may be used for small machines.

Two methods of correction:

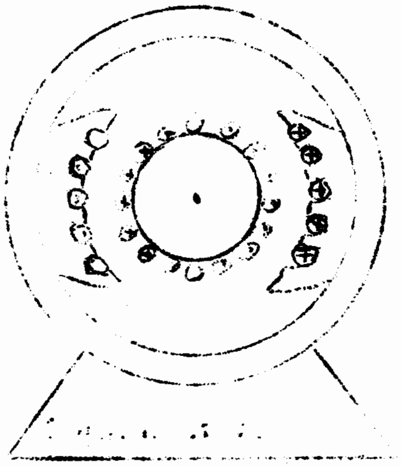
1. Use compensating windings.

   Consist of a series of coils embedded in slots in the pole faces. Coils connected in series with the armature ⇒ field they generate will just cancel the effects of armature reaction. For all values of armature current ⇒ neutral plane remains stationary.

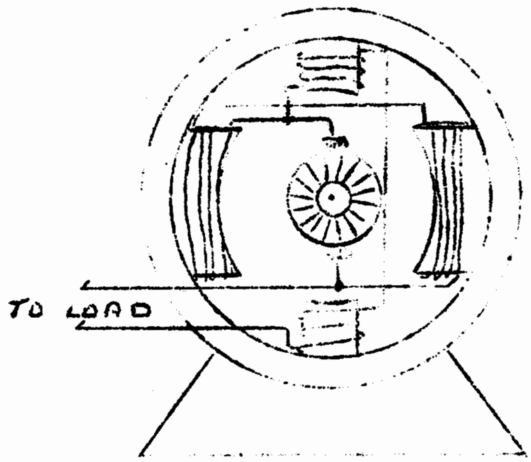
2. Use interpoles.

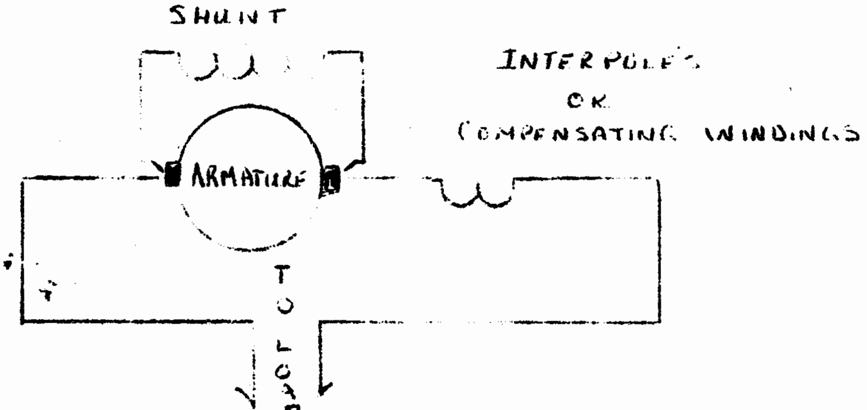
   Few turns of large wire in series with armature ⇒ field just cancels armature reaction for all values of load current.

Compensating Windings

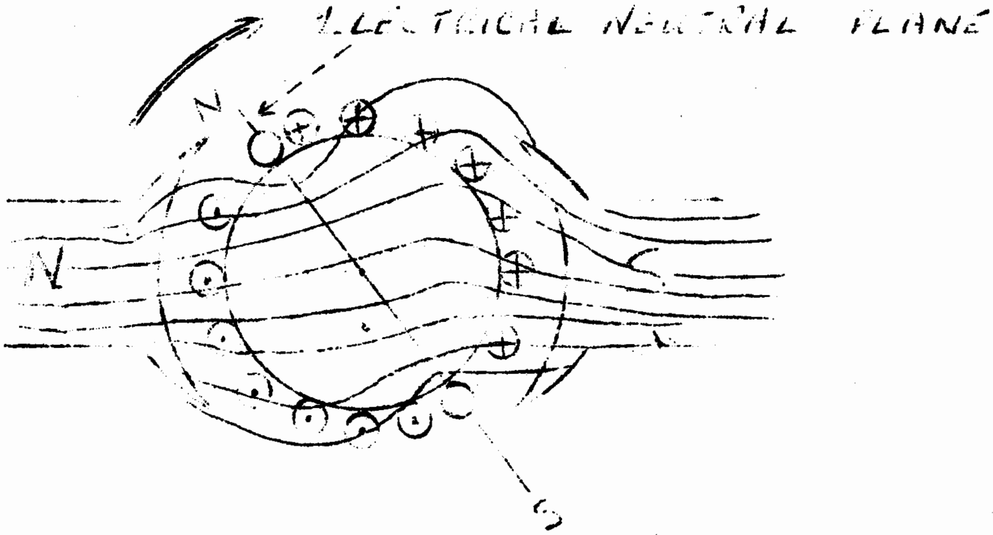


Interpoles





The effect of armature reaction is opposite for a motor c.f. a generator - may be corrected by shifting brushes backwards or using compensating windings or interpoles.



Reversing direction of motor rotation.

Direction of rotation depends on direction of field and direction of current flow in armature.

- As per left hand rule. Lines of force from north pole in direction enter palm, fingers in direction of current, thumb points in direction of motion.

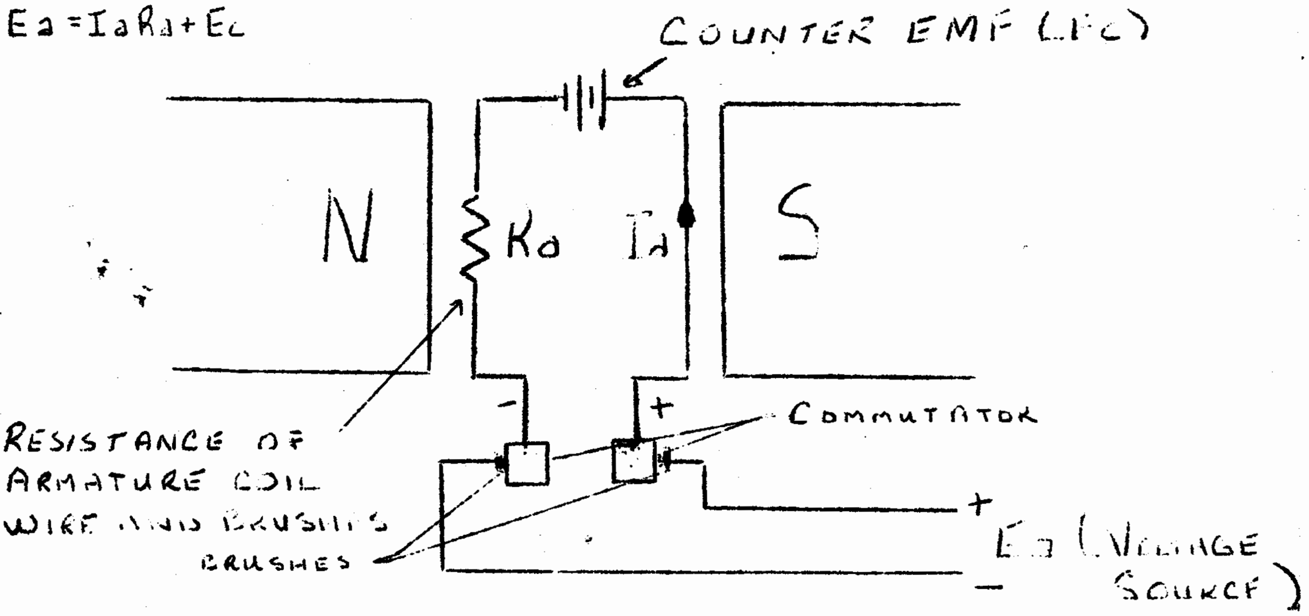
To reverse direction - reverse armature connections or reverse field connections - BUT NOT BOTH!

Counter Electromotive Force

As armature rotates ⇒ generates an emf that depends on same factors as with a generator - speed, direction of rotation, and the field strength ⇒ opposes the rotation generating the counter emf - however, generated emf will be less than applied voltage because of resistance of armature coils.

VOLTAGE SOURCE = ARMATURE DROP + COUNTER E.M.F.

$E_a = I_a R_a + E_c$



$I_a = \frac{E_a - E_c}{R_a}$ Ra = internal resistance of armature of D.C. motor is generally low

Therefore, at start if $E_a = 230V$ & $E_c = 0$

$$I_a = \frac{230 - 0}{1\Omega} = 220 \text{ amps} \Rightarrow !$$

If Ec = 220v when motor is turning,

$$I_a = \frac{230 - 220}{1} = 10 \text{ amps}$$

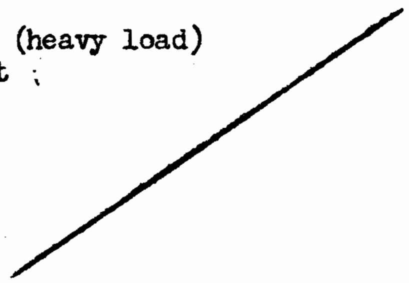
Must use resistance in series with armature to limit current. As rpm ↑ Ec ↑ and resistance may be decreased to 0.

SPEED DEPENDS ON LOAD.

How [illegible] varies with torque
requir[illegible]

Large torque (heavy load)
Large current

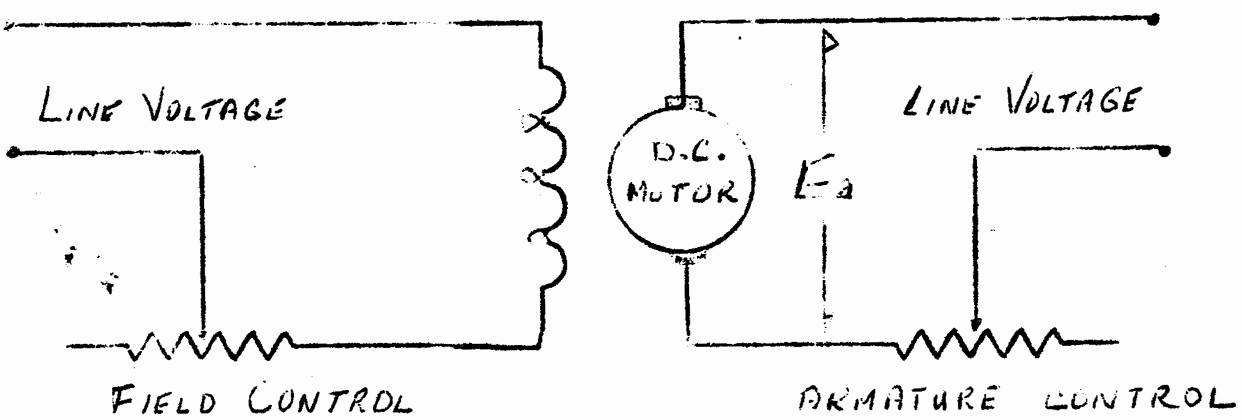
Low speed



Small torque (light load)
Small current ($E_t = I_a R_a + E_c$)

High speed.

Speed of rotation of a D.C. motor depends on the field strength and armature voltage.



As field strength ↓ R.P.M. ↑ to generate counter emf

$$E_t = I_a R_a + E_c$$

magnetic lines ↓ ∴ # cut ↑ ⟹ speed up.

If field circuit opens → only residual magnetism & if load light → will probably fly apart.

Vary field strength - vary speed. Vary armature control - vary speed BUT not usually used because of large rheostat necessary, and starting torque is lowered (effectively we are varying Ea.)

Three Types of D.C. Motors

1. Shunt motors.
2. Series motors.
3. Compound motors.

1. Shunt Motors

- Field connected directly across line and is therefore independent of variations in load and armature current.

- Torque varies with armature current.

  - If load increases - motor slows down - reduces counter emf → allows armature current to increase - provides more torque.

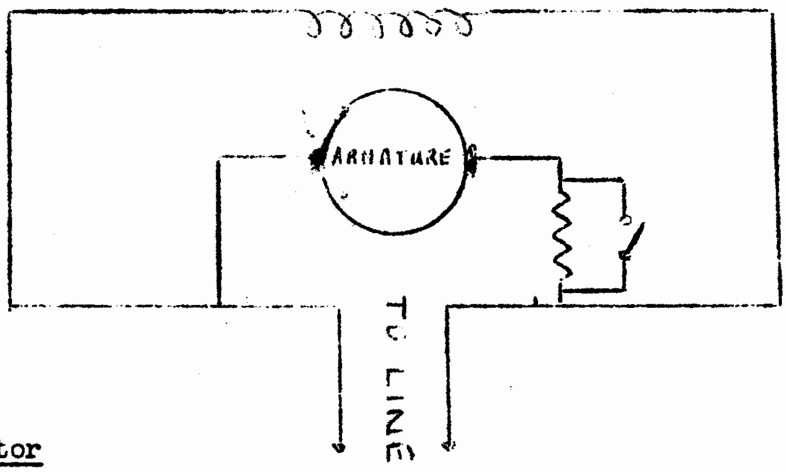
- If load decreases - motor speeds up - increases counter emf → less armature current → less torque.

- Speed variation from full load to no load ≈ 10% of no load speed.

Constant Speed Motor

To start motor - need resistance in series with armature to limit current → low starting torque.

- usually used where constant speed under varying load is desired, and where little or no load is present in starting.



2. Series Motor

Field connected in series with armature and load.
Load increases ⇒ motors slows down
counter emf decreases

→ current increases
→ torque increases.

Runs very slowly with heavy load and very fast with light load.

- Remove load and motor cannot turn fast enough to generate sufficient counter emf.

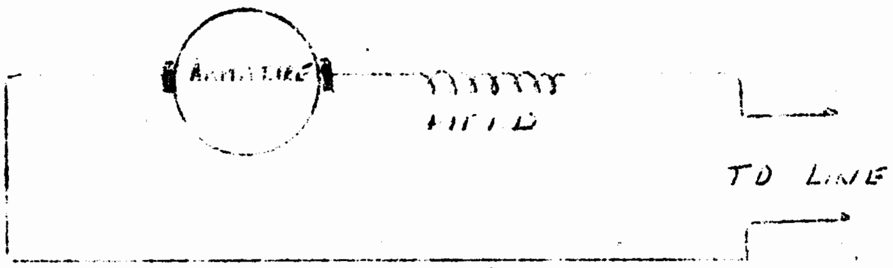
    ⇒ faster - faster ... flies apart

MUST NEVER be run under NO LOAD CONDITIONS,

has: tremendous starting torque.
rapid acceleration.

heavy load - high torque & low speed.
light load - low torque & high speed.

Uses: Cranes
Hoists
Trains
Trolleys



3. Compound Motors

Combination of series and shunt motor.
Field consists of two separate sets of coils:

- One in shunt - large no. turns, fine wire.
  other in series - few turns, large wire.

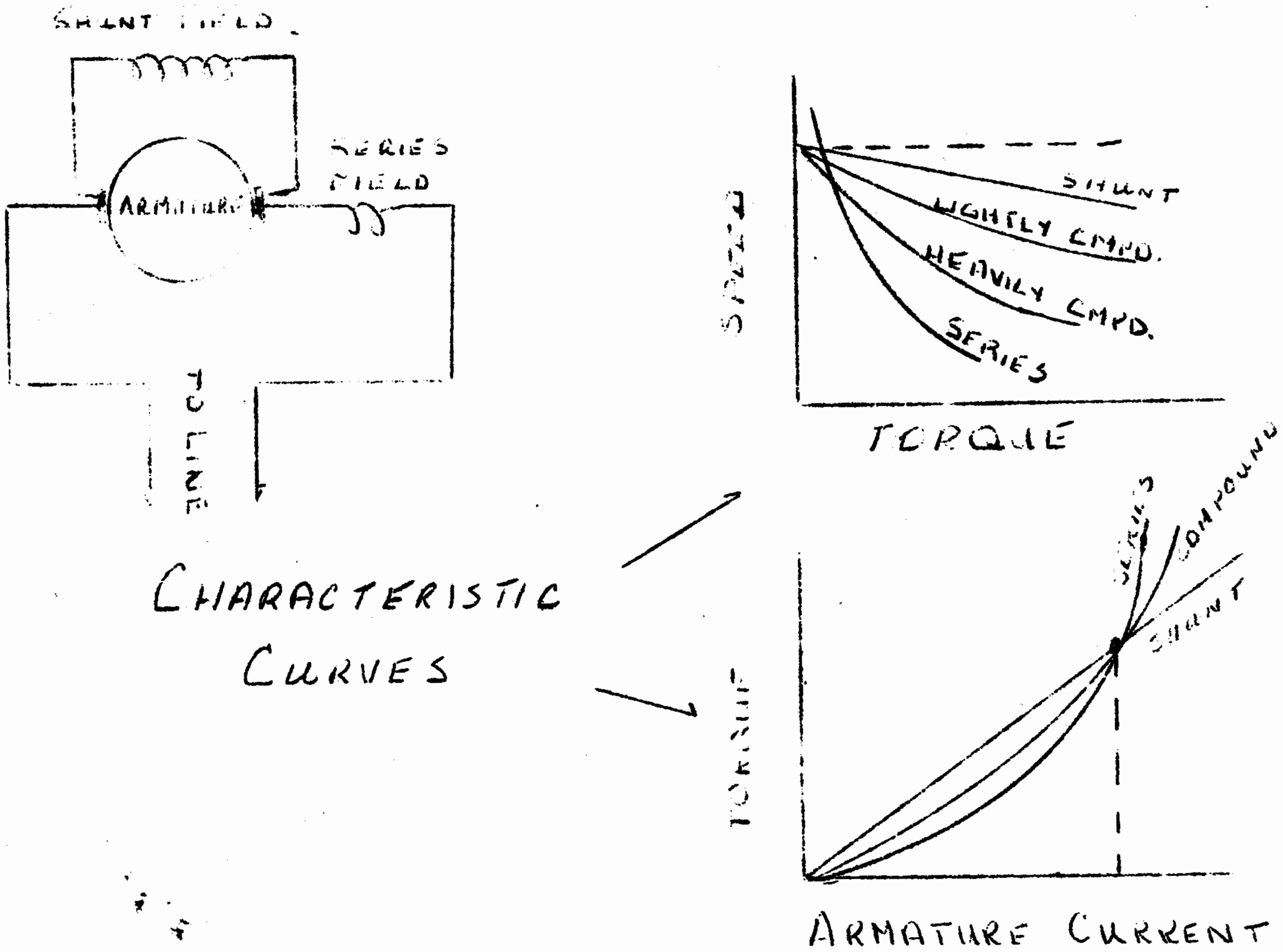
Most common type used - cumulatively compounded.

- An increase in load decreases speed and greatly increases torque.
- Starting torque is also large.

Fairly constant speed motor with high torque on heavy loads and good starting torque.

In differentially compounded motors the two fields oppose each other.

- This type is rarely used.
- Speed increases with increased load (to a point).
- Starting torque is low.



<u>A.C. Generators or Alternators</u>

Relative motion between a conductor and a magnetic field → a generated voltage.

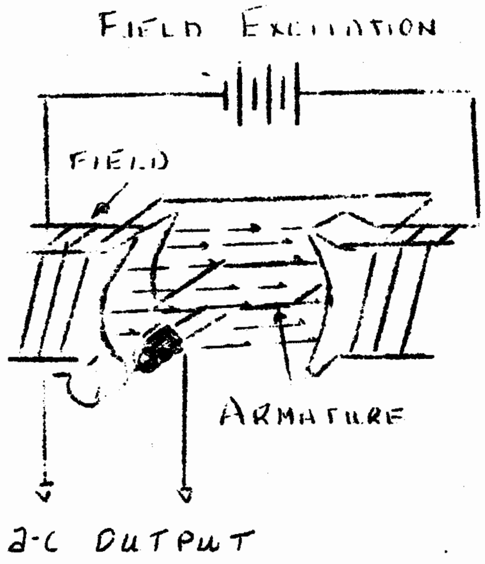
Field - that part which generates the magnetic field.
Armature - that part which the voltage is generated.

<u>Rotor and Stator</u>

- In d.c. generators - armature is always the rotor.
- In a.c. - ?

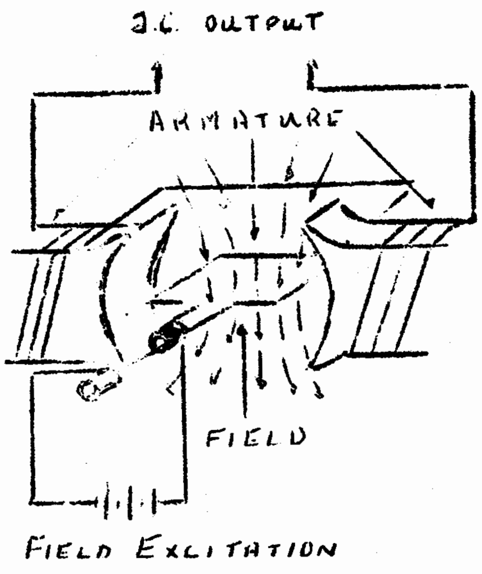
Two types of alternators:

- Revolving armature.
- Revolving field.



Rotating Armature Alternator

Same as D.C. generator except output taken off slip rings instead of commutator.
Used for small power rating.
Not generally used.



Rotating Field Alternator

Generated voltage connected directly to load. The voltage applied to the rotating field is low D.C. and therefore no problem with slip ring arcing as with rotating armature.

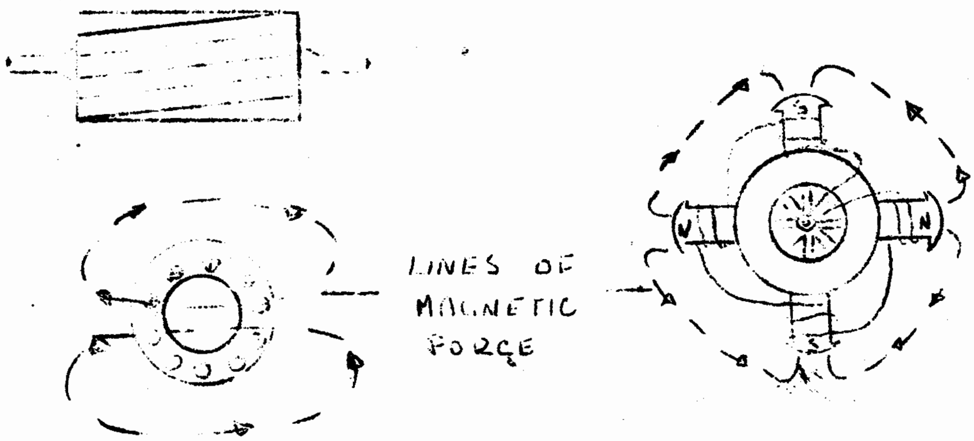
Maximum output of alternator depends on maximum heating (I^2R) power loss.

Alternator generally rated at K.V.A.

<u>Alternator Construction</u>

Turbine driven > 1200 R.P.M.

Salient pole < 1200 R.P.M.



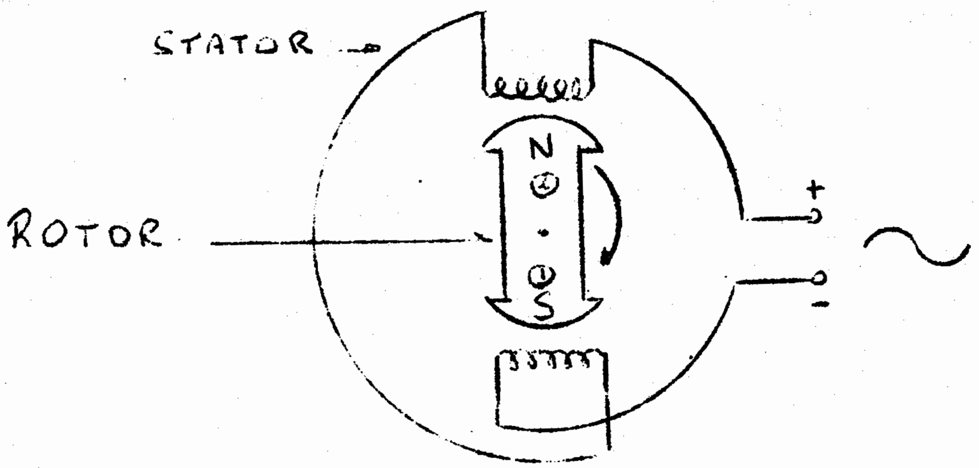
Windings arranged to form 2 or 4 distinct poles.
Can withstand the terrific centrifugal force.

Field windings are in series or series groups - connected in parallel.

The stationary armature or stator of an alternator holds the windings that are cut by the rotating magnetic field. The voltage generated in the armature as a result of this cutting action is the A-C power which is applied to the load.

Stators consist of a laminated iron core with armature windings imbedded in this core.

Alternator - Single Phase



Two pole - single phase

Stator wound in two distinct pole groups.

- both poles wound in same direction around the stator frame.

Rotor consists of two pole groups - adjacent poles being of opposite polarity.

Connected so that AC voltages are in phase or "series aiding."

Assume rotor pole 1 (south pole) induces a voltage as shown in stator pole 1. Rotor pole 2 (north) induces opposite polarity in stator pole 2 As connected is series aiding - therefore, twice the voltage of an individual pole.

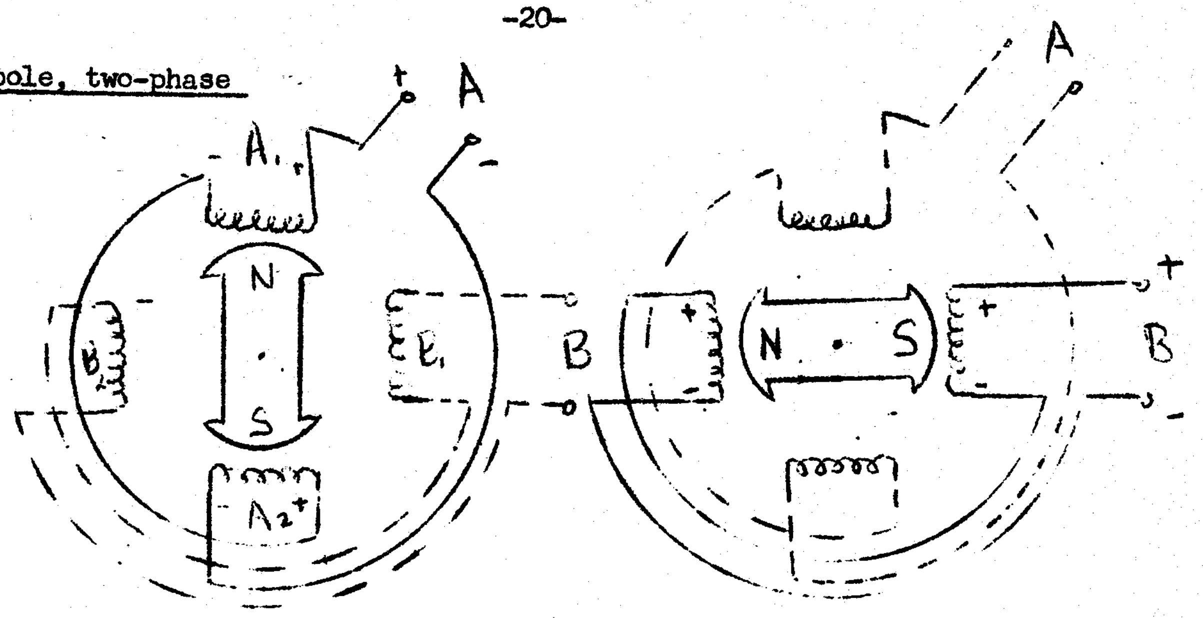
Two-pole, two-phase alternator

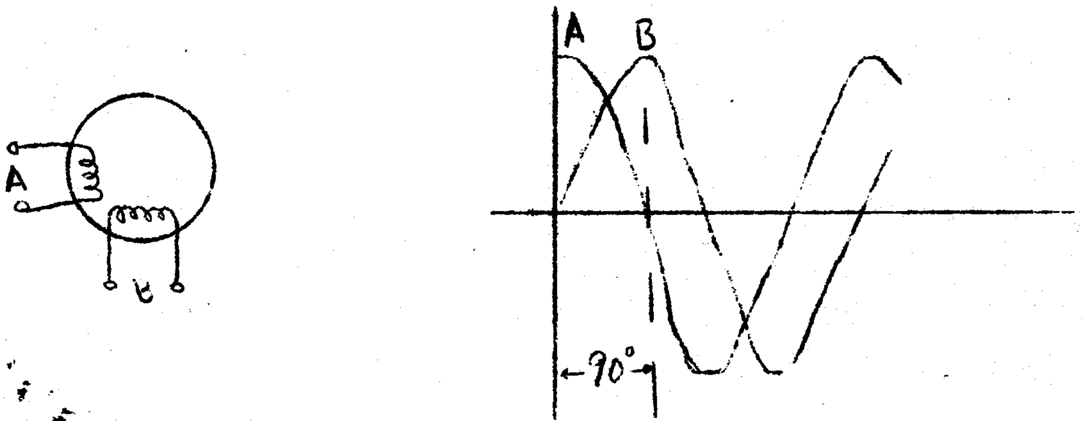
Two separated windings:

90° phase shift - voltage induced in one is maximum while other is minimum.

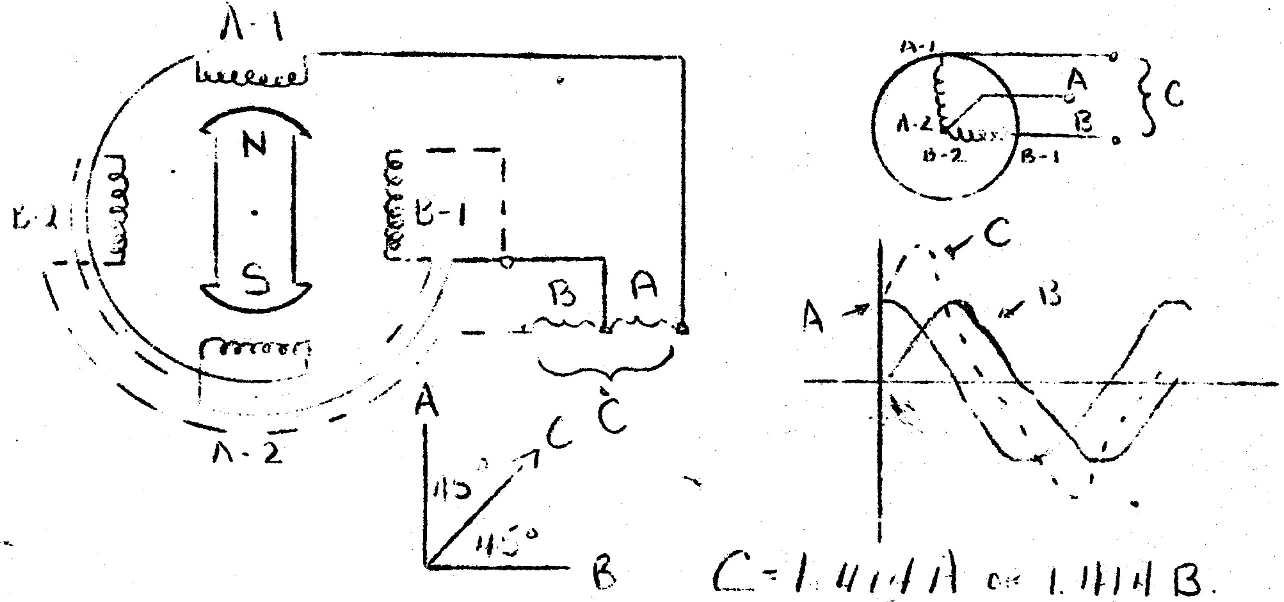
Each winding as in single phase.

Two-pole, two-phase



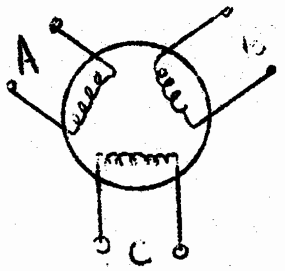


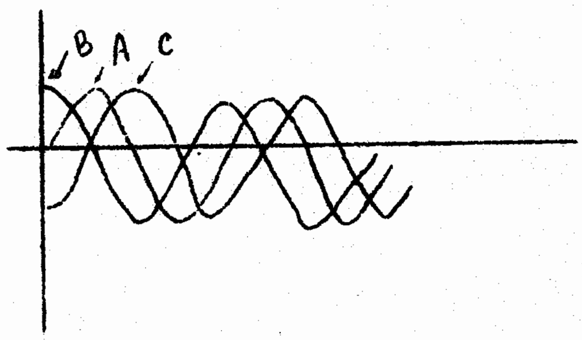
Two-phase, three wire



Three Phase Alternator

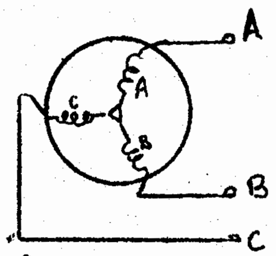
120° apart - three separate single phase generators.





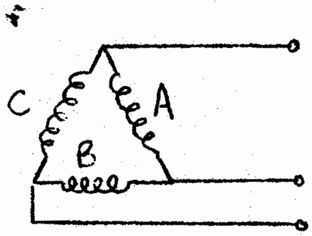
Two types of connections:

Wye or star.



Line to line voltage = $\sqrt{3}$ line to neutral voltage

Delta



Line current = $\sqrt{3}$ phase current

Frequency of generation depends on number of poles and speed of rotation.
More poles → lower rpm to give same generated frequency.

Alternating Current Motors

Since almost all power generated is AC, most motors are designed for AC operation. The advantage over DC motors is that commutation and the associated problems are eliminated.

- Suited for constant speed applications because the speed is determined by the frequency of the applied voltage.

Principle of Operation

- The AC applied to the motors generates a rotating magnetic field which causes the rotor to turn.

Synchronous Motŏr

- Alternator operated as a motir in which three-phase AC is applied to the stator and DC is applied to the rotor.

Induction Motor

- No sourse of power is connected to rotor.
- More common.

Rotating Magnetic Field

- At any instant the magnetic field generated by one phase depends on the current through that phase. If the current is zero, the magnetic field is zero. Since the three phases are 120° out of phase, the magnetic fields generated will also be 120° out of phase.

Synchronous Motors

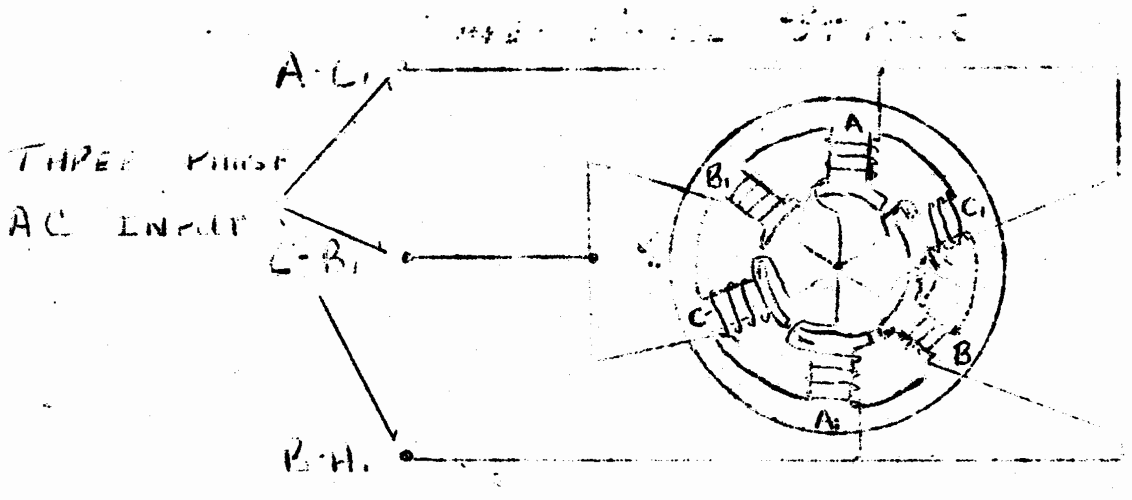
- Essentially the same as the salient-pole alternator.

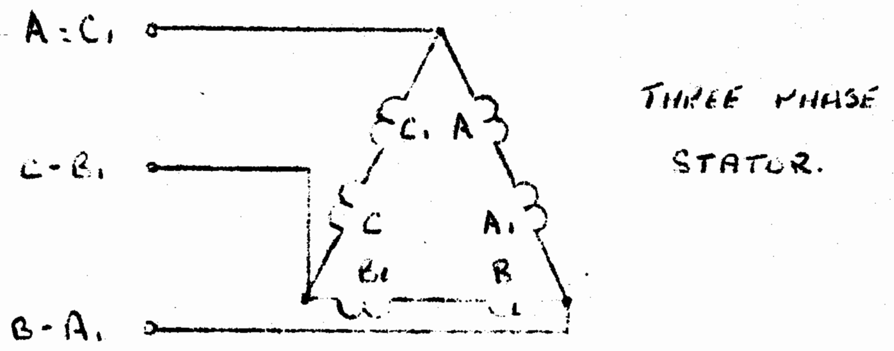
Since the rotor is energized which d.c., it acts like a bar magnet. A bar magnet, like a compass, always lines up with the magnetic field. If the magnetic field turns, the rotor will turn with it.

The starting torque of a synchronous motor in its pure form is very low. When the stator voltage is applied, themagnetic field moves so quickly that the rotor does not have a chance to get started.

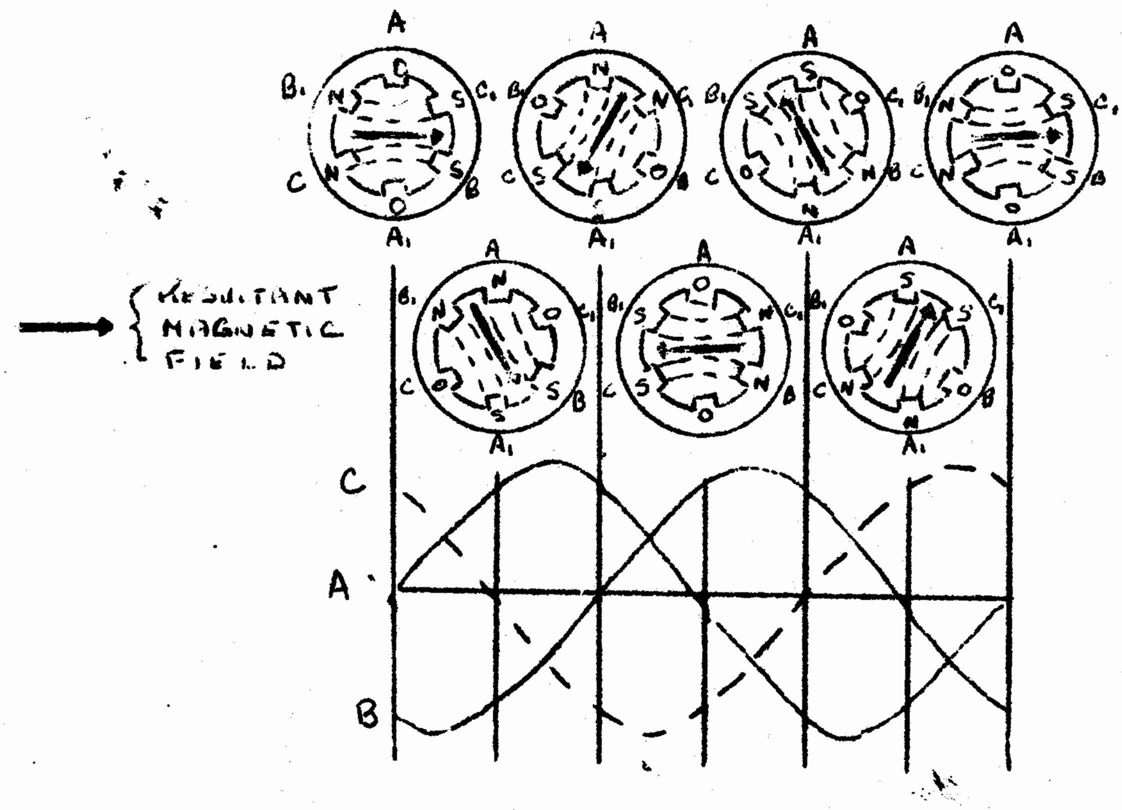
Generally, synchronous motors are started as squirrel-cage motors, i.e. the stator is energized and the d.c. supply to the field is not energized. A magnetic field is generated in the squirrel-cage rotor. The two fields interact and the rotor begins to turn. When near synchronous speed is reached, the d.c. field is energized, locking the rotor in step with the rotating magnetic field.

- Used for loads that require constant speed from no-load to full-load.





GENERATING A ROTATING MAGNETIC FIELD.



If the arrows are followed around, it can be seen that the magnetic field actually rotates.

Induction Motors

- Most often used because of its simplicity, rugged construction and low cost.
- AC currents are induced in the rotor by rotating magnetic field in stator.
- Stator construction similar to that of synchronous motor.
- Rotor is made of a laminated cylinder with slots in surface. The windings in the slots are of two different types:

Squirrel-cage Winding

- Winding is made of heavy copper bars connected at each end by heavy copper plates. Insulation between the core and bars is not necessary because low voltages are generated.

Wound Rotor

- Coils are placed in the slots.

The rotating magnetic field generated in the stator induces a magnetic field in the rotor. The two magnetic fields interact and the rotor turns as a result of the interaction. The rotor will turn in the same direction as the rotating magnetic field.

Slip in Induction Motors

If the rotor would rotate as fast as the magnetic field there would be no motion between them - i.e. there would be no magnetic field induced in the rotor. In order for the induction motor to operate the rotor must turn slower than the magnetic field. The percentage difference between the two velocities is known as "slip".

$$\text{Slip} = \frac{S_s - R_s}{S_s} \times 100\%$$

S_s = synchronous speed R_s = rotor speed

The speed of rotation depends on the torque requirements. The bigger the load, the stronger the torque required. Torque increases with an increased emf- i.e. the motor must slow down so that an increased number of lines of force is cut to generate the increased emf. The induction motor is very sensitive to change in speed - i.e. a small change in speed results in large changes in torque. Therefore, induction motors are also constant speed motors.

Two Phase Induction Motor

- Two phase voltage applied to stator with windings placed 90° apart.

  ⇒ Rotating magnetic field.

Single Phase Motors (2 basic types)

1. Induction motors: - use squirrel cage rotor and a suitable starting device.
2. Series motor: - has commutator and brushes.

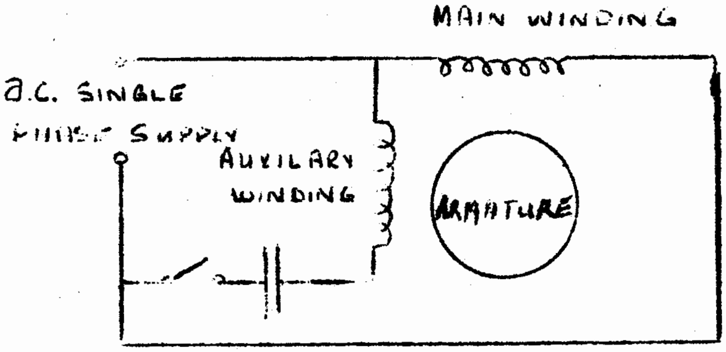
Single Phase Induction Motors

- Field alternates along the axis of the single winding rather than rotating.
- Once started, it will continue to rotate in that direction.

Impedance Start Induction Motors

- Either capacitor or resistor start.

Capacitor Start



- Auxiliary winding: - addition of capacitor gives an effective resistive-capacitive circuit with current leading applied voltage by approximately 45 degrees.

- Main winding: - has sufficient resistance and inductance to cause current to lag applied voltage by approximately 45 degrees.

- Produces two currents approximately 90° out of phase and hence produces a rotating magnetic field as with the two phase induction motor.

- At start up, auxiliary winding draws large current.

- Can be run as a single phase motor by disconnecting auxiliary winding or as a two phase motor by using another smaller capacitor connected in place of the first after start up.

Resistor Start

- Replace capacitor by resistor.

- Maining winding: has high inductance and low resistance.

  ⇒ Current lags voltage by large angle- say 70 degrees.

- Auxiliary winding: has low inductance and high resistance.

  ⇒ Current lags voltage by small angle - say 40 degrees.

- Net effect produces a difference in phase of say 30 degrees.

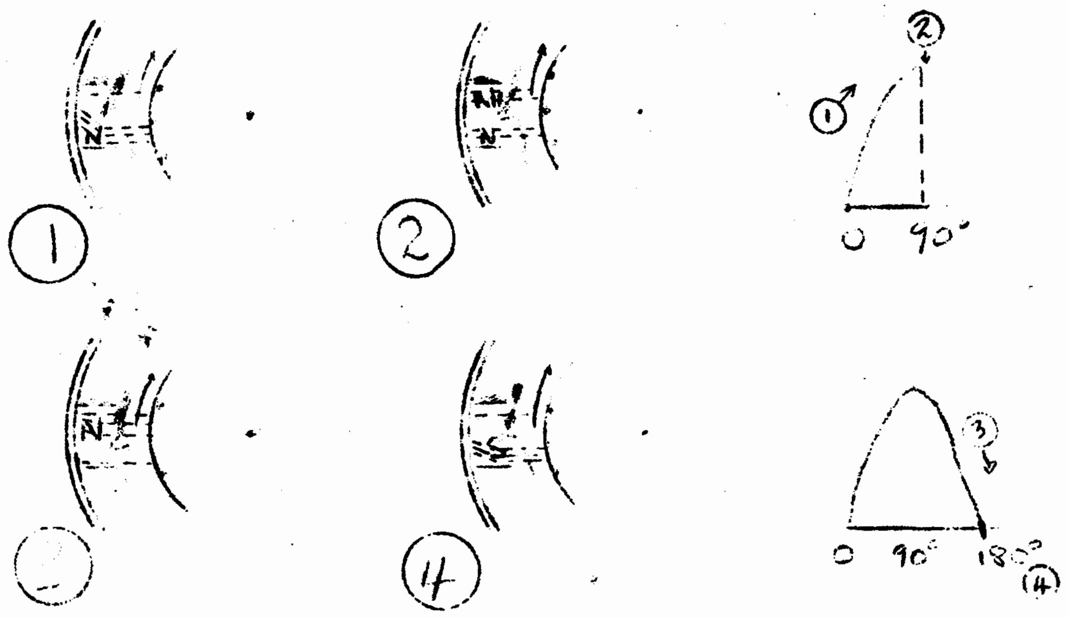
- Motor comes to speed and centrifugal switch can disconnect auxiliary winding.

Shaded Pole Induction Motors

- Has section of each pole face in the stator shorted out by a metal strap.

- Has affect of moving the magnetic field back and forth across the pole face.

- Produces same effect as rotating magnetic field and motor can start up by itself.

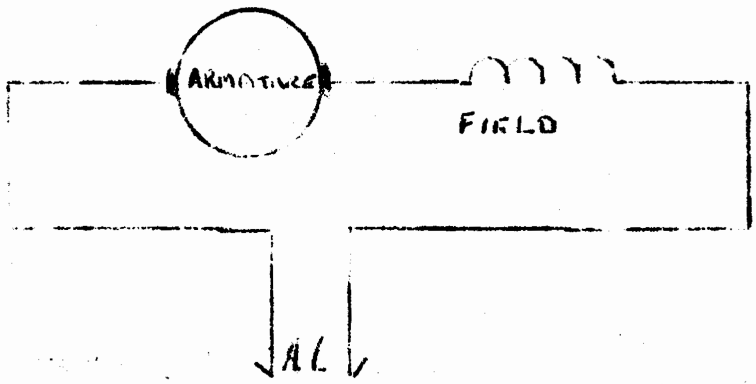


A-C Series Motor

- Recall current through series motor can be reversed and direction of rotation will remain the same.

- Number of turns for the a.c. series motor are less than d.c. to decrease reactance of field to allow sufficient current to flow.

- Reduced field - reduced torque and hence only useful for fractional horse power motors.



- Can design to be universal - operate off either a.c. or d.c., but efficiency is lost.

Single Phase Repulsion Motor

- Practically identical to a d.c. motor having a drum wound rotor and a commutator except that the brushes are shorted out.

- Position of brushes determines values of torque.