Three Phase Synchronous Machine

Synchronous machine is an a. c. machine

Three forms
1. Synchronous Motor
2. Syn Generator or Alternator
3. Syn Condenser

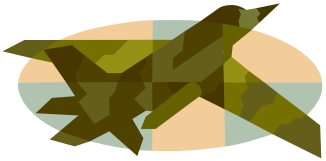
Main Two windings: 1. Armature winding

a) Similar to stator wdg of Ind. m/c.

b) Distributed ac winding.

c) Absorbs or imports ac power- Motor

d) Delivers or exports ac power - Generator



2. Field winding

a) Similar to field wdg of dc machine

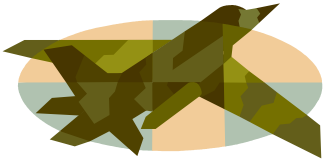
b) Concentrated dc winding.

c) Always absorbs or imports dc power whether Motor or Generator

Therefore, syn. m/c is a DOUBLY excited ac m/c.

Armature winding is connected to ac source.

Field winding is connected to dc source.



Third winding: Damper or ammortisseur winding

a) Similar to compensated winding of dc machine, housed in the pole shoe.

b) But short circuited similar to squirrel cage wdg

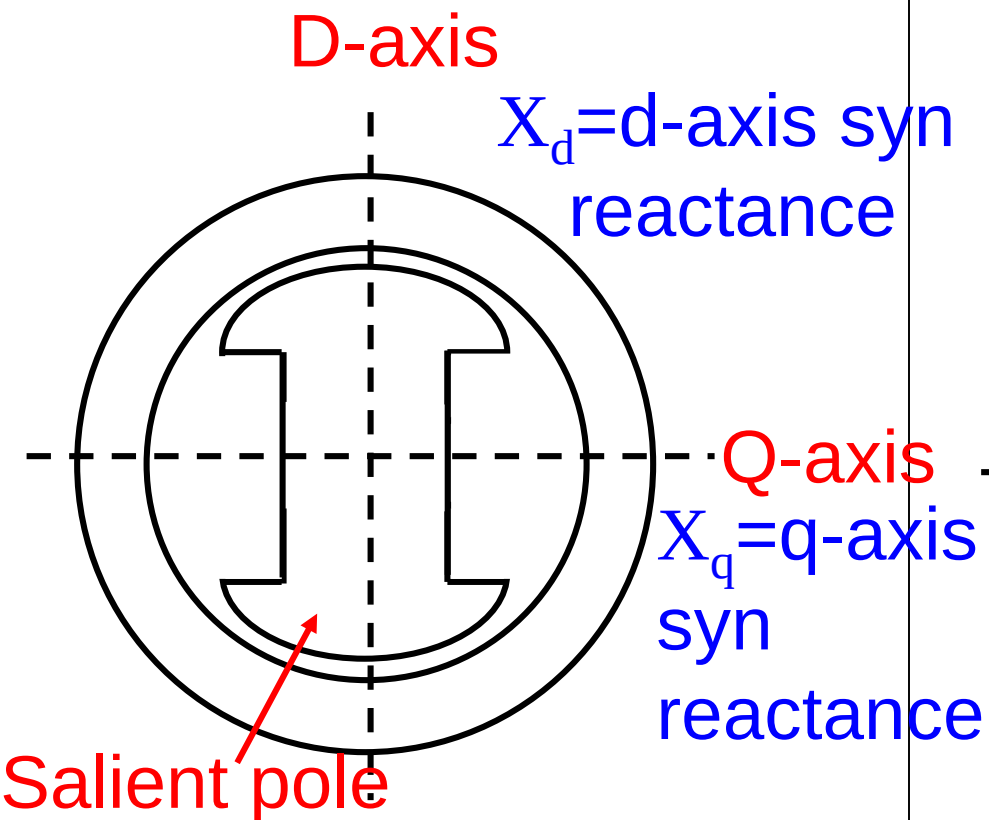
c) Damps the rotor oscillations.

Rotor material: Chromium-Nickel –Molybdenum steel=High tensile strength.

Construction

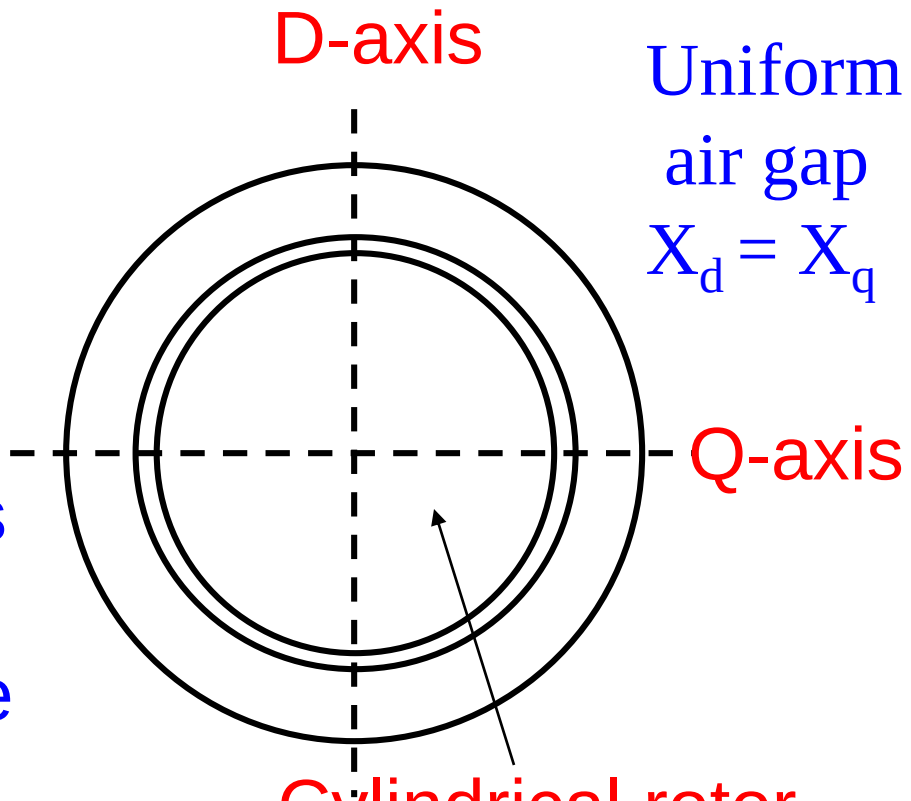
Two types:

1. Salient pole or Projecting pole type syn m/c

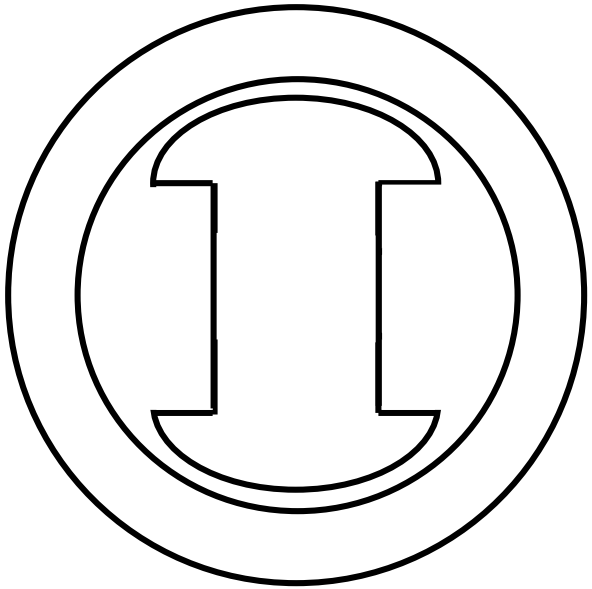


Non-uniform air gap, $X_d \neq X_q$

2. Cylindrical rotor or Round rotor or Non-salient type syn m/c



Construction

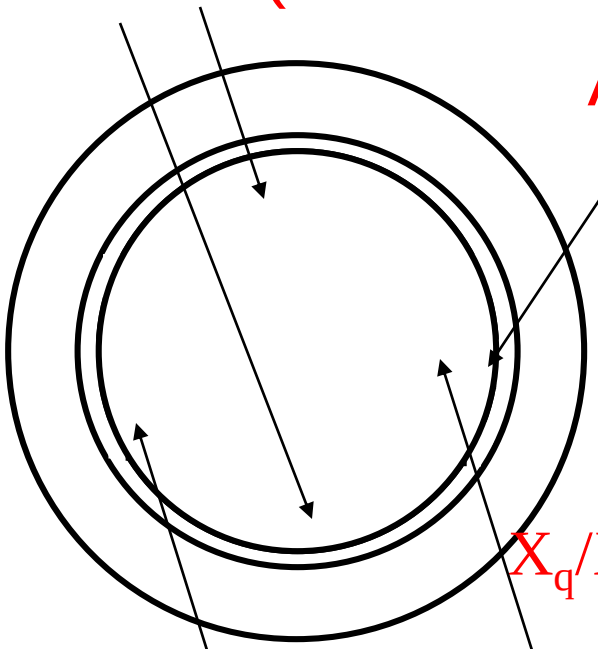


There are two types of cylindrical rotor

1. Parallel slot rotor

Pole (1/3 without slot)

Air gap



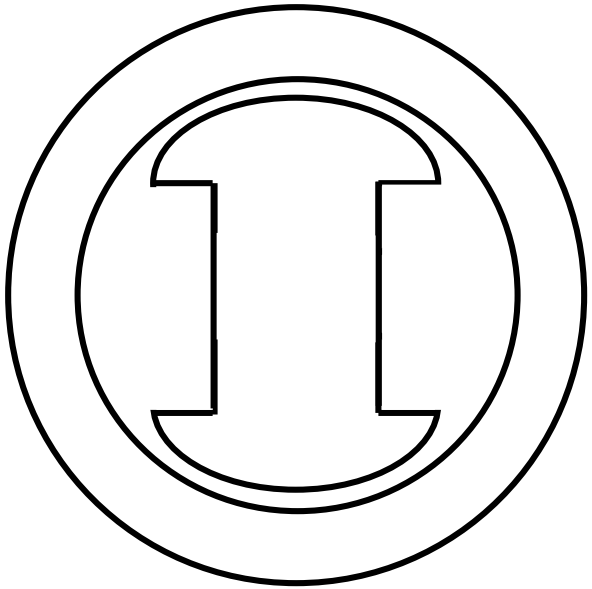
$X_d \neq X_q$

$X_q/X_d \neq 1$

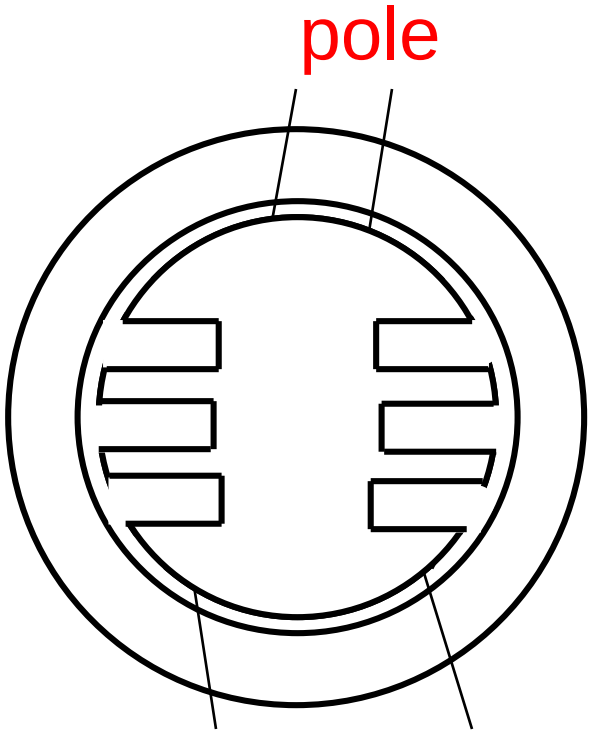
$X_q/X_d = 0.95$ to 0.98

Parallel sided slots

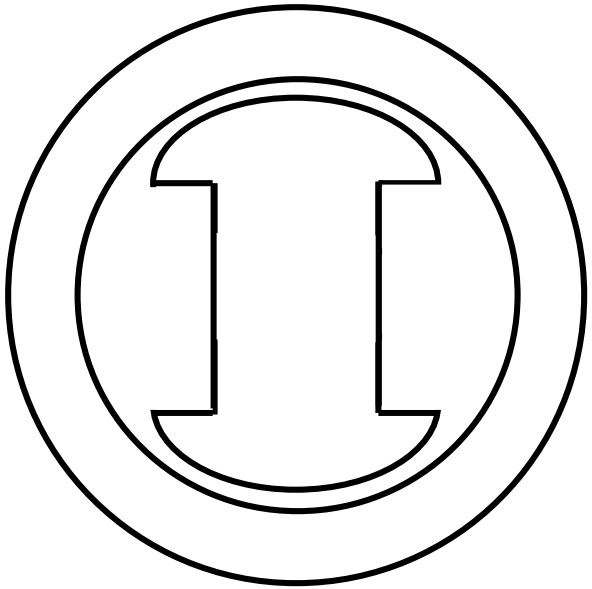
Construction



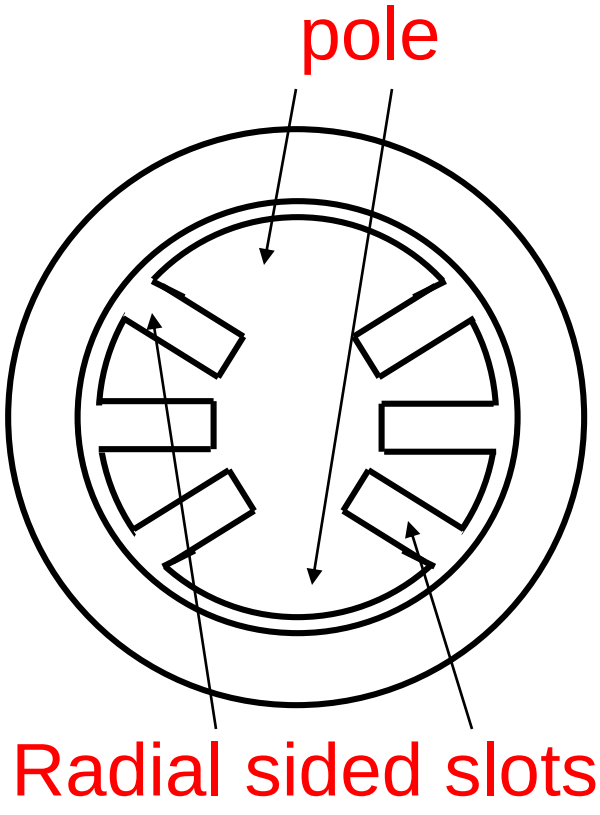
2. Radial slot rotor



Construction



2. Radial slot rotor



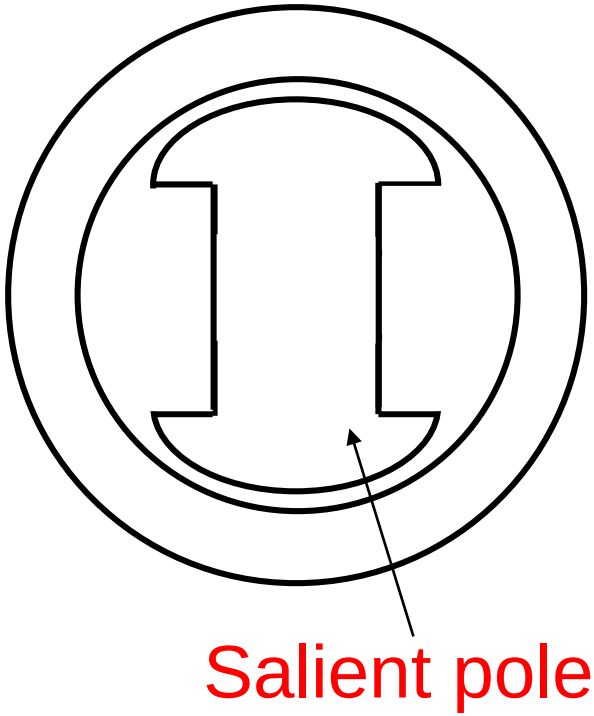
Construction

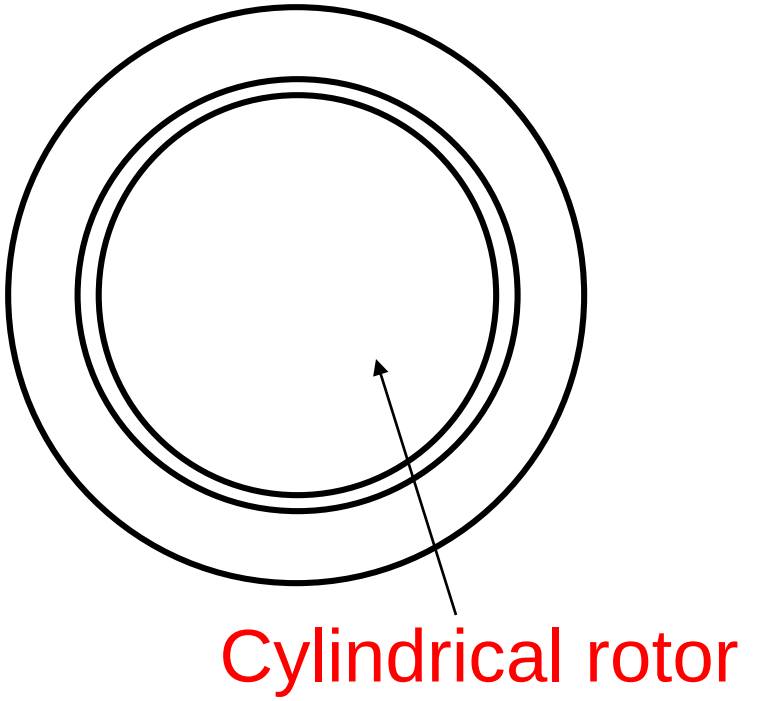
1. Salient pole syn m/c

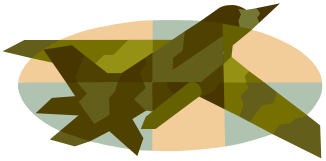
2. Cylindrical rotor syn m/c

The Differences are:

1.

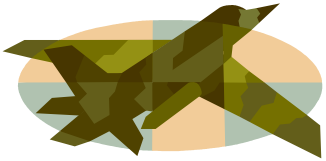






Construction

2. Non-uniform air gap	Uniform air gap
3. X_d d-axis syn reactance ≠ X_q q-axis syn reactance	$X_d = X_q = X_s$
4. Poles > 4	Poles ≤ 4
5. Used in LOW speed m/c	HIGH speed machine
6. Small core length, large diameter to accommodate large no of poles.	Long length, small diameter to limit large centrifugal forces due to high speed.

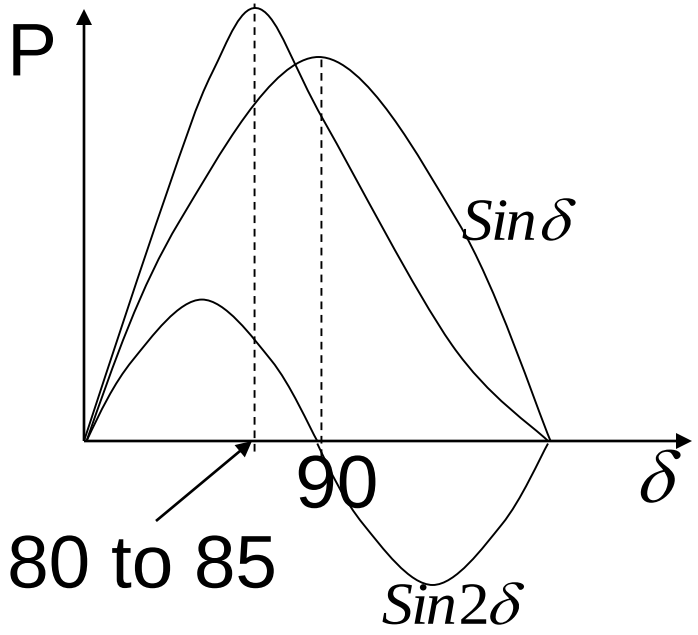


7. Hydro-generator in which rotor is driven by Hydro-Turbine is designed with this pole.	Turbo-generator in which rotor is driven by Steam-Turbine.
8. Under fault, there are more chances of deformation of rotor due to non-uniform air gap.	Under fault, there are less chances of deformation of rotor due to uniform air gap.
9. Output waveform is not sinusoidal (more harmonics)	Output waveform is more nearer to sine wave.

10. Output Power

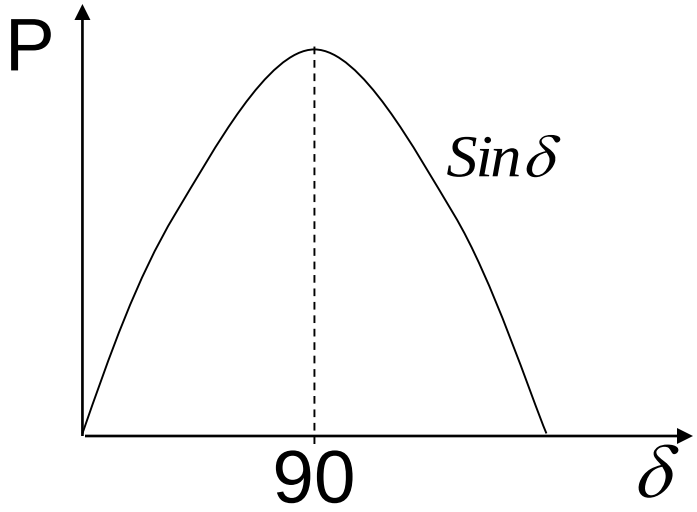
$$P = \frac{E_f V_t}{X_d} Sin\delta + \frac{V_t^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right) Sin2\delta$$

=Electromagnetic Power
+ Reluctance Power

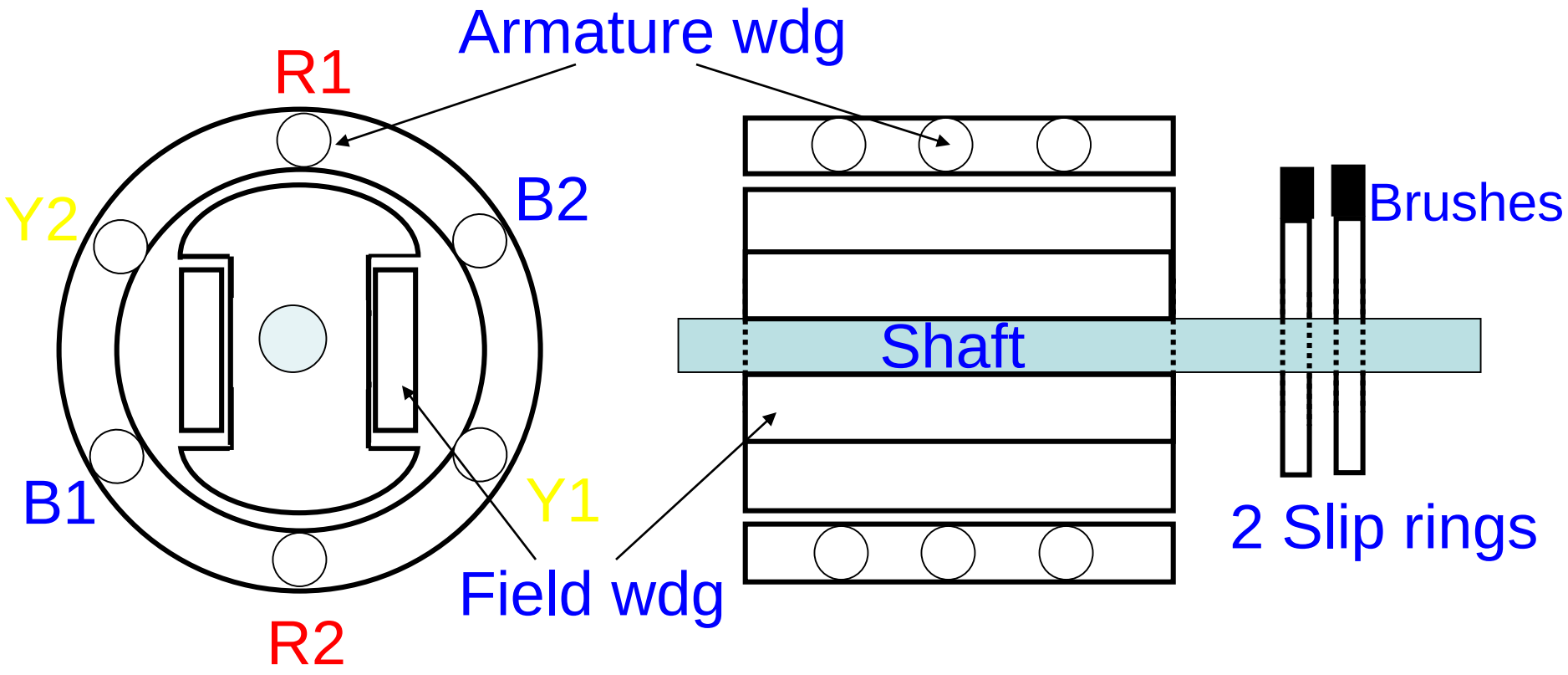


$$P = \frac{E_f V_t}{X_s} Sin\delta$$

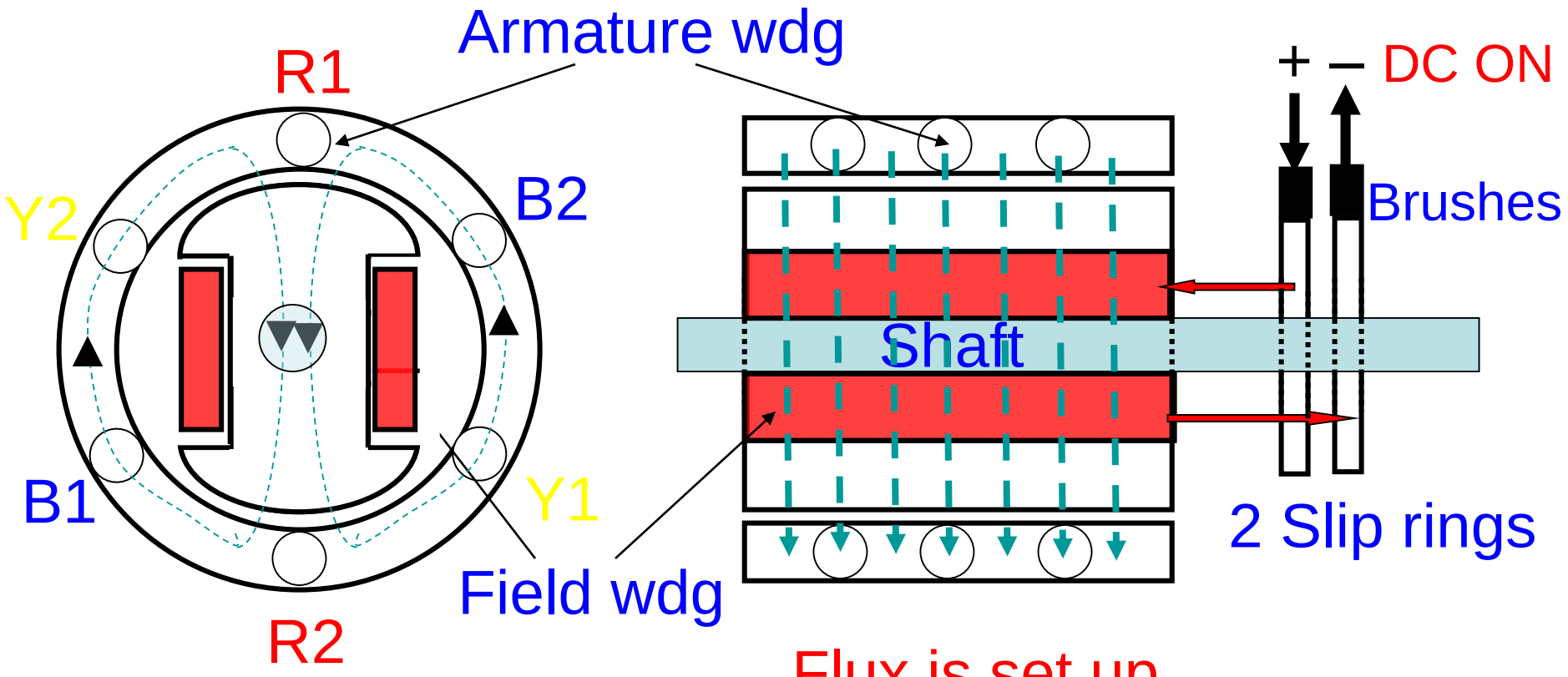
=Electromagnetic Power



Usually field wdg is on rotor and armature wdg on stator



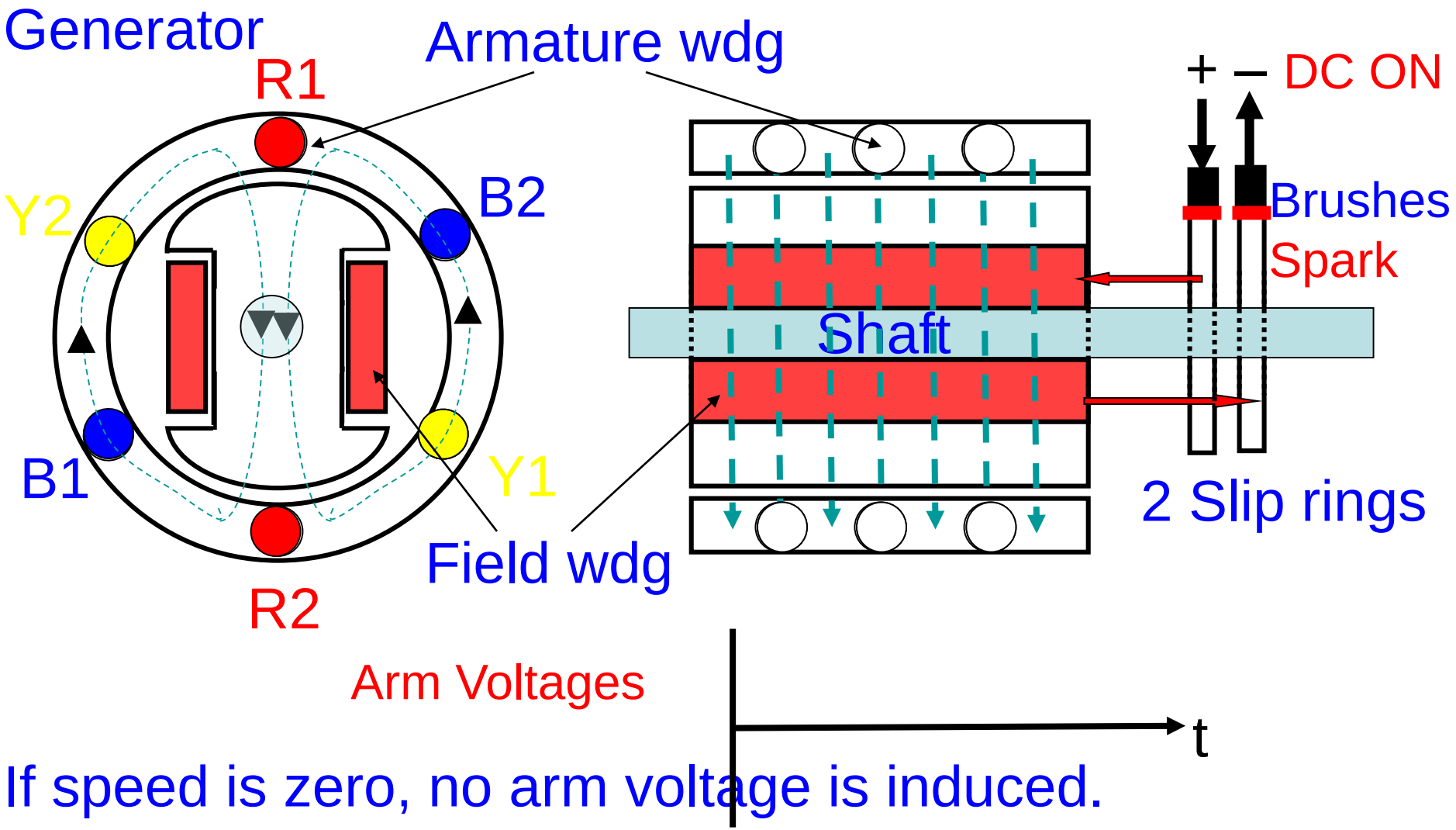
Usually field wdg is on rotor and armature wdg on stator



Flux is set up

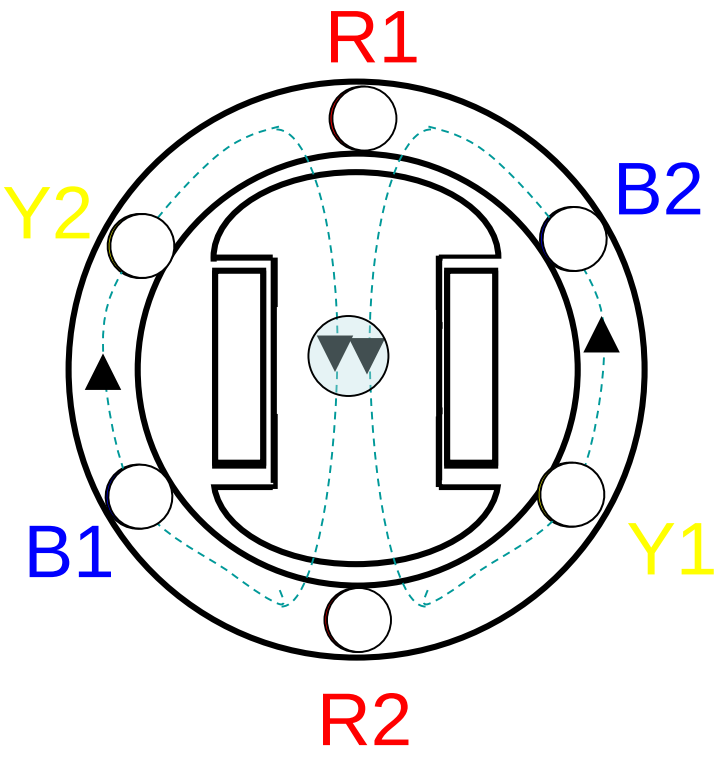
If rotor is rotated by Prime Mover or by Motor or by Turbine

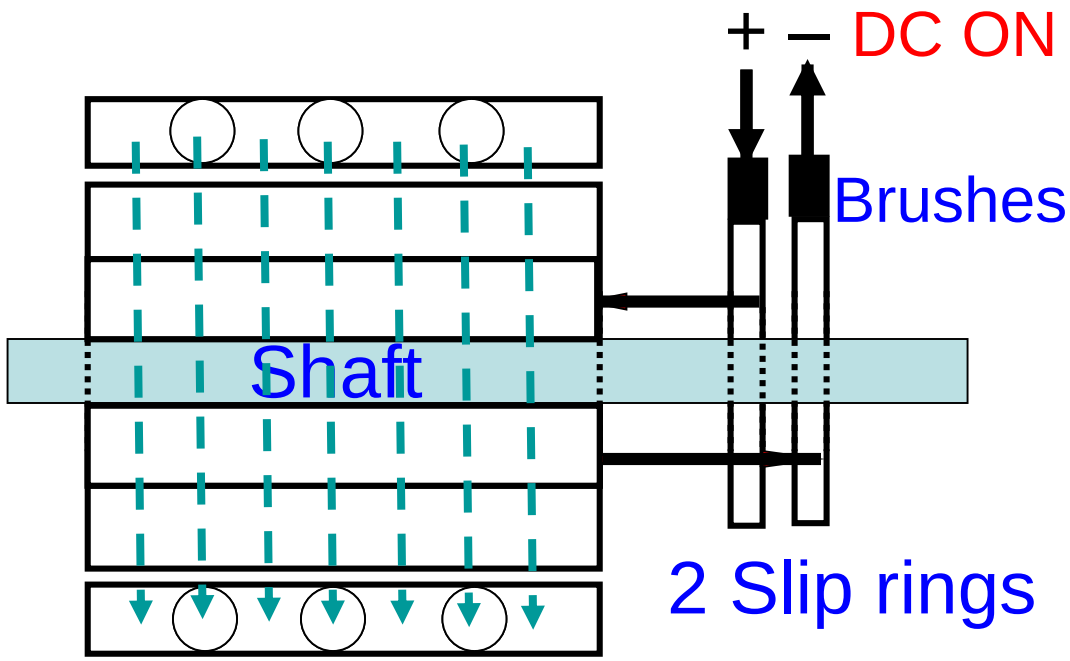
Usually field wdg is on rotor and armature wdg on stator



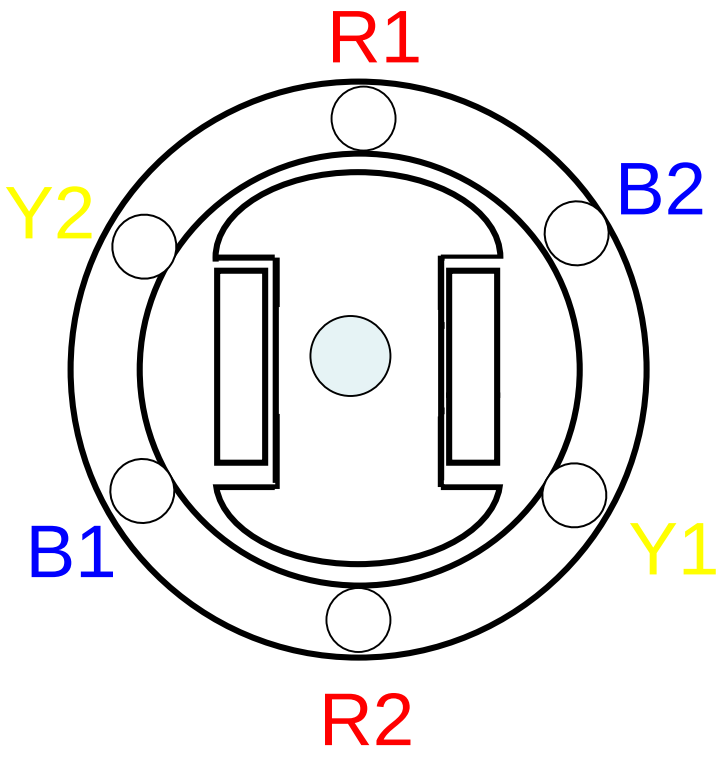
If speed is zero, no arm voltage is induced.

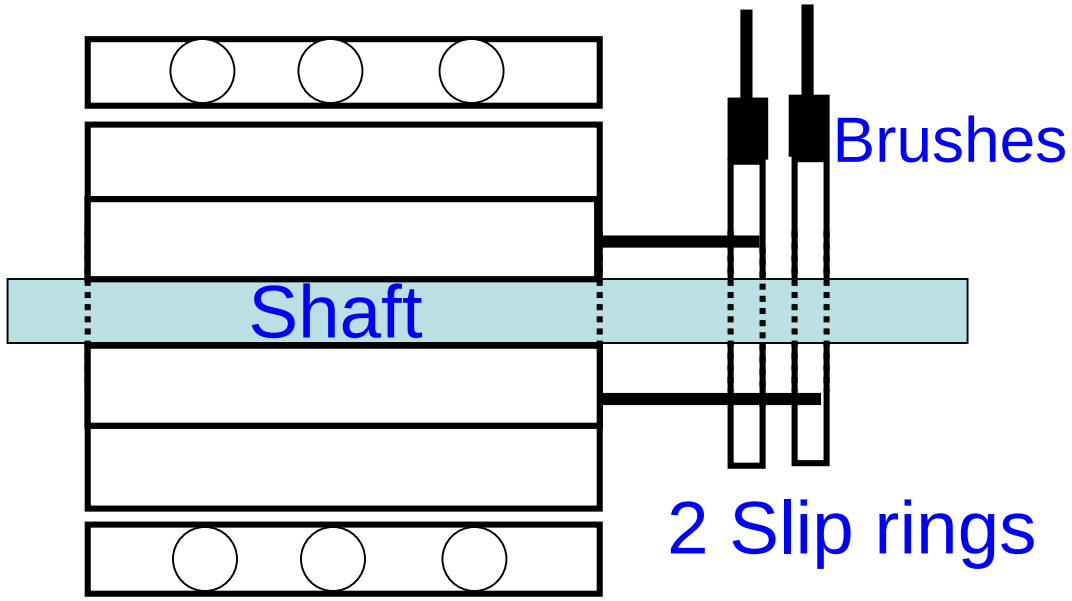
If DC supply is turned OFF





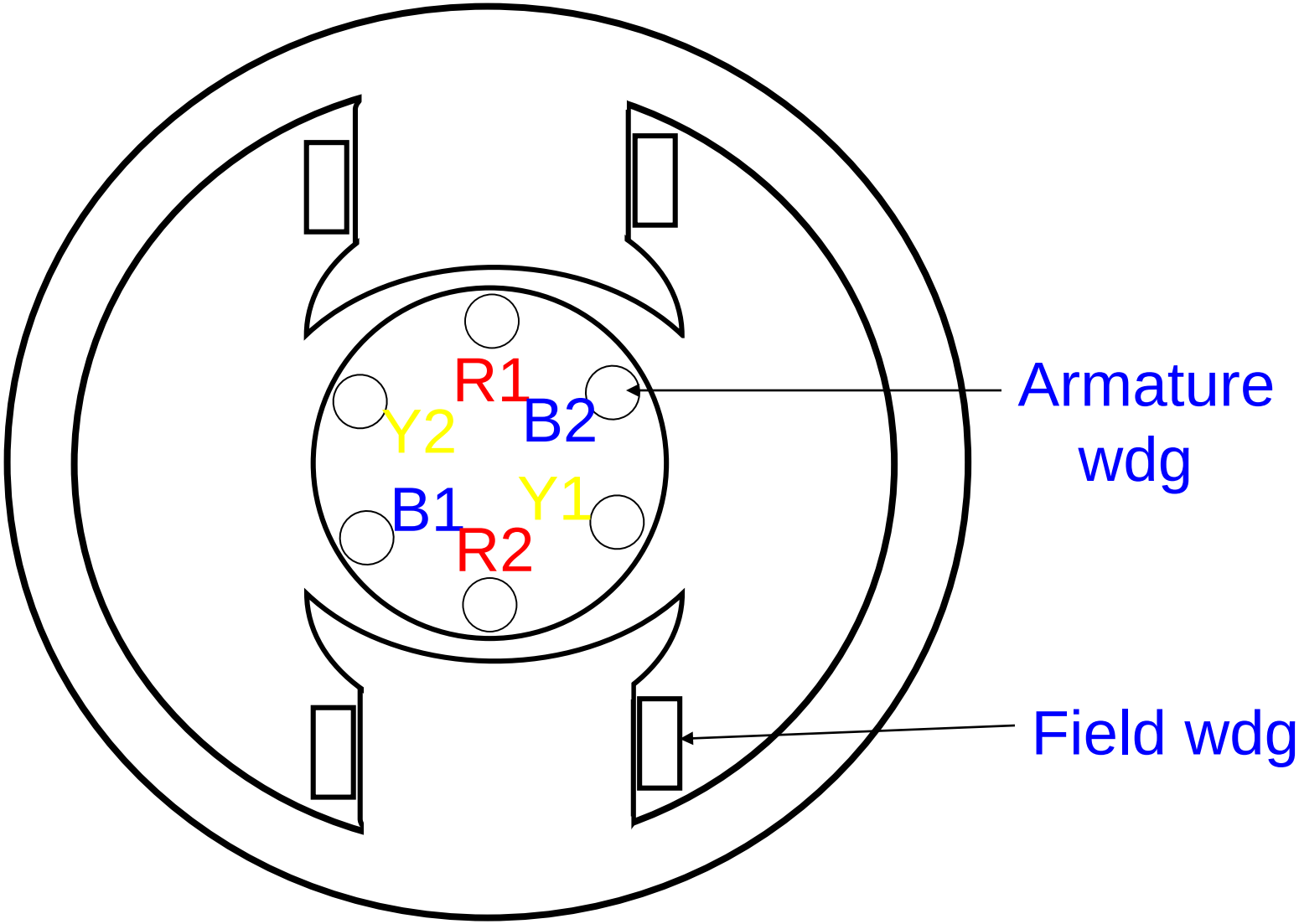
If DC supply is turned OFF

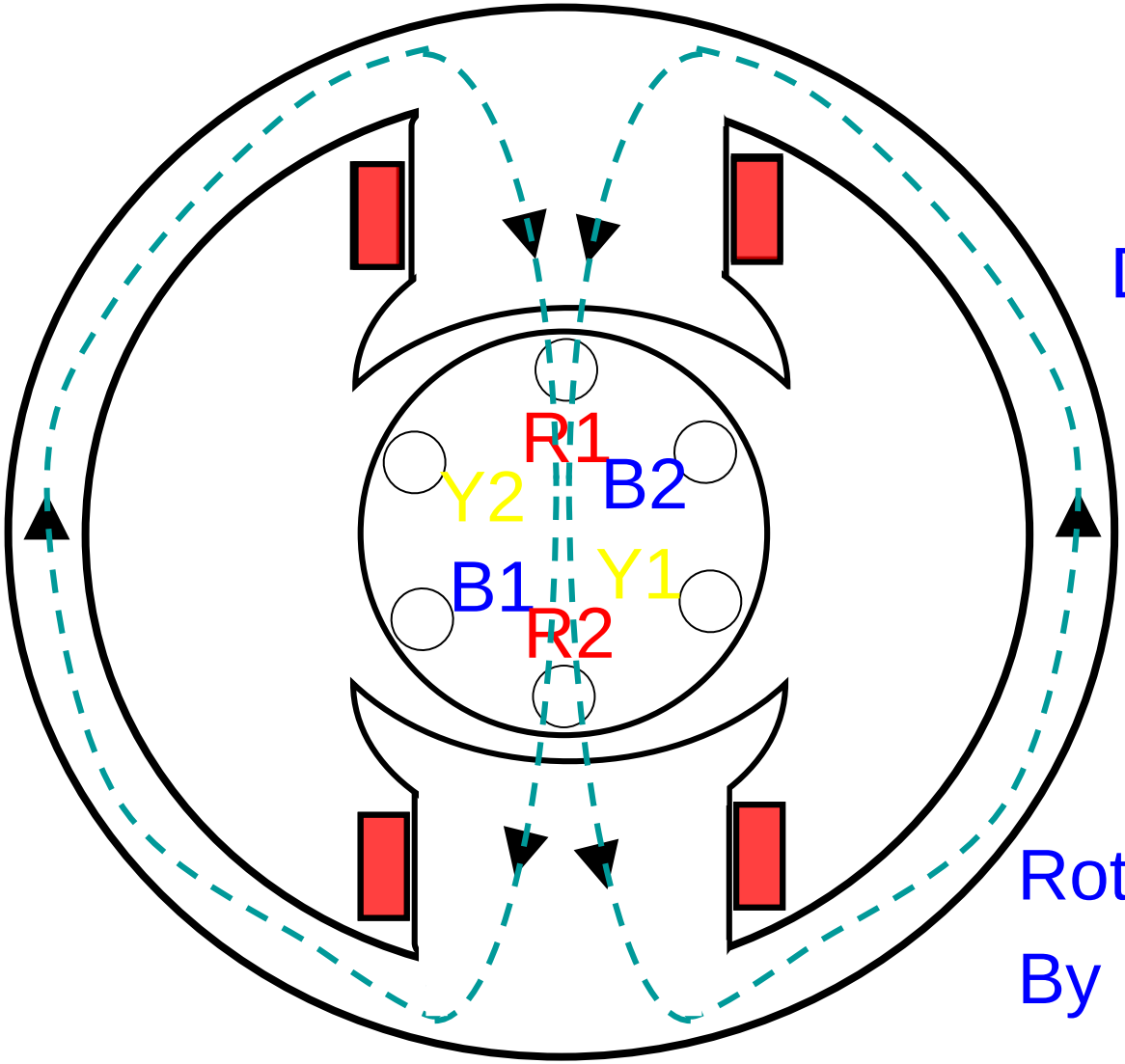




With no flux, if rotor is rotated, no arm voltage is induced.

Now consider armature wdg is on rotor and field wdg on stator





DC supply is given to field wdg

Flux is set up

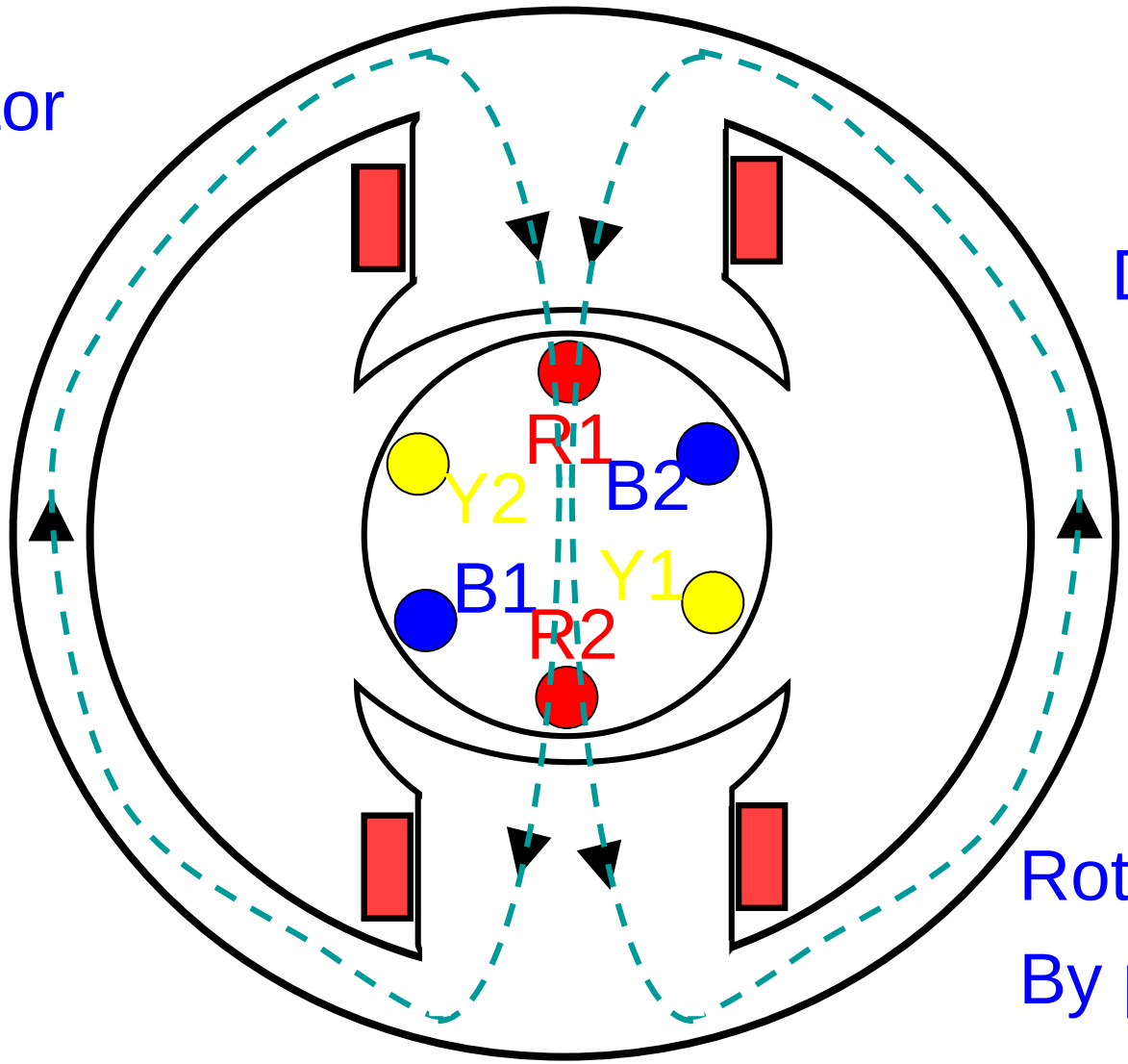
Rotate the arm

By prime mover

Armature Voltage

t

Generator



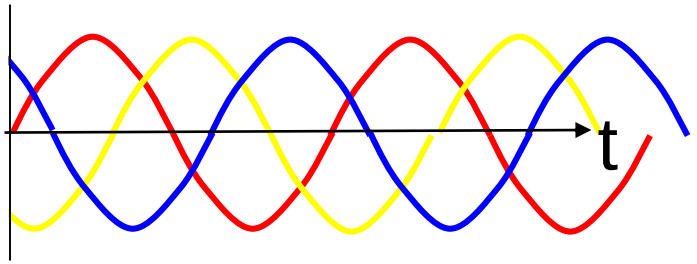
DC supply is given to field wdg

Flux is set up

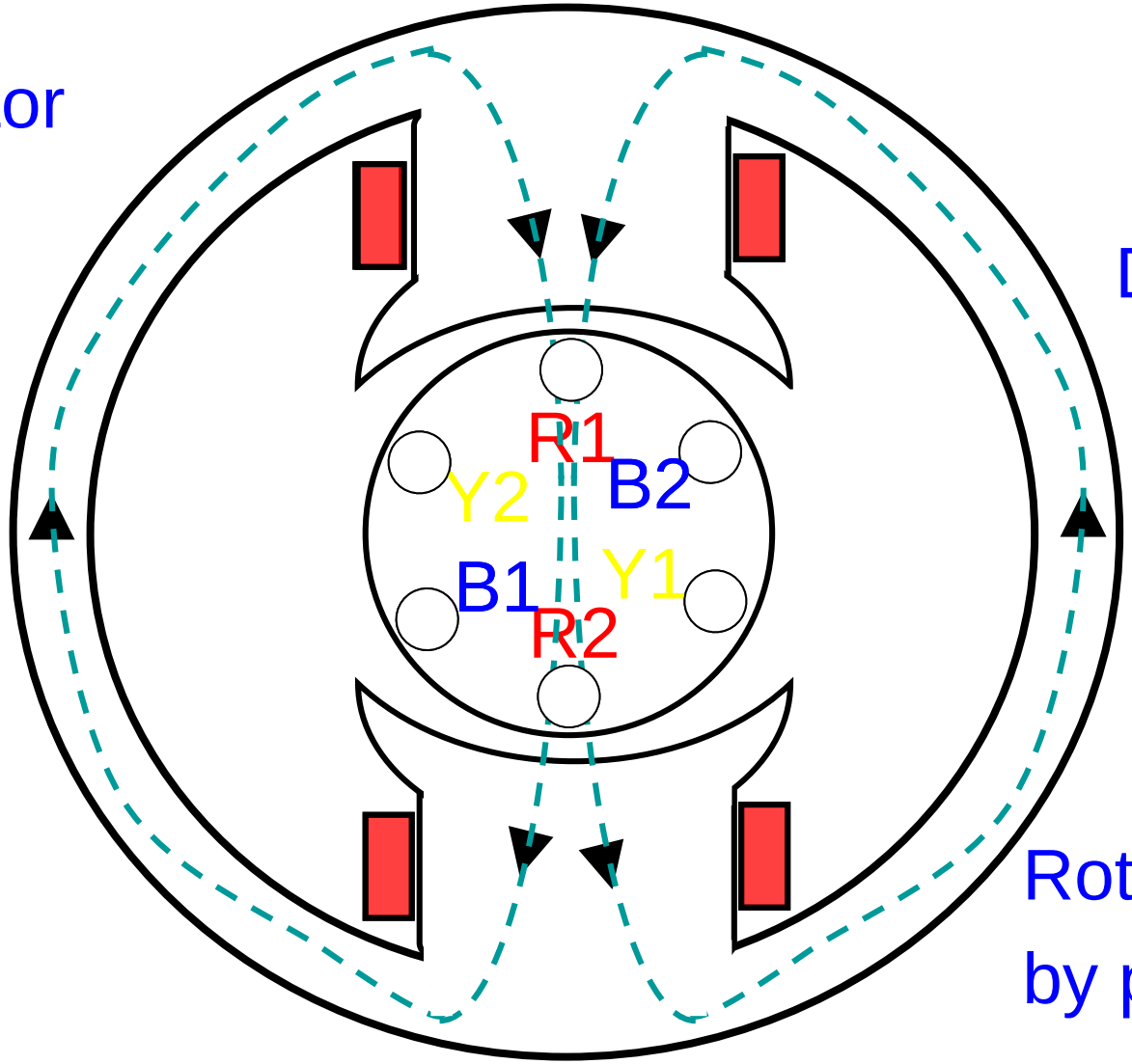
Rotate the arm

By prime mover

Armature Voltage



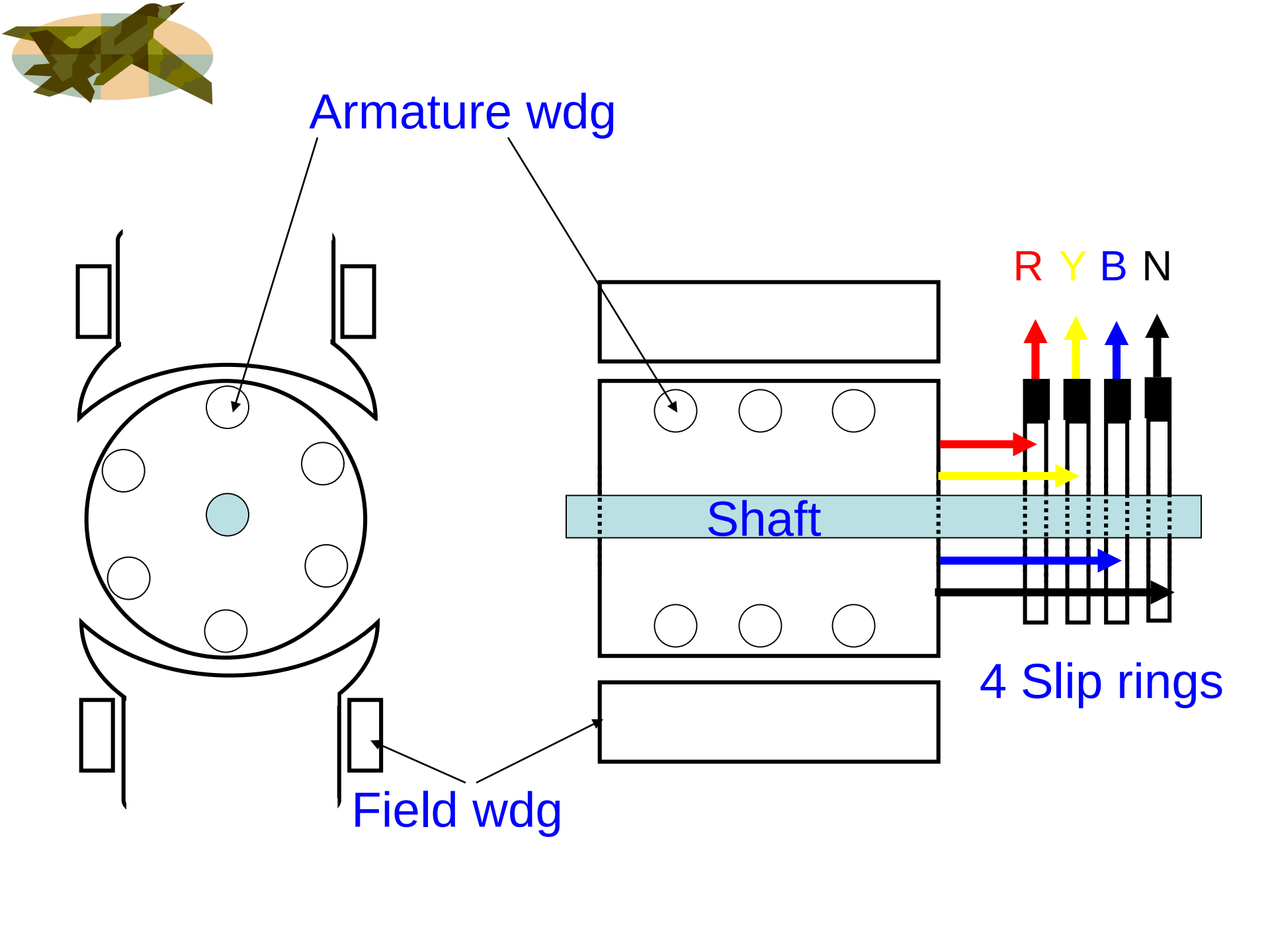
Generator

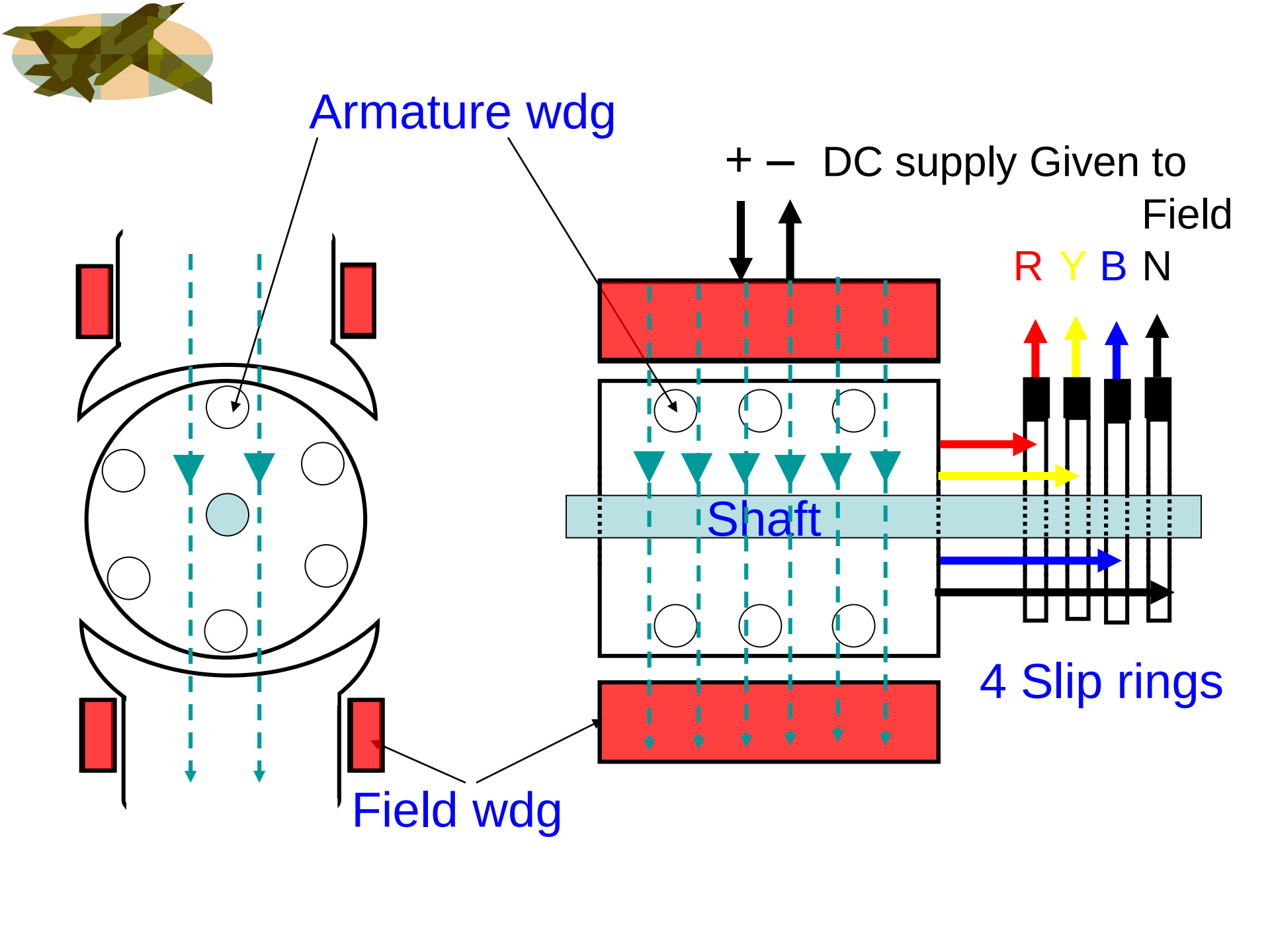


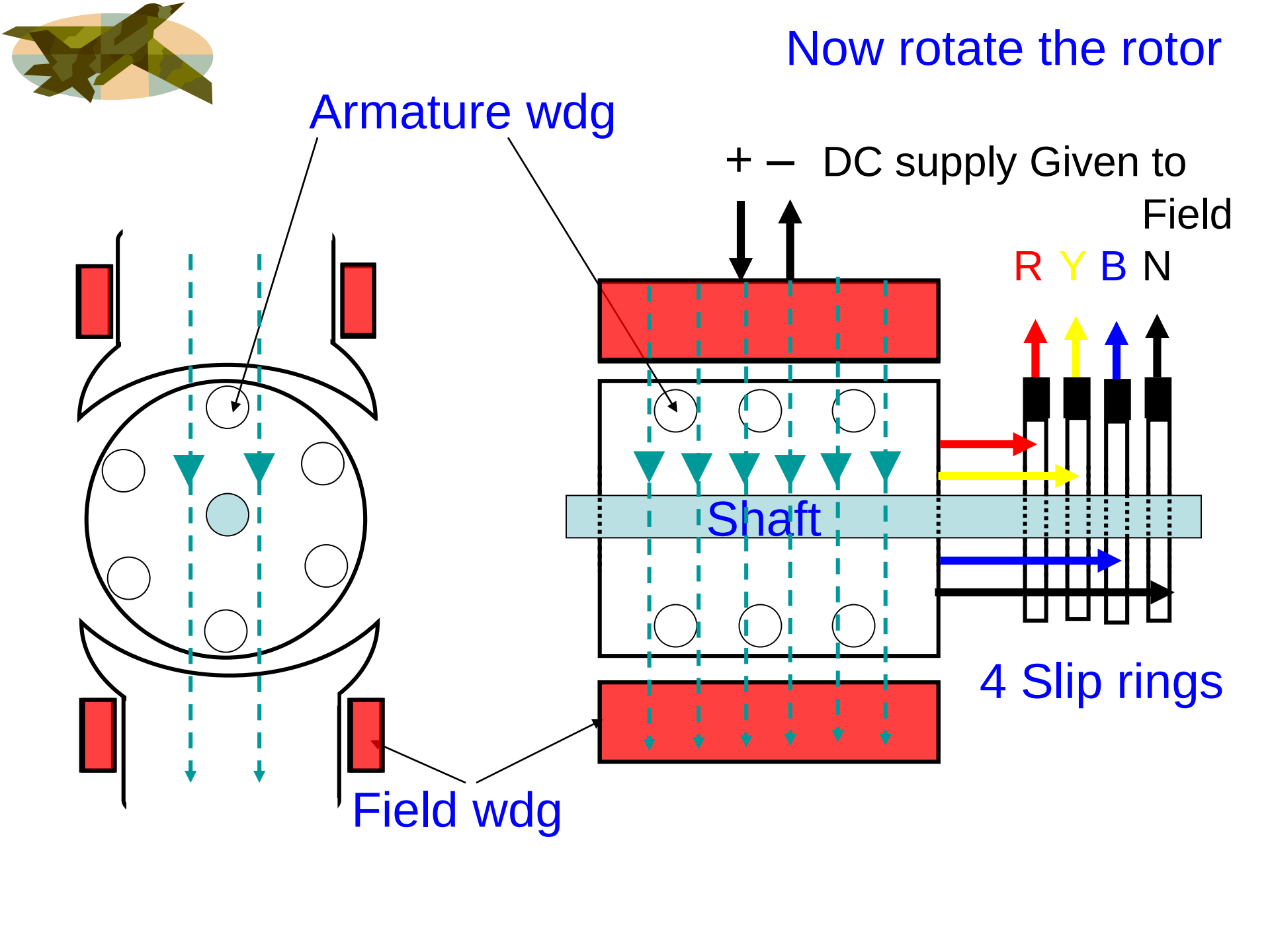
DC supply is given to field wdg

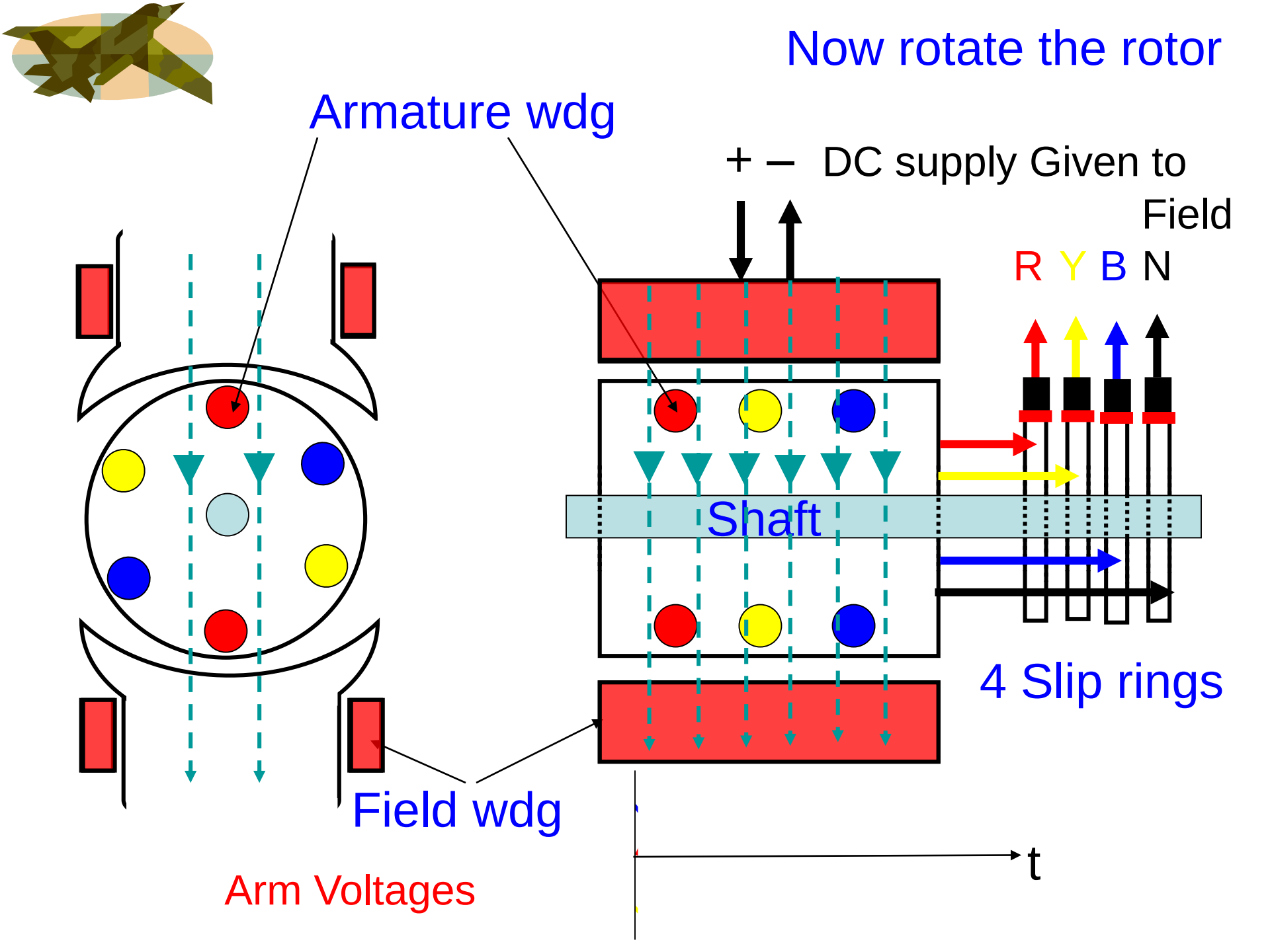
Flux is set up

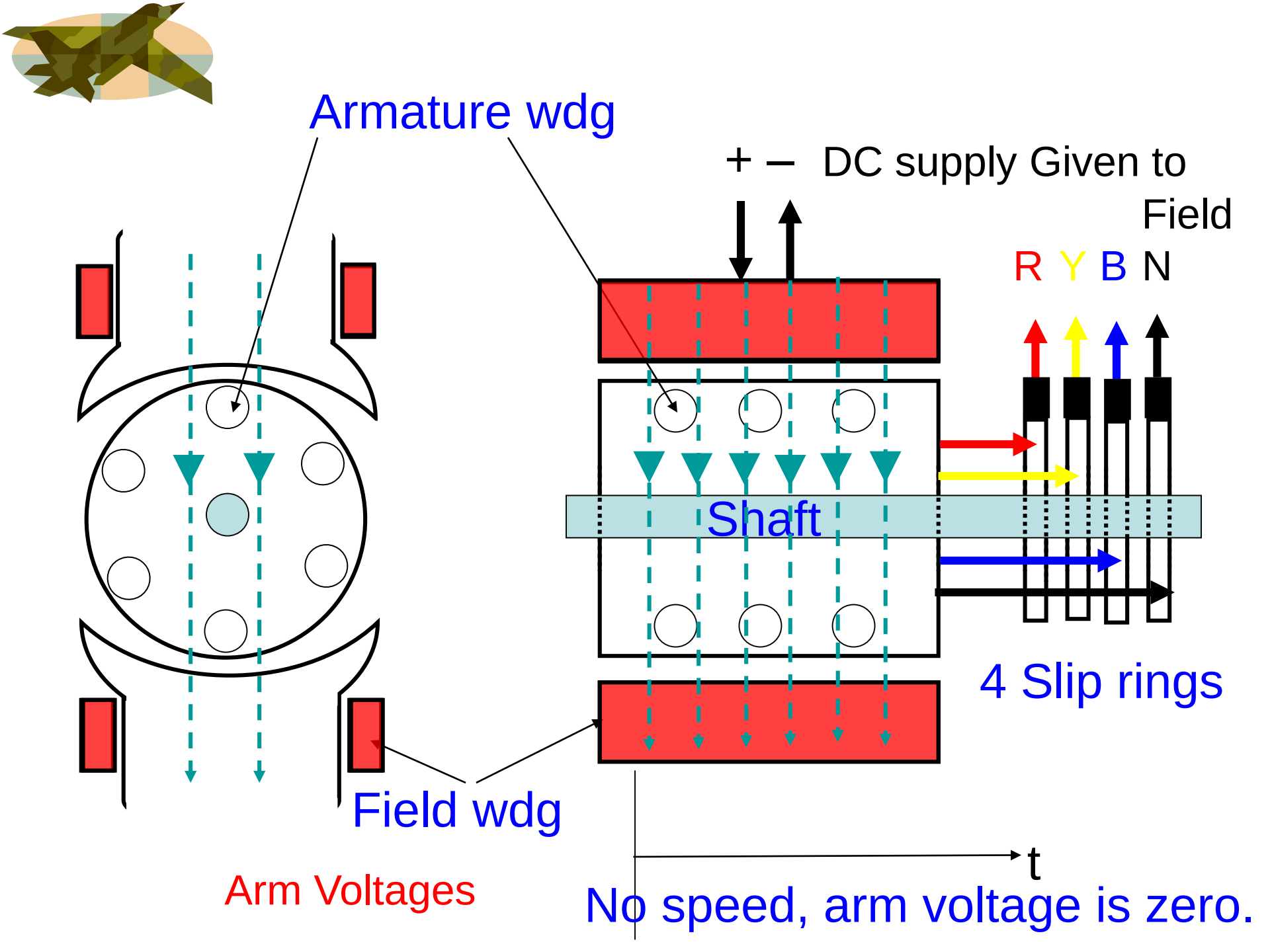
Rotate the arm by prime mover

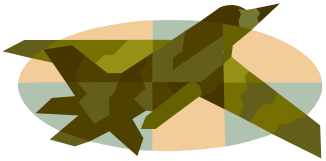

Armature wdg
R Y B N
Shaft
4 Slip rings
Field wdg


Armature wdg
+ – DC supply Given to Field
R Y B N
Shaft
4 Slip rings
Field wdg


Now rotate the rotor
Armature wdg
+ – DC supply Given to Field
R Y B N
Shaft
4 Slip rings
Field wdg


Now rotate the rotor
Armature wdg
+ – DC supply Given to Field
R Y B N
Shaft
4 Slip rings
Field wdg
Arm Voltages
t


Armature wdg
+ – DC supply Given to Field
R Y B N
Shaft
4 Slip rings
Field wdg
Arm Voltages
t
No speed, arm voltage is zero.



The advantages of providing the field winding on rotor and armature winding on stator:

1. Field on rotor requires TWO slip rings. Armature on rotor requires FOUR slip rings. Less slip ring losses.
2. It is economical. For example:

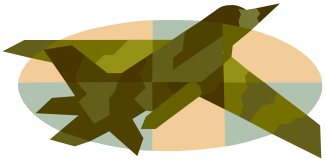
Rating of armature=200MVA, 11kV

$$\therefore Line\ current = \frac{200\times10^3}{\sqrt{3}\times11} = 10{,}500A$$

For this current, slip rings should be larger in size and properly insulated from the shaft for 11kV.

Rating of field=1MW, 500V

$$\therefore Field\ current = \frac{1000}{0.5} = 2000A$$



Slip rings should be smaller in size and are insulated for 500V only.

3. Stationary armature can be INSULATED satisfactory for higher voltages, ie upto 33kV.

4. Stationary armature can be COOLED more efficiently upto 1000MW or above.

5. Low power field wdg gives LIGHTER rotor, so LOW torque is required to rotate the rotor .

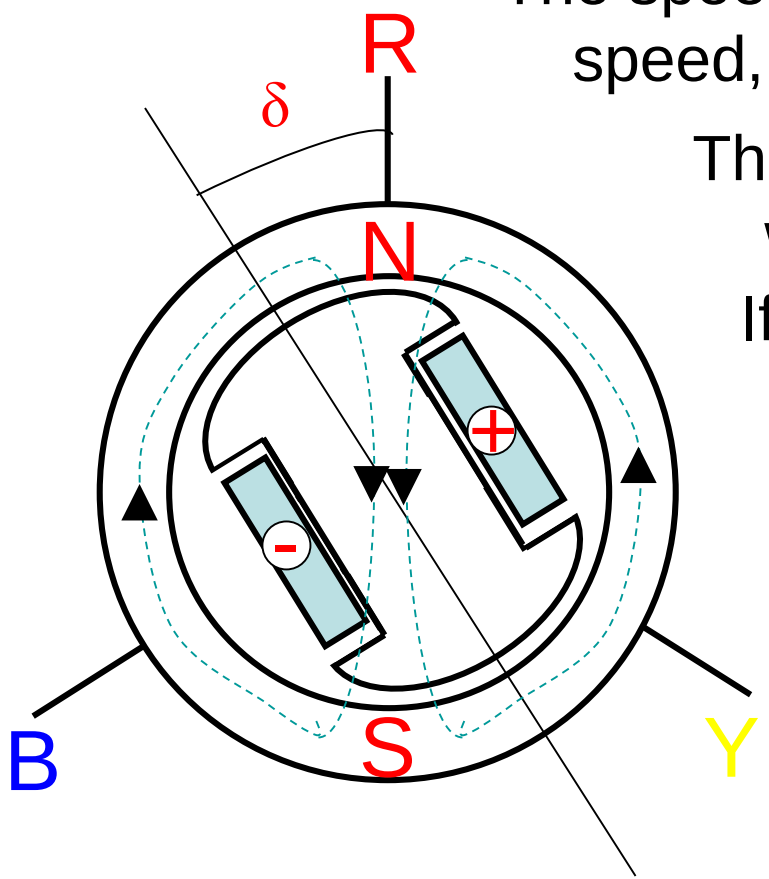
6. Higher speed and more output are possible for a given dimensions.

Synchronous Motor

Starting:

If 3-phase supply is given to armature, a rotating magnetic field is produced.

The speed of this rotating field is synchronous speed, $N_s=120f/P$.



The stator produces a two pole field, which is rotating in clockwise direction.

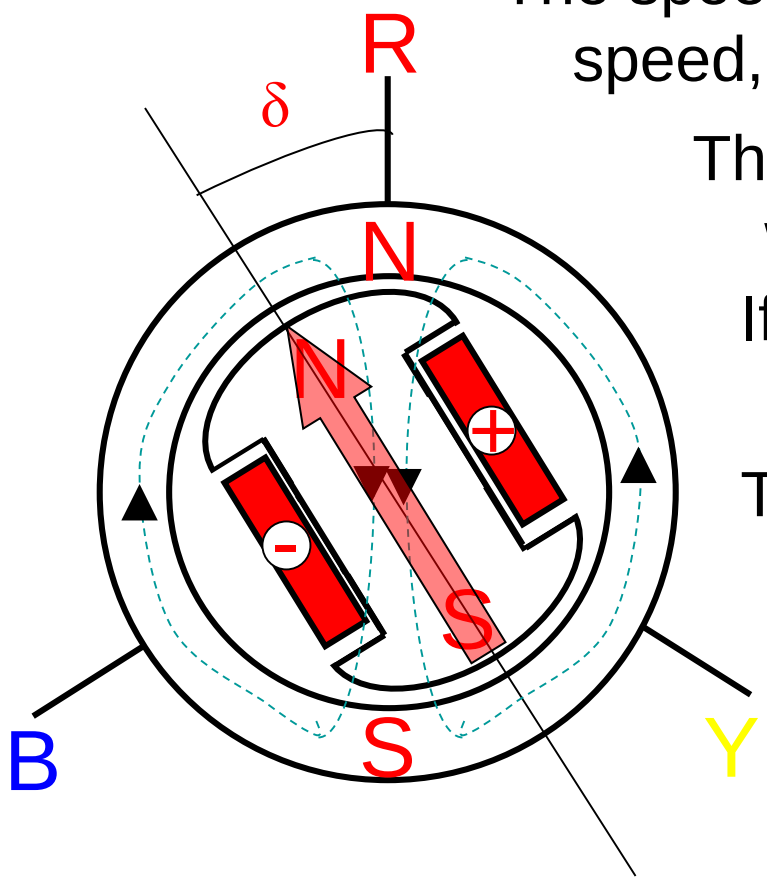
If field winding is excited, poles are created on rotor as shown.

Synchronous Motor

Starting:

If 3-phase supply is given to armature, a rotating magnetic field is produced.

The speed of this rotating field is synchronous speed, $N_s=120f/P$.



The stator produces a two pole field, which is rotating in clockwise direction.

If field winding is excited, poles are created on rotor as shown.

The angle between stator and rotor field axes is δ, torque angle

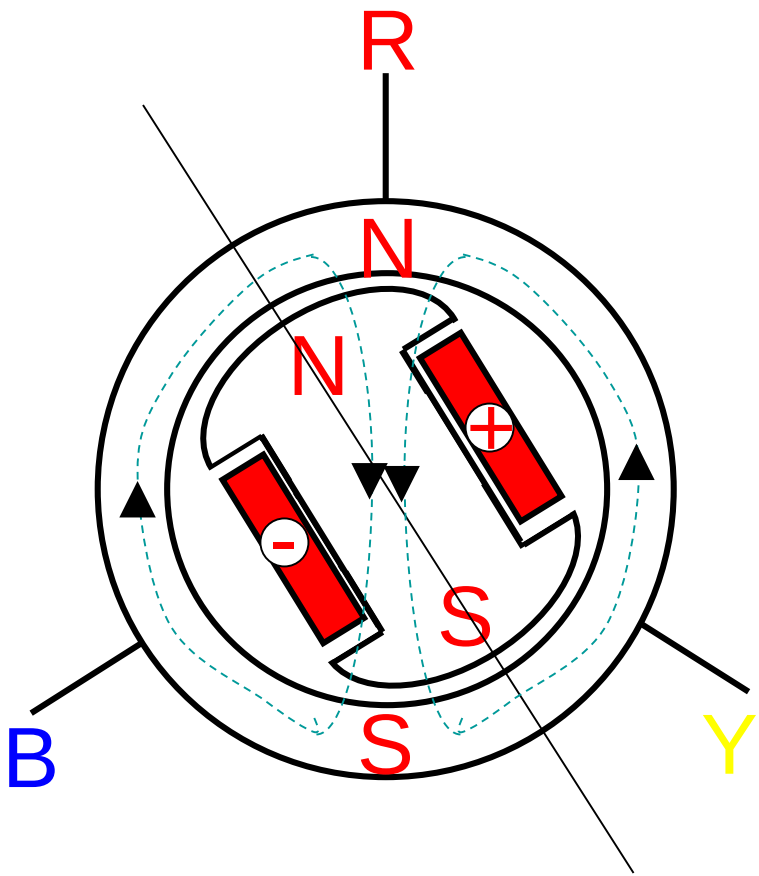
$T=(P/\omega)$

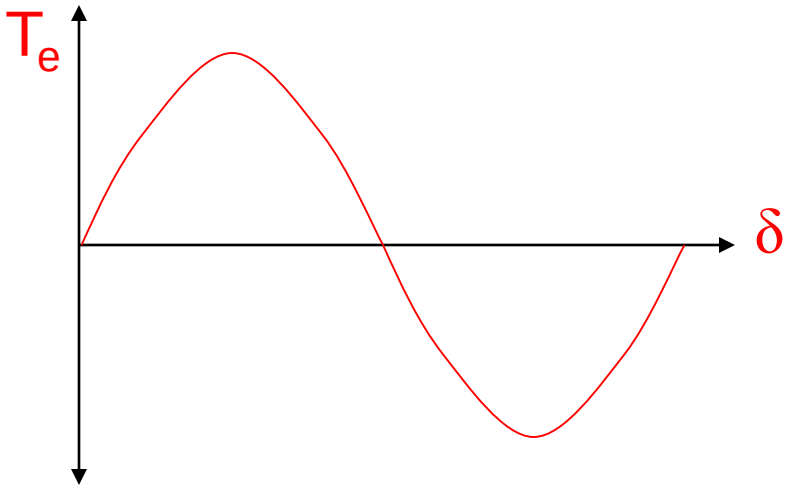
The torque is proportional to $\sin\delta$.

Synchronous Motor

Starting:

The torque varies sinusoidally with time, it reverses during each half cycle.





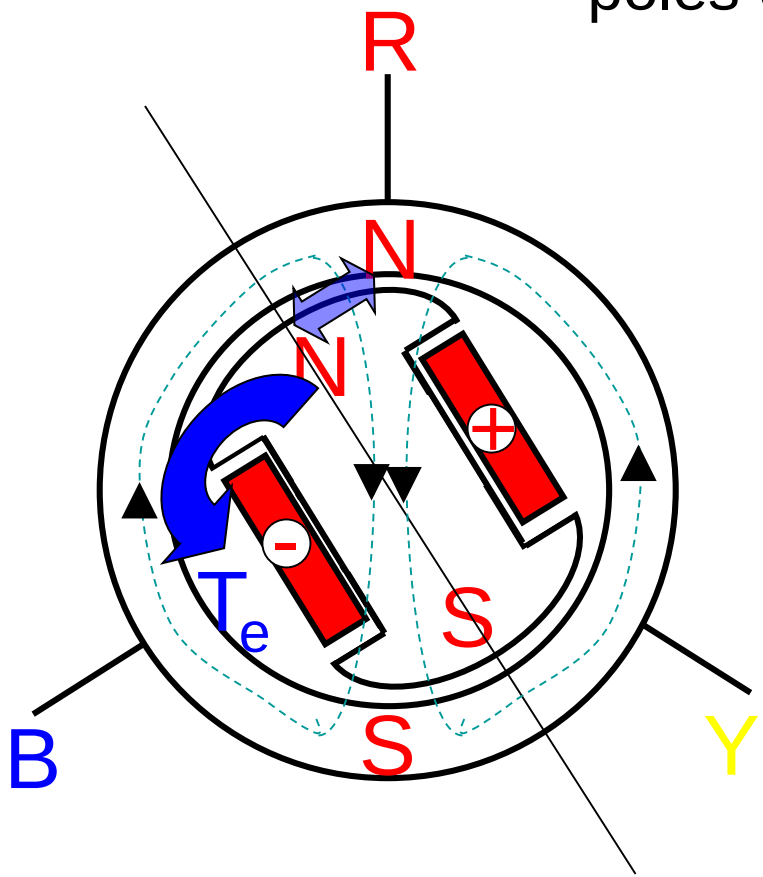
Therefore, the average torque over a complete cycle is ZERO.

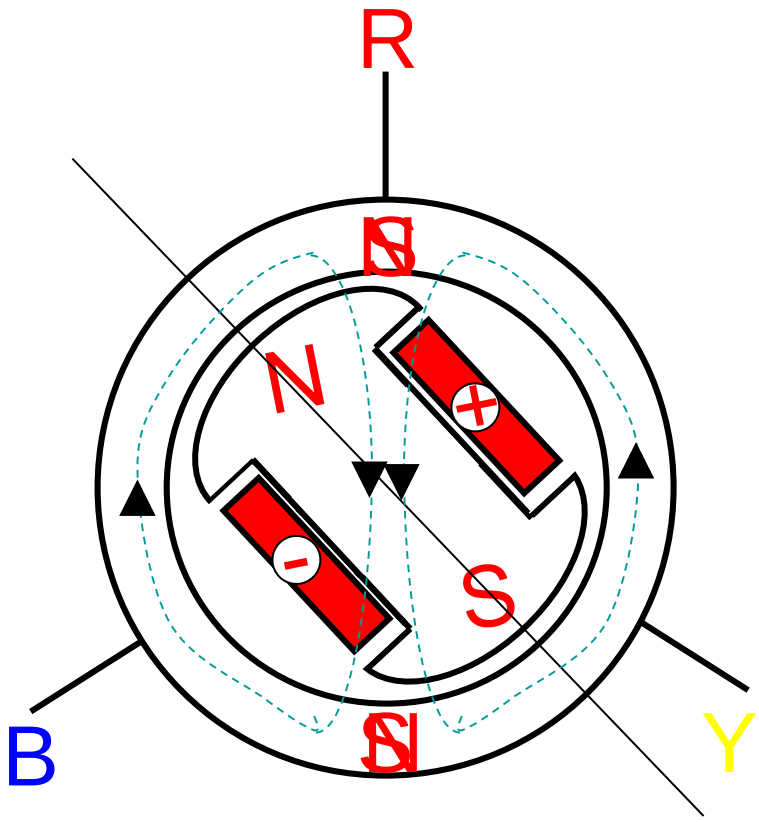
Hence, syn motor, on its own, has NO NET starting torque.

Another way: Consider the instant shown in Fig.

N pole of stator repels N pole of rotor, producing anticlockwise torque.

After half cycle, i. e. after 10 msec =1/2f, for 50Hz supply, stator poles occupy new positions as shown in Fig.



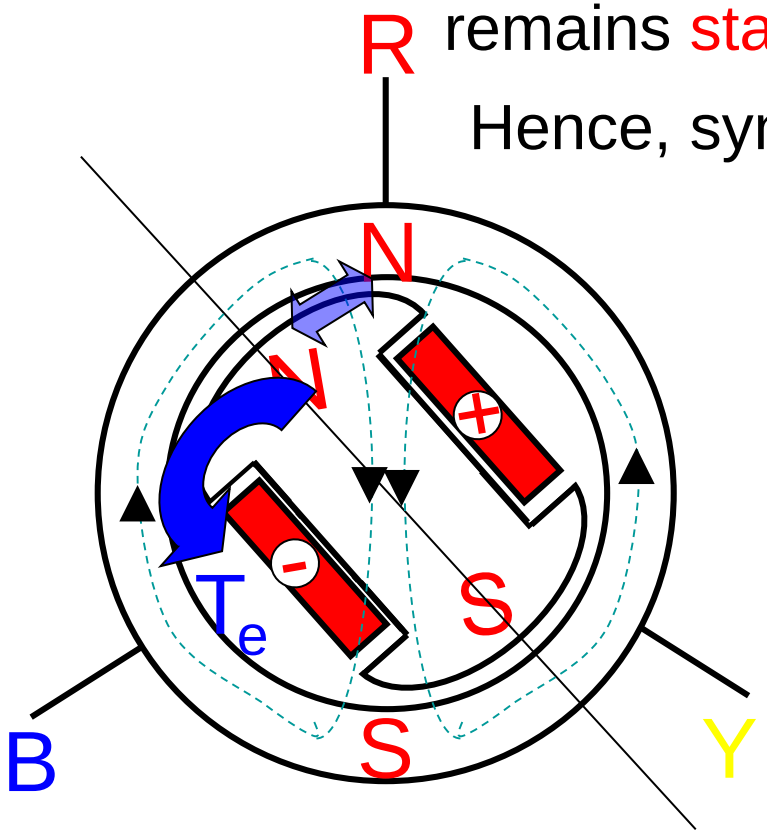


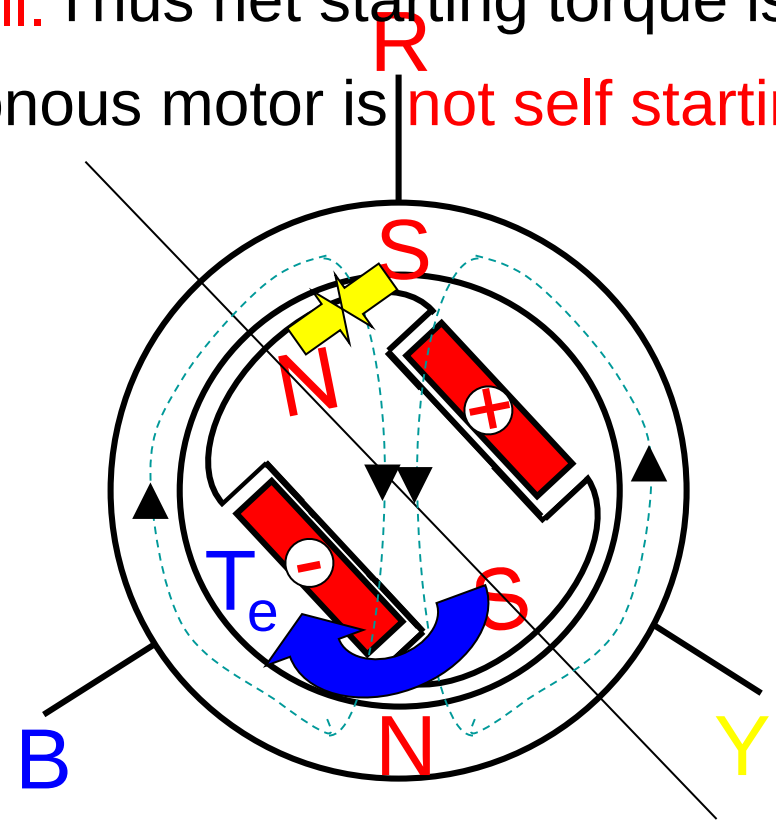
Another way: S pole of stator attracts N pole of rotor, producing clockwise torque.

Thus rotor rotates anticlockwise at one instant and after 10msec rotor rotates clockwise direction.

Due to inertia, rotor does not move in one direction and rotor remains standstill. Thus net starting torque is zero.

Hence, synchronous motor is not self starting



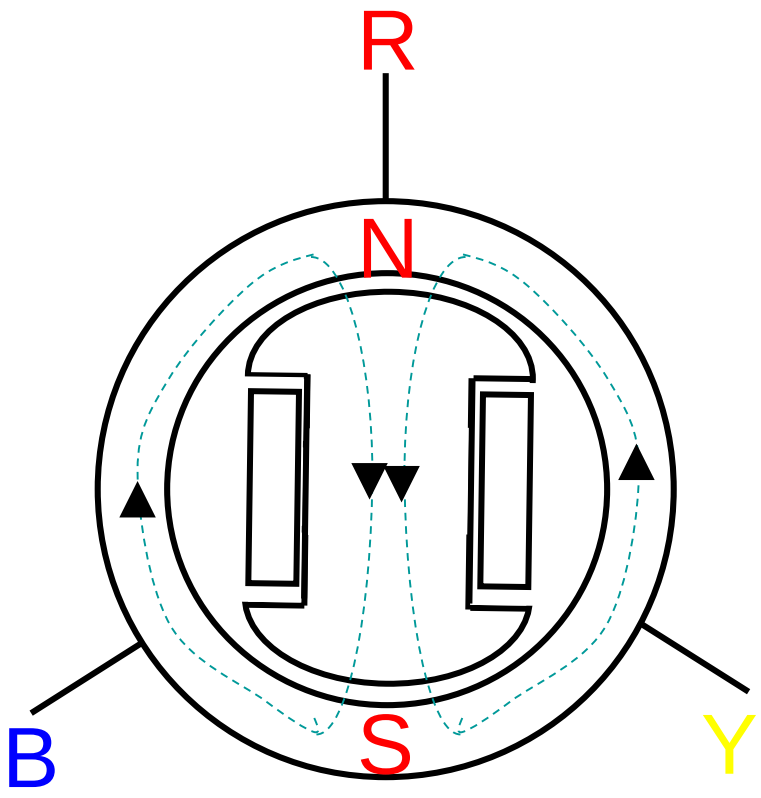


Three phase supply is given to stator.

Synchronously rotating magnetic field is produced.

Now rotate the rotor in the same direction with same speed or speed near to syn speed.

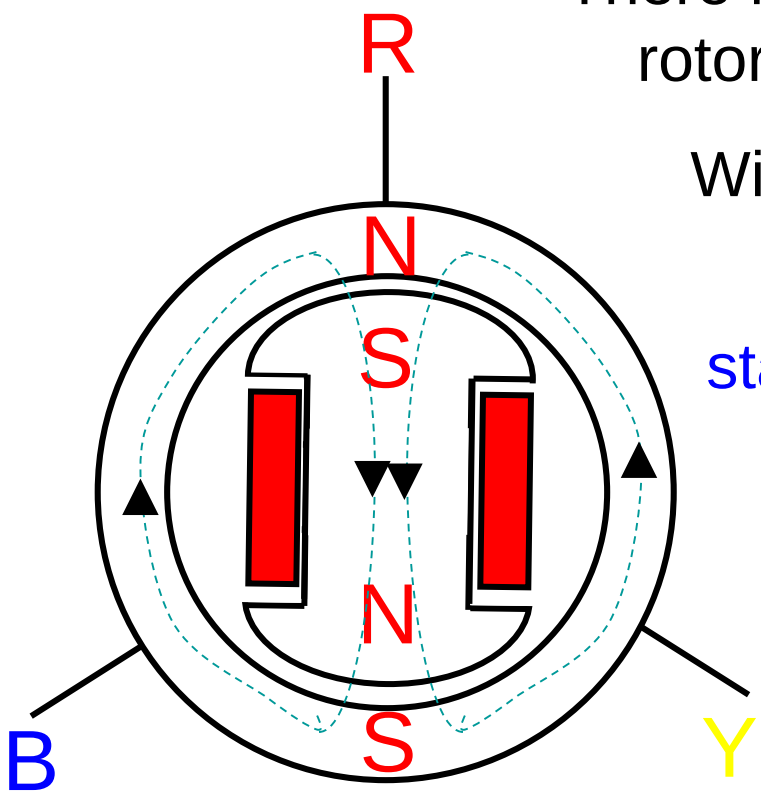
Then field wdg is excited.



Three phase supply is given to stator.
Synchronously rotating magnetic field is produced.
Now rotate the rotor in the same direction with same speed or speed near to syn speed.

Then field wdg is excited.

There is magnetic locking between stator and rotor magnetic field



With relative speed zero, stator N pole is locked with rotor S pole and

stator S pole is locked with rotor N pole.

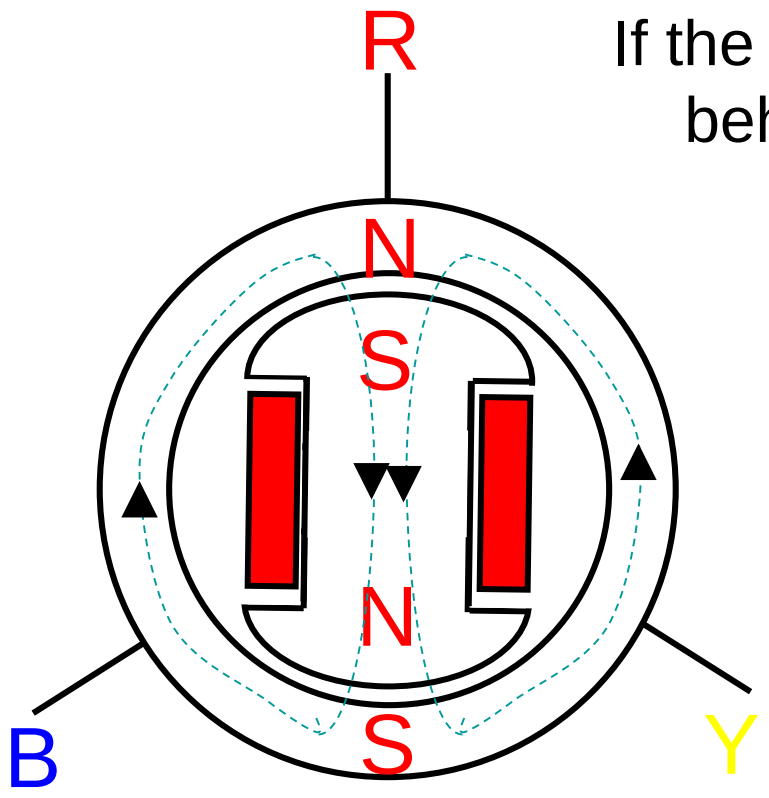
Rotor will now experience a torque.

If prime mover of rotor is cut off, rotor will continue to rotate in the same direction, with same syn speed.

Thus rotor always rotates at synchronous speed.

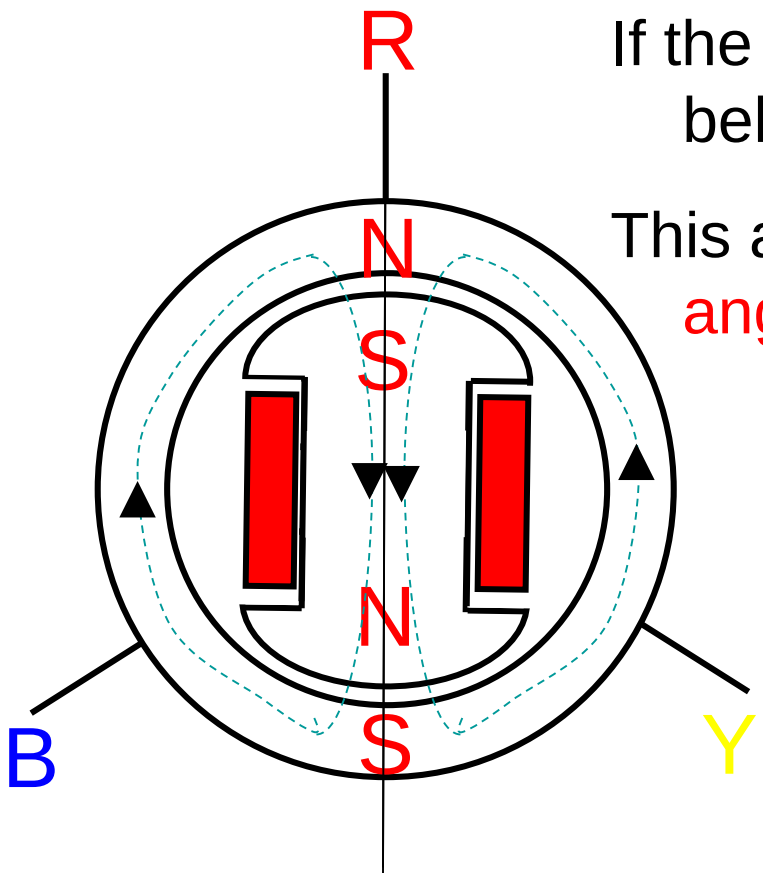
Hence name of this motor is synchronous motor.

If the load is applied on the rotor, rotor lags behind the stator field by some angle.



Thus rotor always rotates at synchronous speed.

Hence name of this motor is synchronous motor.



If the load is applied on the rotor, rotor lags behind the stator field by some angle.

This angle is called as torque angle / load angle or power angle δ.

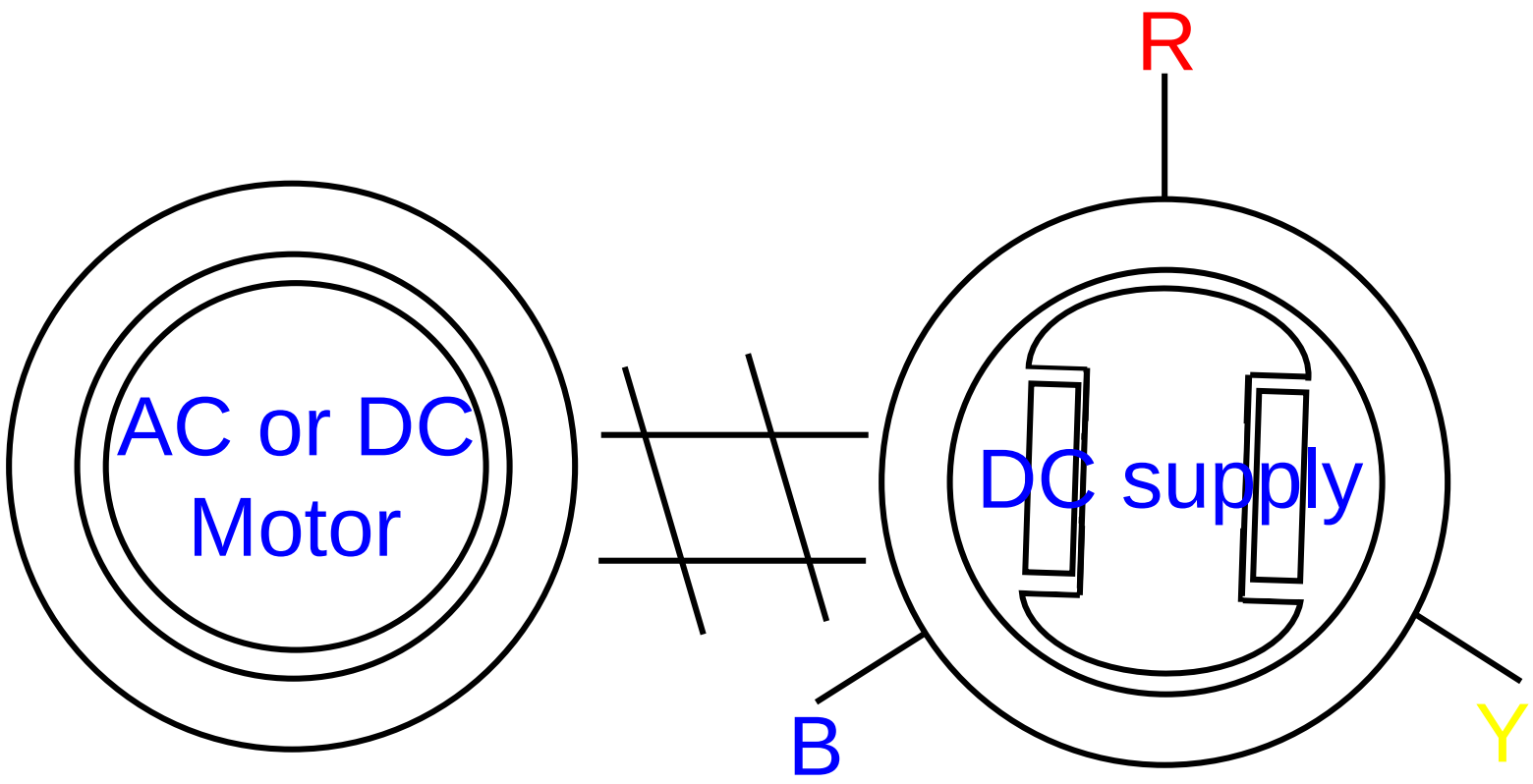
The starting methods are

1. Auxiliary motor starting
2. Starting by Damper Winding (SCIM)
3. SRIM starting with High Torque

1. Auxiliary motor starting

The auxiliary motor may be ac motor or dc motor.

It is mechanically coupled with synchronous motor.



The armature wdg of synchronous motor is energized from 3-phase supply.

AC or DC motor is started and run near to synchronous speed

Now DC supply is given to field wdg of synchronous motor.

Field poles get locked with armature poles.

Synchronous motor starts running as a motor at syn speed.

The auxiliary motor can now disconnected from the supply or decoupled from mechanical coupling.

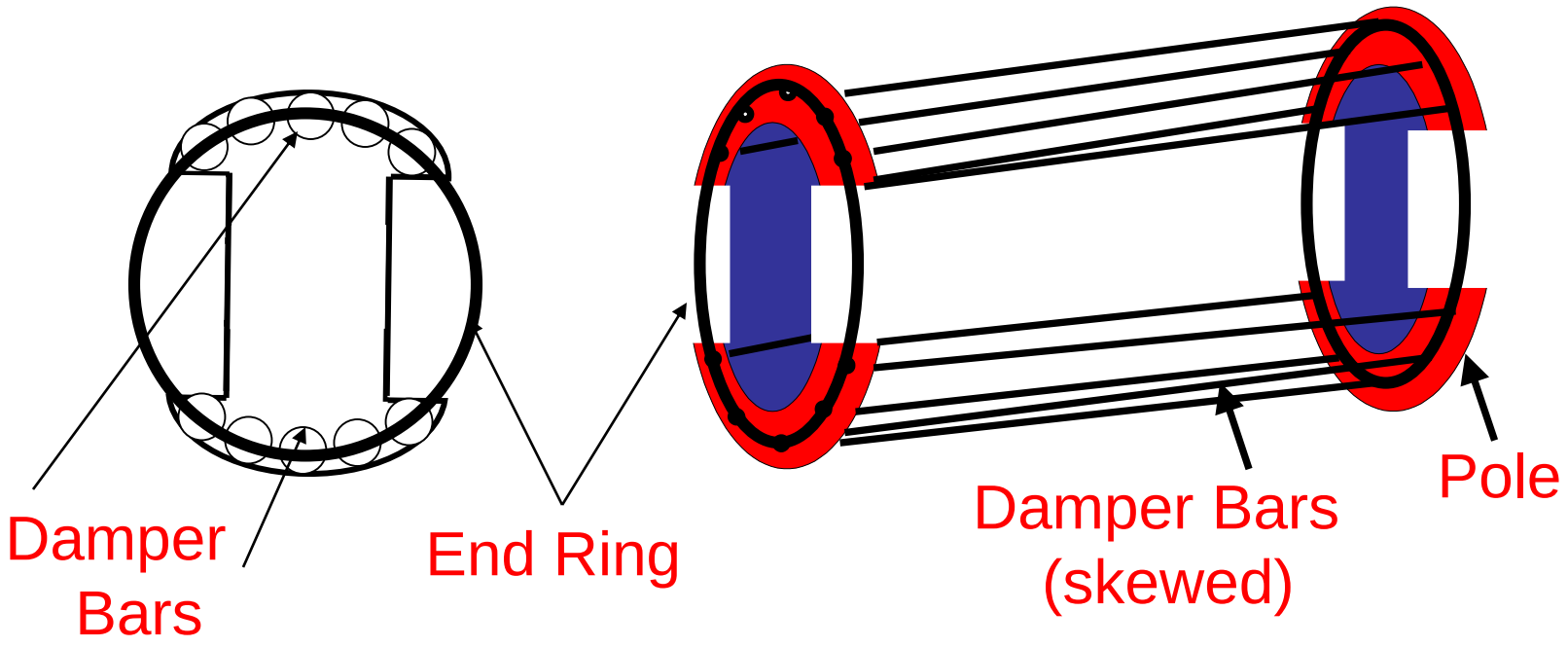
2. Starting by damper winding (Squirrel cage Induction motor starting)

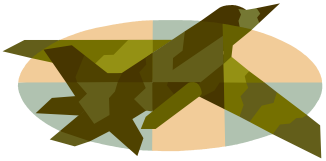
2. Starting by damper winding (Squirrel cage Induction motor starting)

In order to make the motor self starting, the damper or amortisseur wdg is embedded in slots in the rotor pole faces.

This wdg is short –circuited at both ends by end rings.

This damper winding is similar to squirrel cage wdg of 3-ph induction motor.





2. Starting by damper winding (Squirrel cage Induction motor starting)

In this case, the syn motor can be started by star-delta starting, reactor starting or auto-transformer starting.

When 3-phase supply is given to armature, a rotating magnetic field is established.

Damper wdg develop induction motor torque.

The rotor is accelerated and speed is near to synchronous speed.

Before starting the field wdg can be short-circuited with or without some resistance

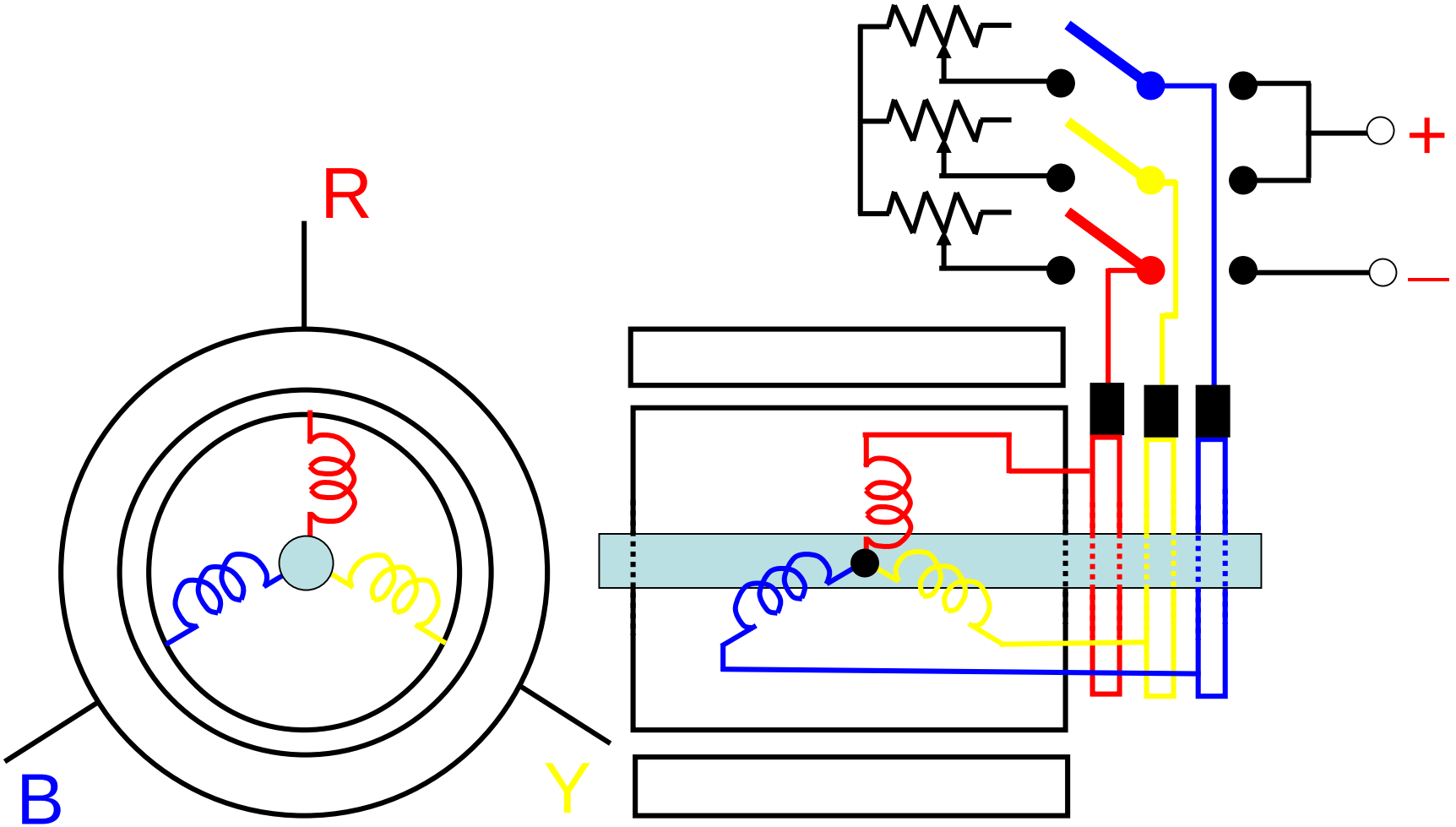
With some resistance, starting torque will be more.

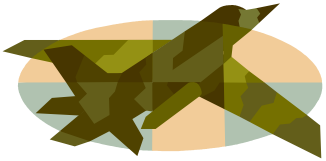
Now the field wdg is open circuited and is energized from a DC source, stator and rotor poles will lock together.

Then rotor will run at synchronous speed.

3. Slip Ring Induction Motor starting with High Starting Torque (Synchronous – Induction Motor)

First it is operated as SRIM and then synchronous motor, therefore, syn motor may be called as Syn-duction motor.





For load requiring high starting torques, this type of starting method is used.

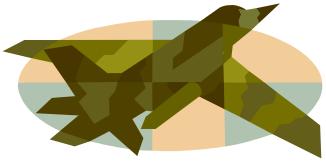
Rotor is similar to SRIM or wound rotor induction motor.

At the time of starting high resistance is inserted in rotor circuit to develop high starting torque.

As speed increase, this resistance is gradually reduced to zero .

The rotor short circuit is removed and rotor wdg is switched over to DC supply.

Thus rotor poles are created and are attracted by stator poles and synchronism is achieved.



Excitation Systems

Field winding

Always absorbs or imports dc power

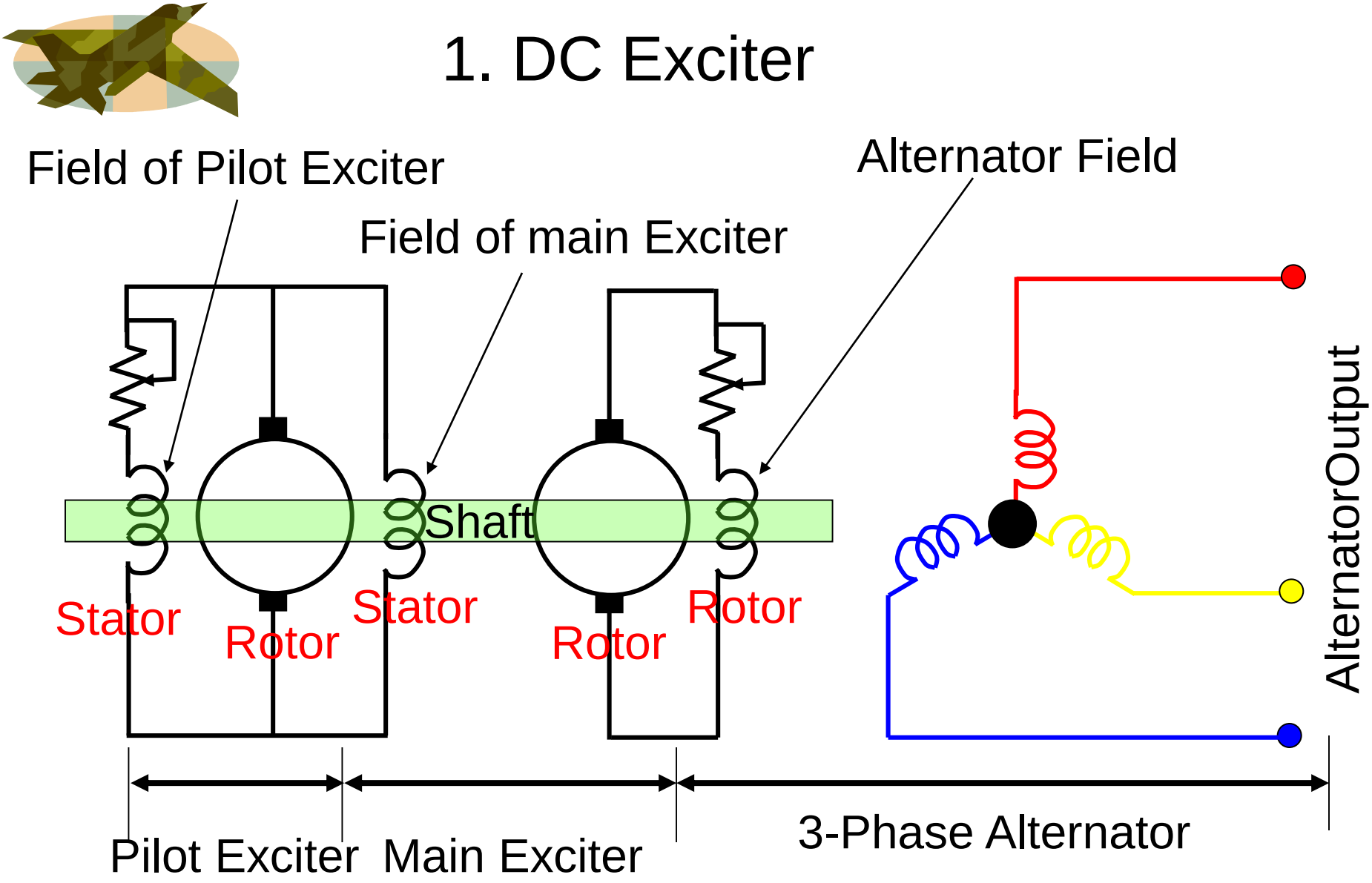
whether Motor or Generator operation.

Field winding is connected to dc source.

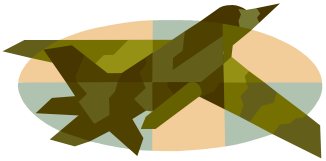
The excitation systems are:

1. DC exciter

1. DC Exciter



Alternator field on rotor is connected to armature of main exciter on rotor through slip rings and brushes.



1. DC Exciter

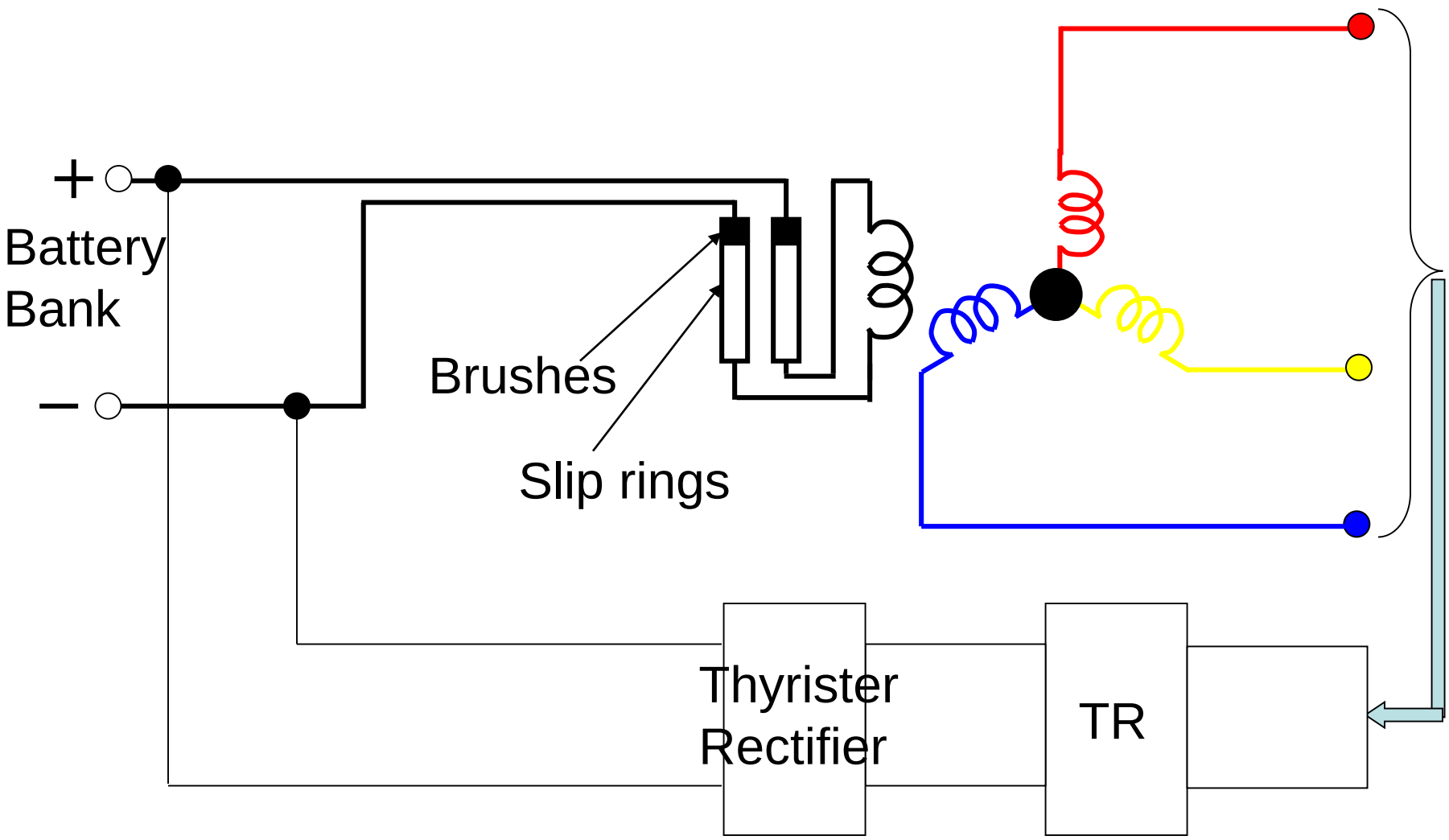
An old conventional method of exciting field winding.

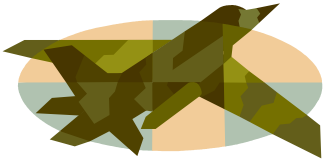
Three machines

1. Pilot exciter: DC shunt generator feeding field wdg of main exciter
2. Main exciter: Separately Excited DC generator feeding field wdg of main alternator.
3. Main 3-phase alternator:

They are mechanically coupled and driven by same shaft.

2. Static Excitation





2. Static Excitation

No rotating type of exciter, no friction.

Initially field winding is excited by battery bank through slip rings and brushes.

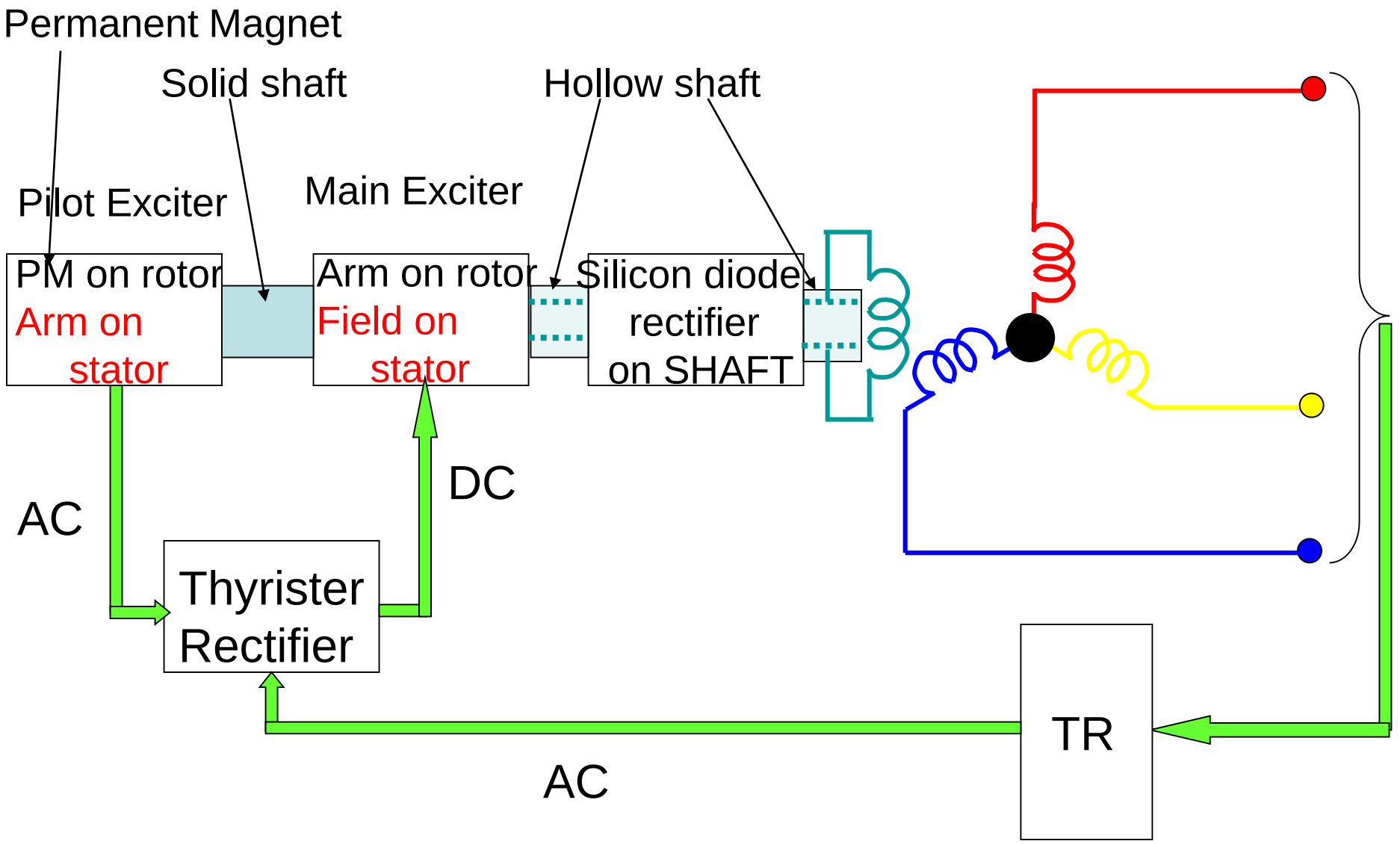
After building up of voltage, the output voltage is fed back to field through transformer and rectifier.

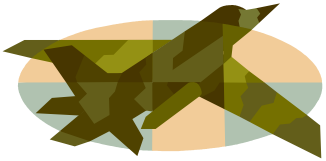
Then battery bank is disconnected.

Use of reliable and high power SCR (silicon controlled rectifier) gives fast response.

If other generators are in operation, then there is no need of battery bank for new generator.

3. Brushless Excitation





3. Brushless Excitation

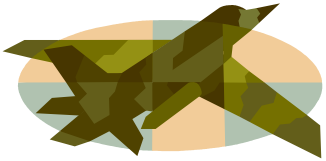
This method consists of:

1. Pilot exciter: 3-phase generator with permanent magnet field or poles on rotor and 3-phase armature wdg on stator.
2. Main exciter: 3-phase generator with field on stator and armature on rotor.
3. Main 3-phase alternator:

They are mechanically coupled and driven by same shaft.

4. Rectifiers: 1. Thyrister controlled bridge.

2. Silicon diode bridge, mounted on shaft.



3. Brushless Excitation

The output of pilot exciter is fed to thyrister controlled rectifier.

After rectification, dc output is given to stationary field winding of main exciter

3-phase output of main exciter is fed through hollow shaft to diode rectifier which is mounted on shaft.

The dc output of diode rectifier is given to the main alternator field without brushes and slip rings.

Since this scheme does not require any sliding contact and brushes, this is called as brushless excitation.

For large 500MW and above, turbo-generator, dc current is up to 10kA or above, this scheme is used.

References

- Slideshare.com