EEP 225 : Electric Machines

Lecture 1

Introduction To DC Machines

1 Introduction To Machines

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1. Q — If I had a machine, converting mechanical energy to electrical energy, can the same machine convert mechanical energy to electric energy?

A — Not always, some machines can work as a motor and a generator as it is (e. g.: DC motors), some machines require some changes to convert from motor to generator

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2. Q — Importance of magnetic field and how to generate it?

A — Magnetic fields are the fundamental mechanism by which energy is converted from one form to another in motors, generators, and transformers.

How magnetic field used in devices?

1. A current-carrying wire produces a magnetic field in the area around it

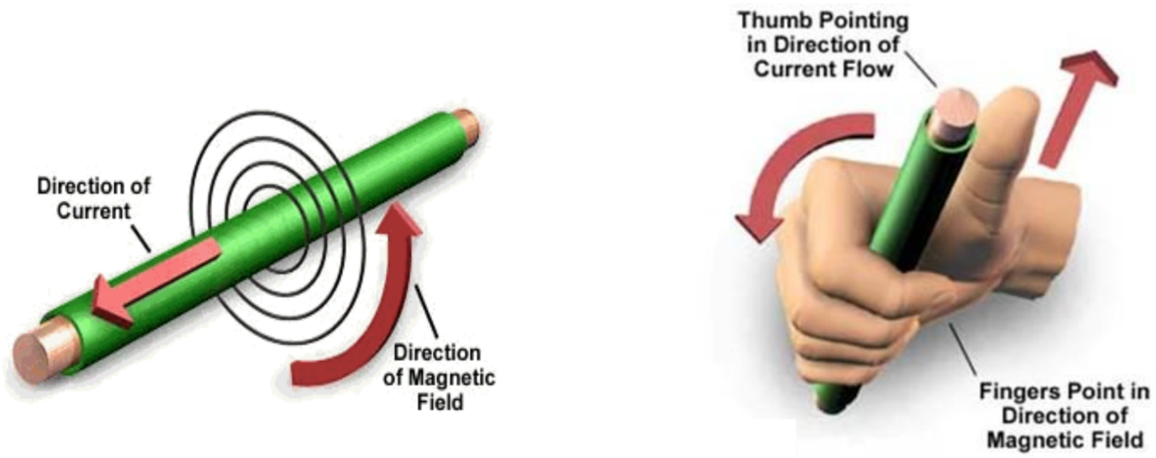


Figure 1: Magnetic field produced by a current in a wire, and the right hand rule

- Remember: The right hand rule

2. A time-changing magnetic field induces a voltage in a coil of wire if it passes through that coil. (This is the basis of transformer action)

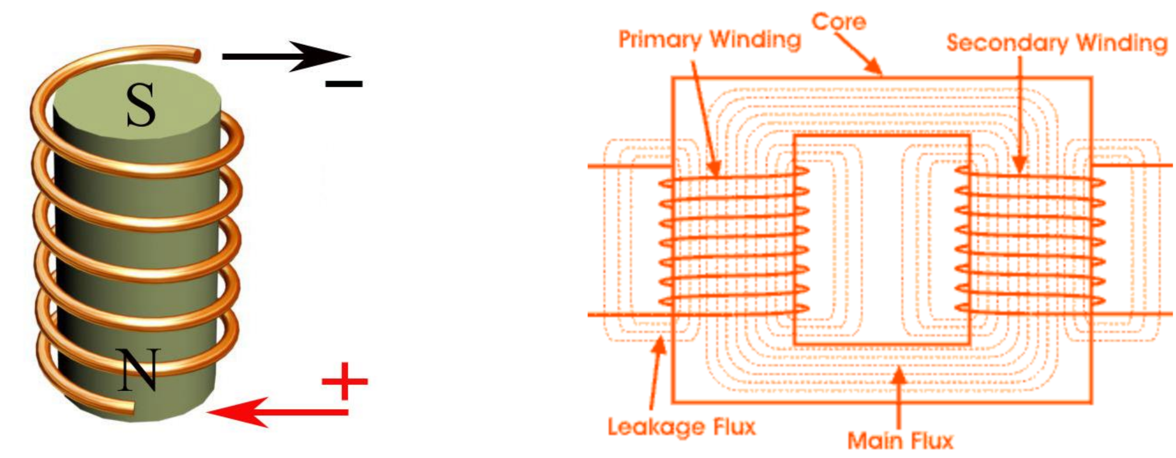


Figure 2: Transformers

- Remember: A transformer is a passive component that transfers electrical energy from one circuits to another circuit. A varying current in any coil of transformer produces a varying magnetic flux in the transformer core. Electrical energy can be transfered between circuit without a connection between them (isolated circuits, works as buffer)

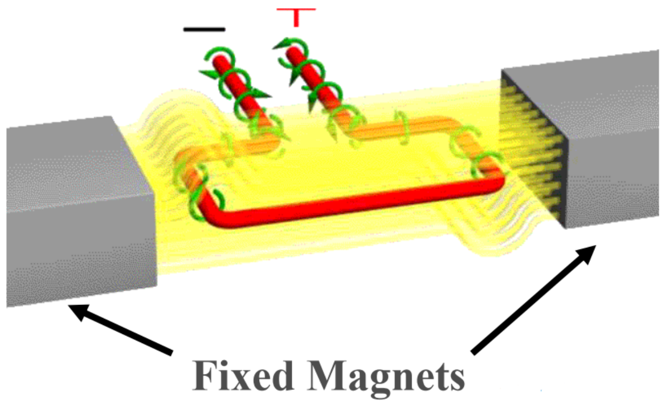
  No electric-mechanical conversion here

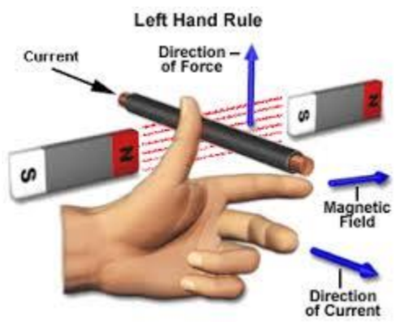
- Remember: Faraday's law:

$$\text{emf} = -N\frac{\Delta\phi}{\Delta t}$$

emf = inducted voltage
N = number of turns
$\Delta\phi$ = change in magnetic flux
Δt = change in time

3. A current-carrying wire in the presence of a magnetic field has a force induced on it. (This is the basis of **motor action**)



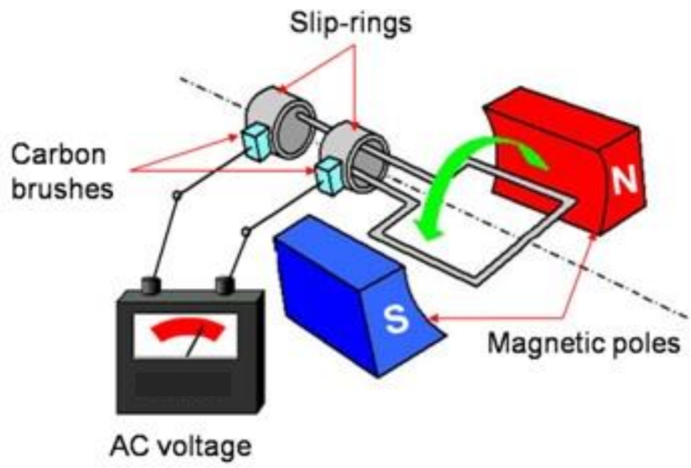


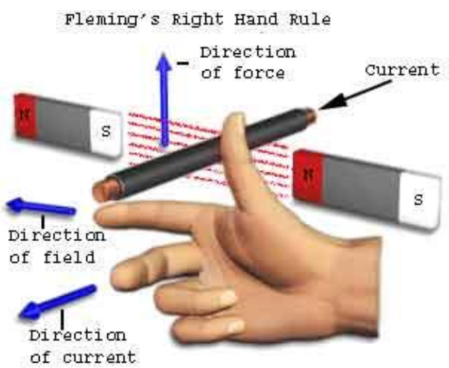
- Remember: Fleming left hand rule from figure
- Remember:

$$F = BIL\sin(\theta)$$

F	= force
B	= magnetic flux density
I	= current
L	= length of the conductor
θ	= angle between B and I

4. A moving wire in the presence of a magnetic field has a voltage induced in it. (This is the basis of **generator action**)





- Remember: Fleming right hand rule from figure

2 Drive Systems

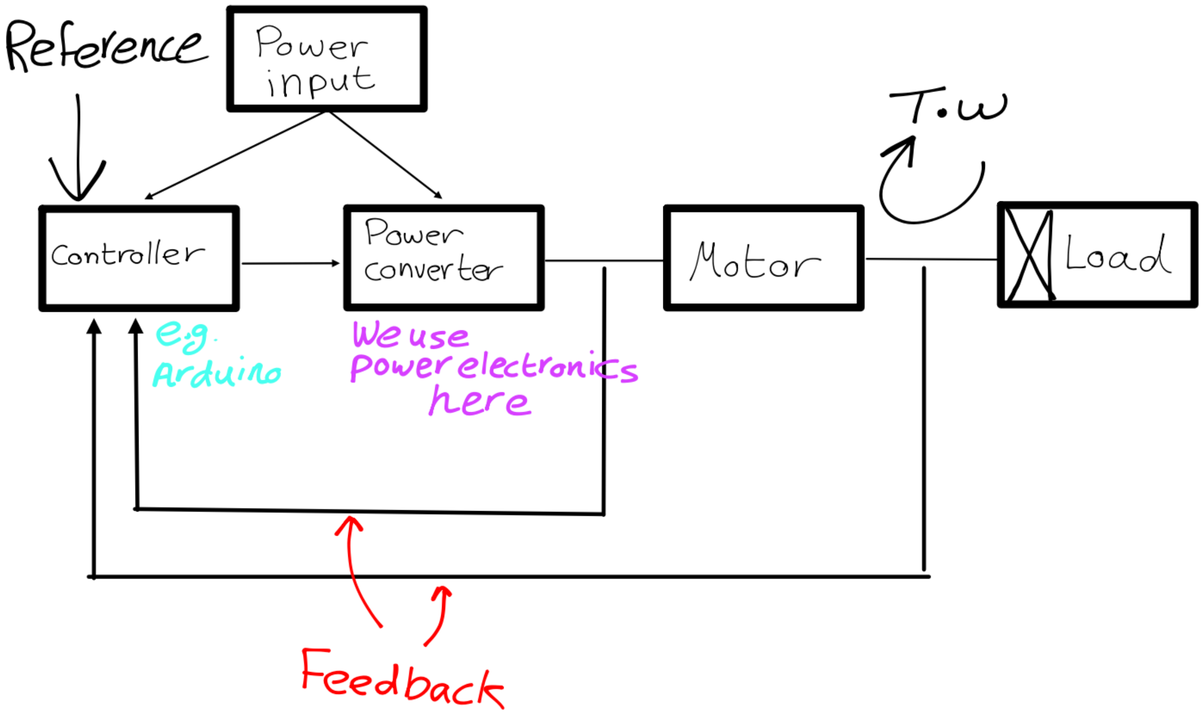


Figure 3: Components of a typical drive system

3 Introduction to DC Drives

1. Most of the electrical machines in service are AC type, we start by studying DC machines for the sake of simplicity
2. DC Drives: Electric drives employing DC motors as prime movers.
3. Dominated variable speed applications before introduction of Power Electronic converters.[1]
4. Still popular even after Power Electronics.
5. DC machines are of considerable industrial importance.
6. DC motors provides a fine control of the speed which can't be attained by AC motors.[2]
7. DC motors can develop rated torque at all speeds from standstill to rated speed

[1]Normal electronics works in three modes: Saturation, active and cut-off mode. In power electronics, we work with high voltages and currents e.g. 5KV and 1K amps, it works in two modes: saturation and cut-off

[2]fine tuning the speed e.g. 5 rpm, can achieved easily with DC motors, rather than AC

8. Developed torque at standstill is several times greater than the torque developed by an AC motor of equal power and speed rating.[3]

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3. Q — What is advantages & disadvantages of DC drives?

A — **Advantages:**

1. High starting torque
2. Stable at all speeds
3. Rapid acceleration and deceleration
4. Speed can be easily controlled over wide speed range.[4]
5. Used in tough jobs , when we need high torque (traction motors, electric trains, electric cars,. . . .)
6. Built in wide range of power ratings (1W to 10,000 hp[5]).

Disadvantages:

1. Needs regular maintenance.
2. Speed limitations.
3. Can't be used in explosive areas.
4. High cost.[6]

Applications:

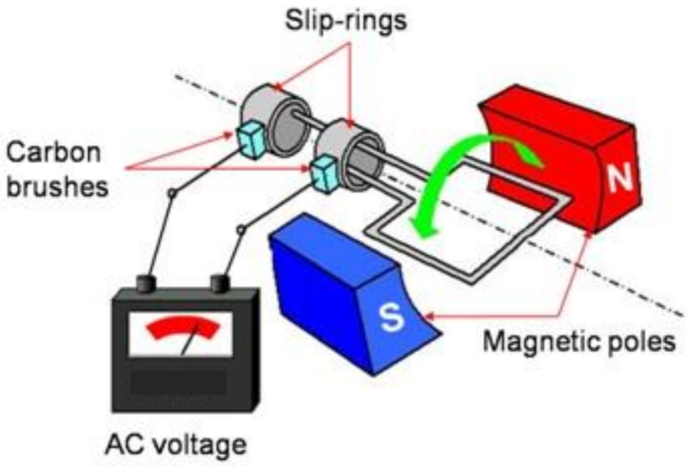
- automobiles
- robots
- VCRs

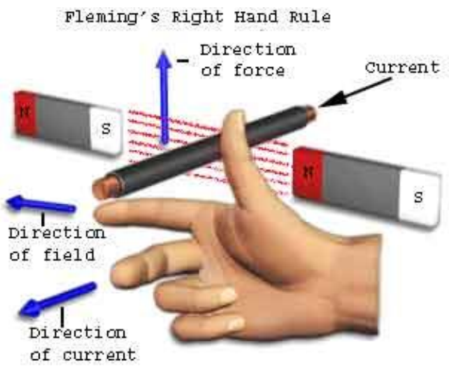
[3]Machines need great tourqe to start
[4]if you have 1000 rpm machine, you can access every speed from [0, 1000] rpm
[5]horse power = 746 Watts
[6]For the same rate, DC motor cost ¿ AC motor cost .... but if i want for my application the ability to fine control the speed then: fine controlling DC motor cost ¡ fine controlling AC motor cost .. it is easier to fine control ac motors

- movie camera
- electric vehicles
- in steel and aluminum rolling mills
- electric trains
- overhead cranes
- control devices

4 DC Generators, Operating Principle

• Remember from previous page : A moving wire in the presence of a magnetic field has a voltage induced in it. (This is the basis of **generator action**)

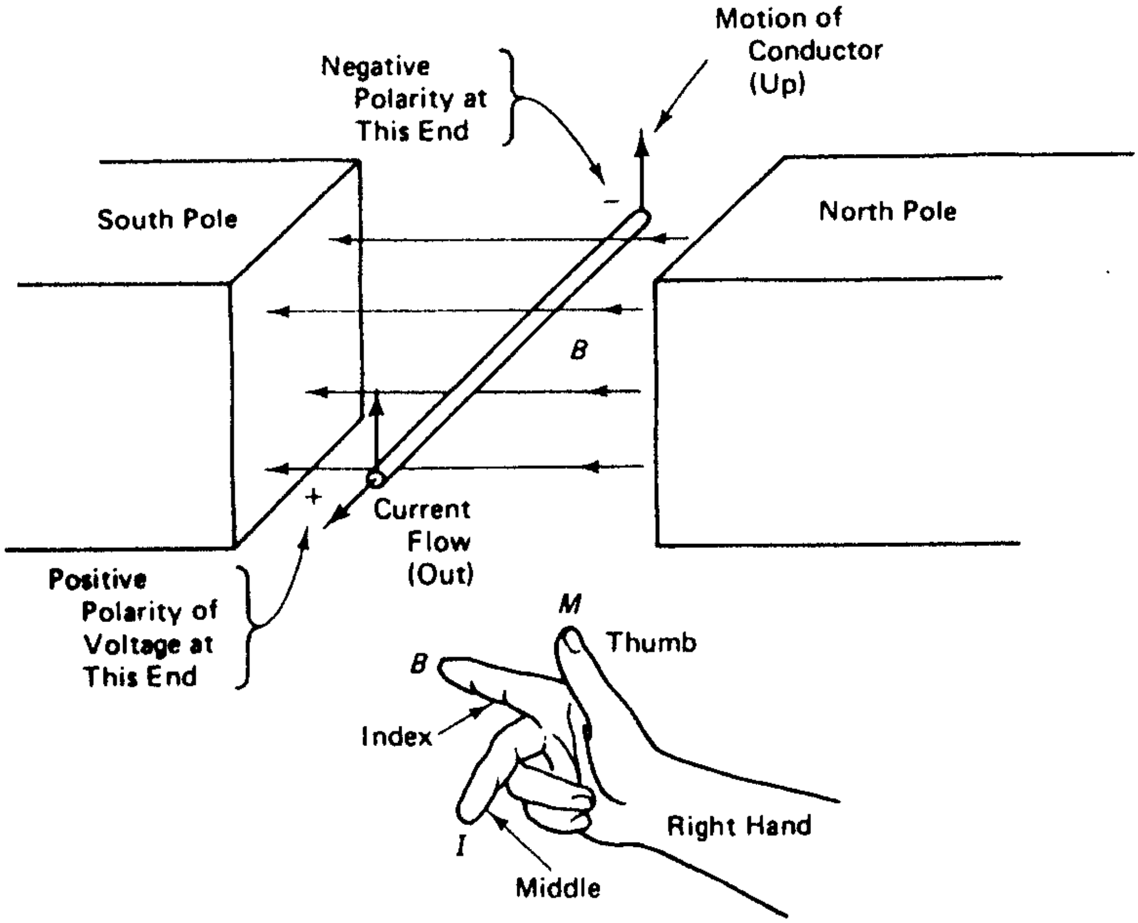




• Remember: Fleming right hand rule from figure

• Notice that: The resulting current is an **AC current**[7]

[7] when connected to a galvanometer, the pointer oscillates


Motion of Conductor (Up)
Negative Polarity at This End
South Pole
North Pole
B
Current Flow (Out)
Positive Polarity of Voltage at This End
M
Thumb
B
Index
Right Hand
I
Middle

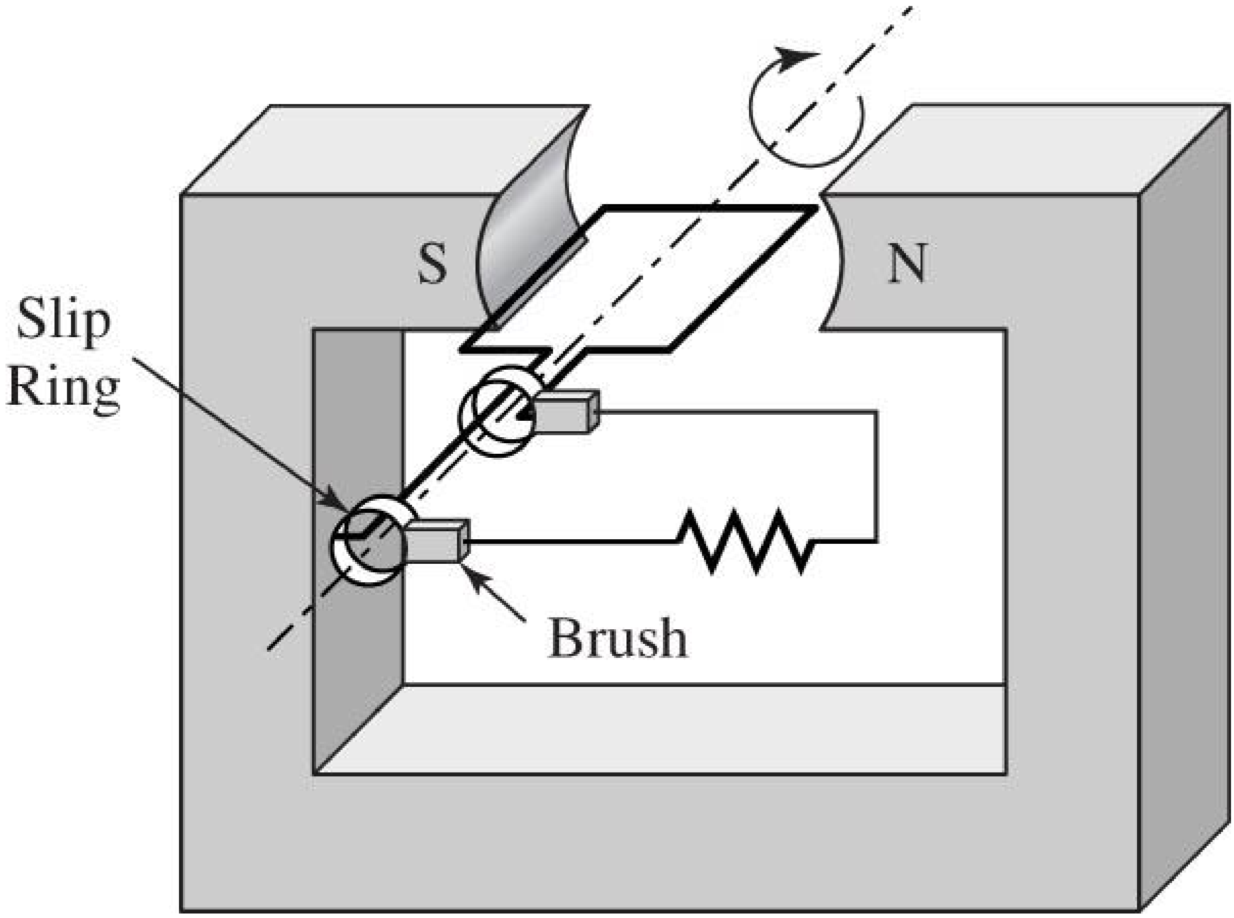


Figure 4: Elementary **AC** Generator

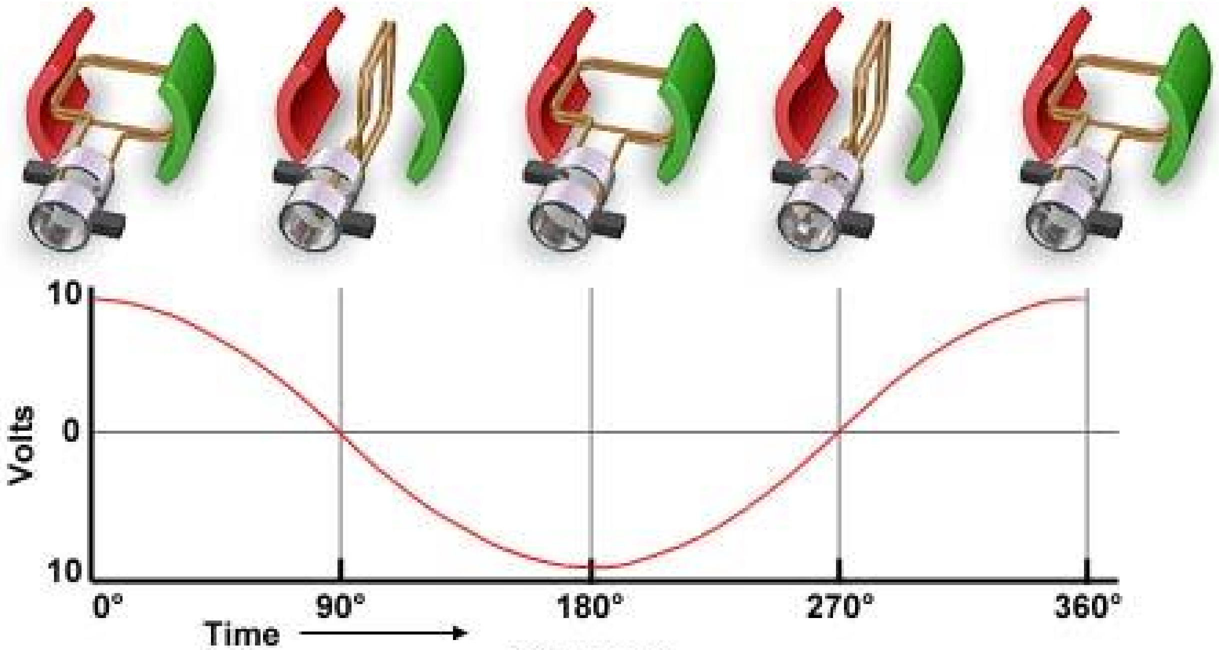


Figure 5: Generated AC Voltage

$\boxed{\text{4. Q}}$ — How to output a DC current instead of AC?

Explain the use of commutator

Commutator is a mechanical rectifier.

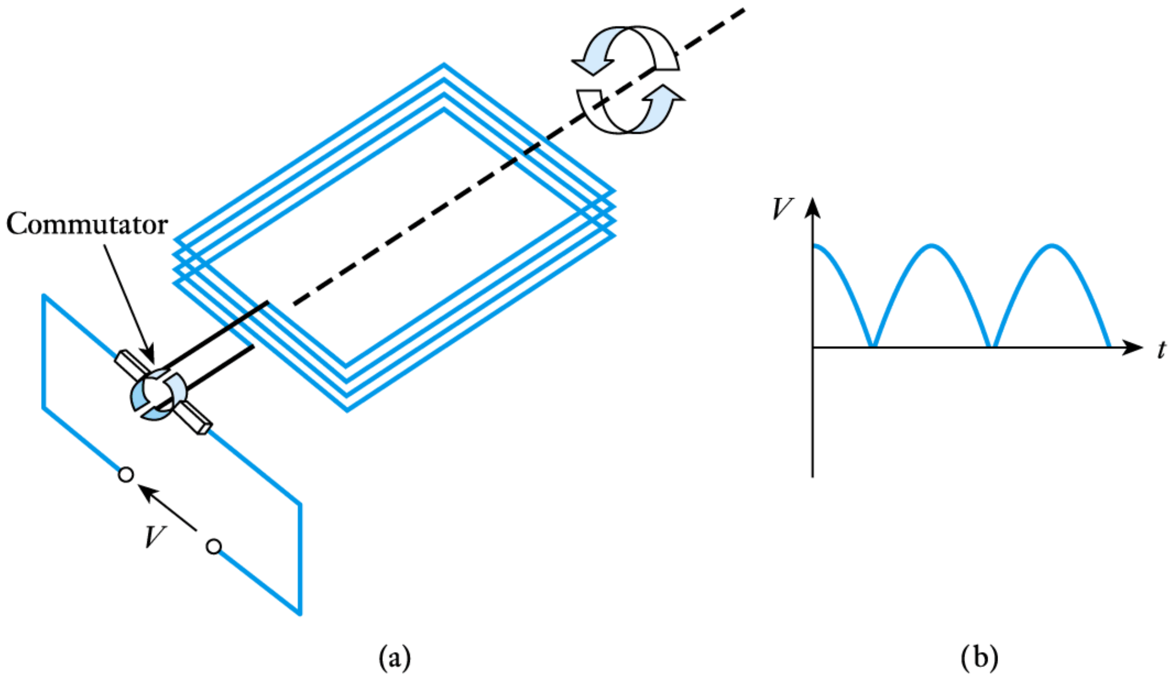


Figure 6: Commutator

if w increased the number of the coils (2, 4, 6, 8, ...), we can output the current from the coil which is in its maximum state, generating nearly a constant DC current

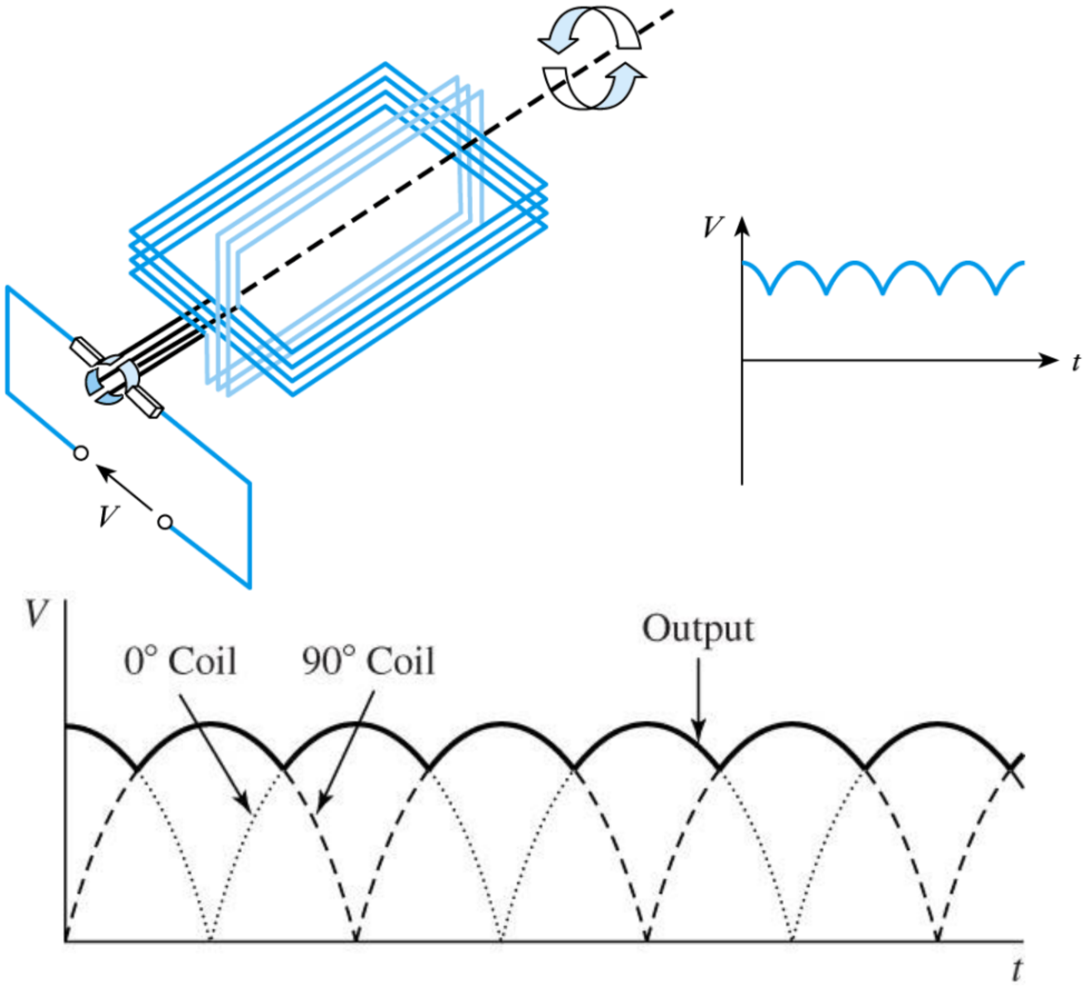


Figure 7: Commutator with several coils

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5. Q — Explain DC machine construction

1. Stator:

   - Usage : Produces magnetic field flux
   - Construction: Magnetic Poles with field windings
   - Material : Steel(iron)

     There are permanent magnet machines, uses permanent magnets in the stator, resulting in smaller and cheaper machines.

     On the other hand, there are electro-magnet machines, uses electricity going through coils to create magnets, resulting in bigger and more expensive machine

     Notice that although electro-magnet machines are more expensive, they have the ability to control the field(variable magnetic filed).

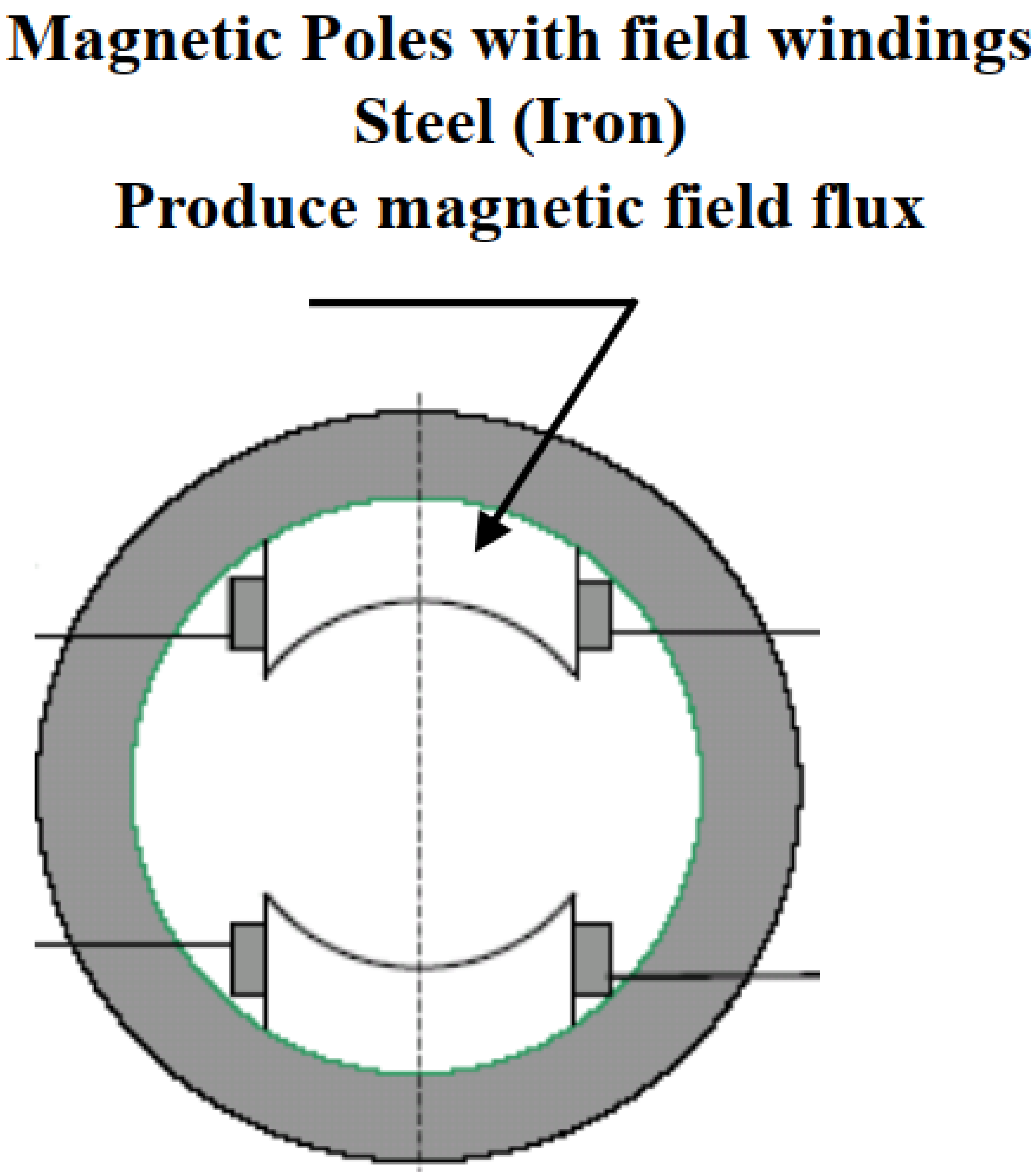

Figure 8: Stator

2. Rotor:

   (a) Brushes:

   - Usage: collect (if motor) or supply (if generator) DC voltage.
   - Material : Graphite (Carbon)

   (b) Commutator

   - Usage: Convert AC to DC (mechanical rectifier)
   - Material : Copper[8]

   (c) Armature:

[8]Think when we use copper (which have high conductivity) and iron-steel (which have high)

- Usage: Produces emf
- Material : Silicon steel (iron)

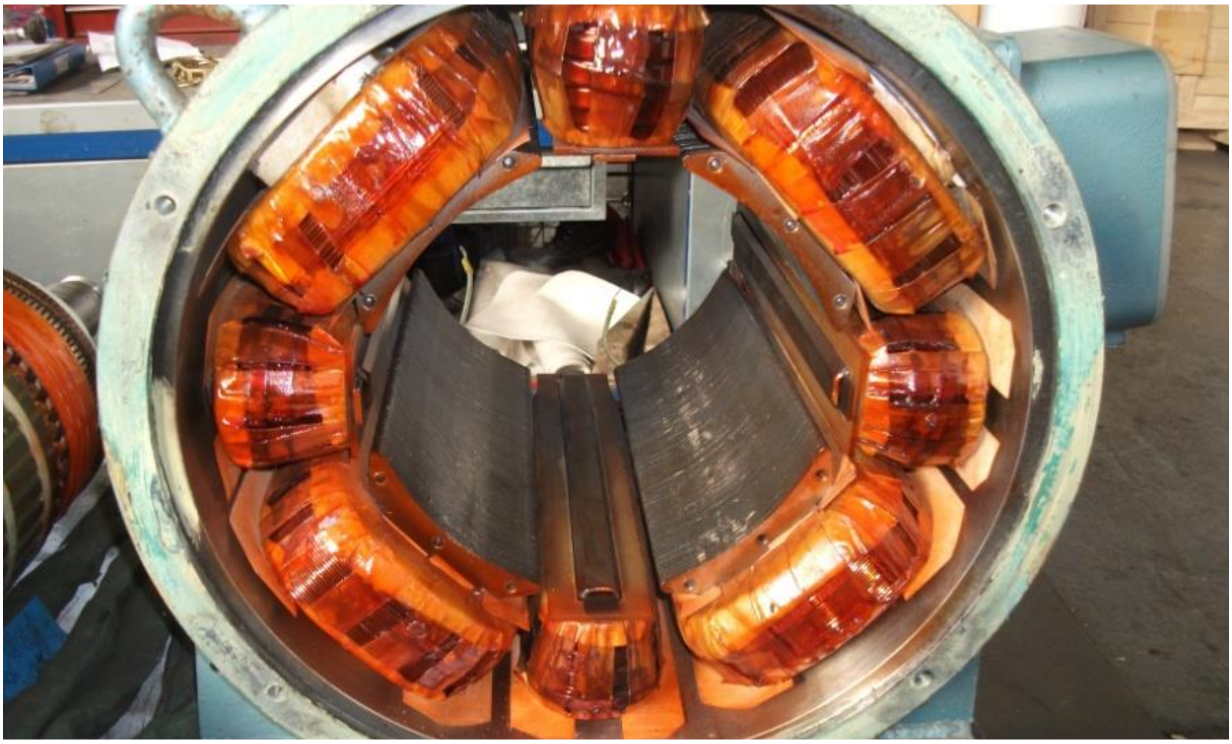

Figure 9: Actual Stator: there are 4 main poles, and 4 inter poles, why? to compensate (decrease) Armature reaction

distance between rotor and stator is verry small $\simeq$ 2mm

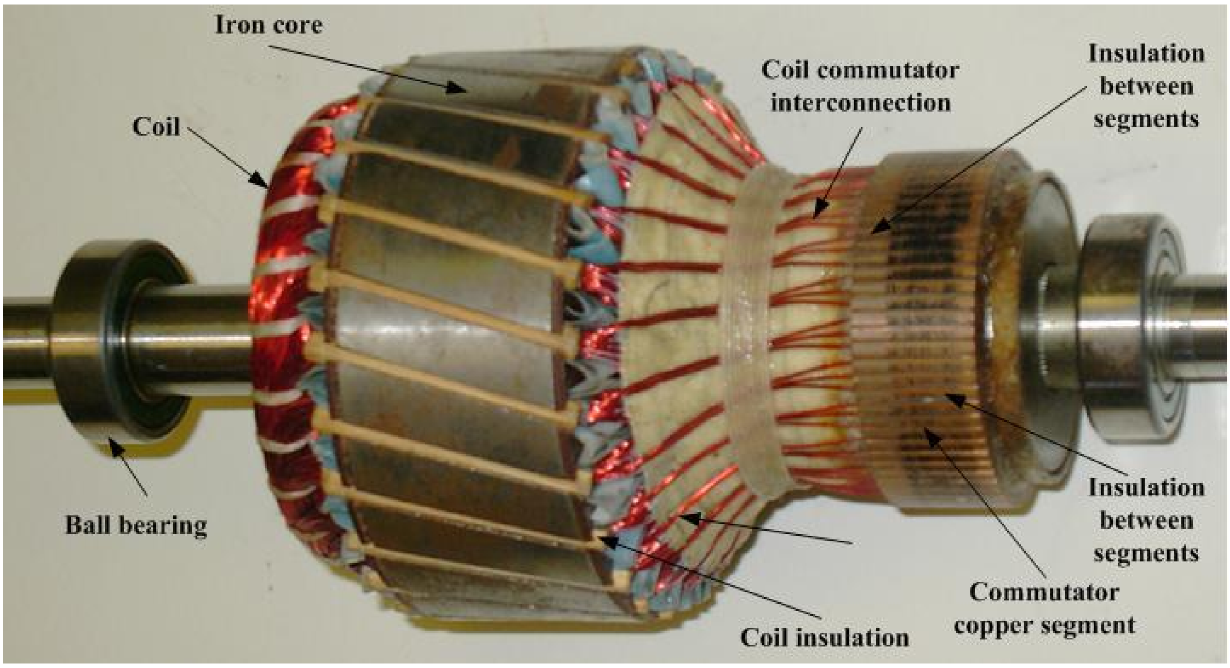

Figure 10: Actual Rotor

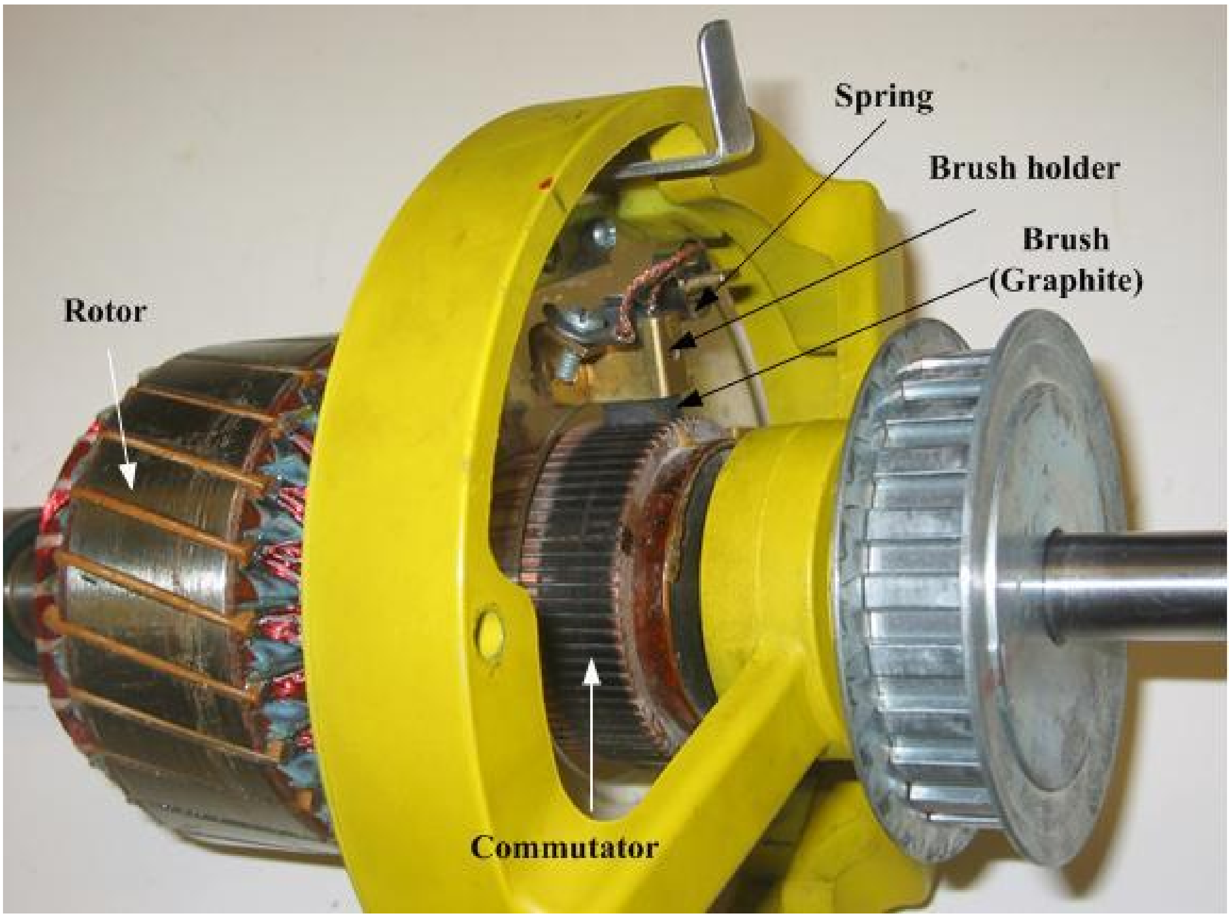

Figure 11: Brush arrangement. Why springs? because brushes wear out, the springs keep pushing the brushes to keep it in contact with the slip ring

- Remember the disadvantages of DC motors (needs regular maintenance, speed limitations, can't be used in explosive areas). and think how the brush arrangement caused this disadvantages

5 Armature Winding

$\boxed{\text{6. Q}}$ — How we connect winding coils?

What is winding ?

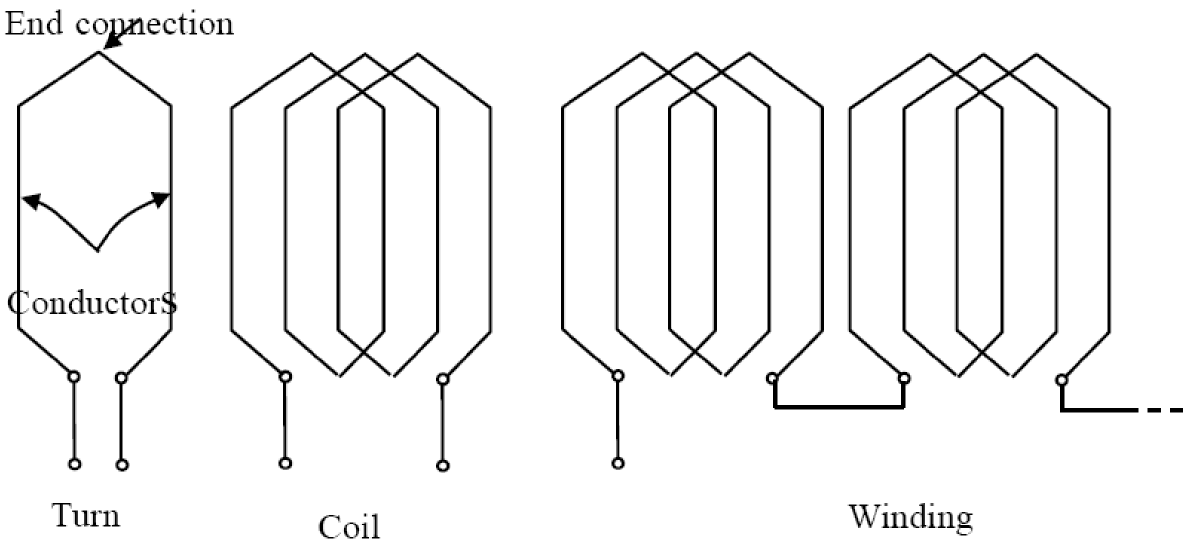

Figure 12: Turn, Coil and Winding

- A turn consists of two conductors connected to one end by an end connector
- A coil is formed by connecting several turns in series.
- A winding is formed by connecting several coils in series.

Armature winding can be divided into two types, depending on how the coils are connected together and how they are joined to the commutator.

1. Lap windings
2. Wave windings

5.1 Lab Winding

In lap winding, connection starts from conductors in first slot, then connections overlap each other as winding proceeds, till starting point reached again. The finishing end of one coil is connected to a commutator segment and to the starting end of the adjacent coil and so on, till all the coils have been connected.

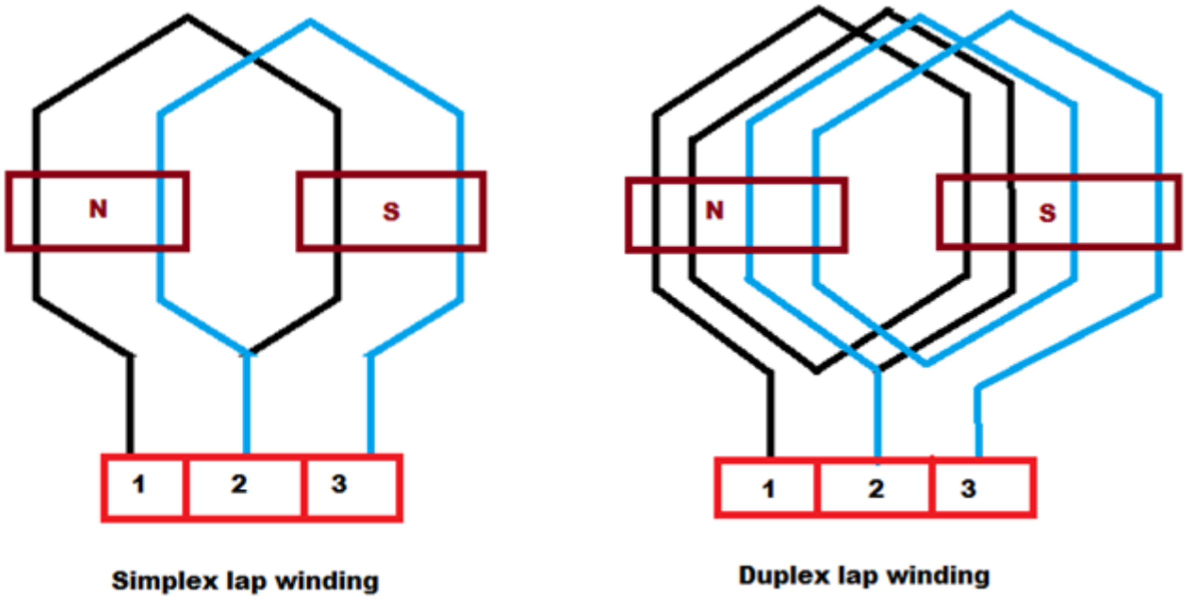

Figure 13: Lab Winding

$\boxed{\text{7. Q}}$ — In an armature winding, the resistance of one coil is 1 Ω , what is the overall resistance of the armature winding

or

Do we connect the coils in series or parallel

A — Neither series nor parallel, a group of coils are connected in series, then the groups are connected in parallel (which called **parallel paths**)

the number of parallel paths is always equal to the number of poles. [9]

The total current output divides equally between them, that is why it is used in **high current, low voltage output**

5.2 Wave Winding

In wave winding, the end of one coil is connected to the starting of another coil of the same polarity as that of the first coil. This winding forms a wave with its coil.

[9]which also is equal to the number of brushes.

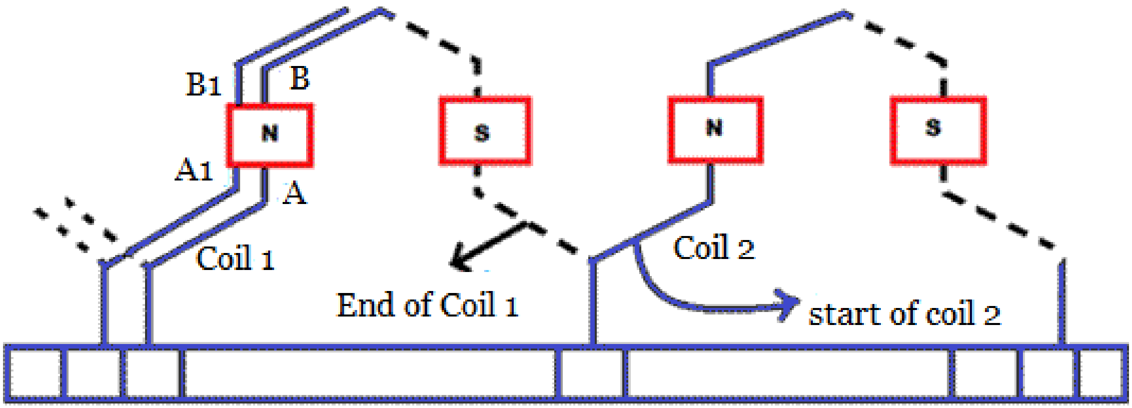

Figure 14: Wave Winding

There are two paths in parallel no matter what the number of poles is, each path supplying half the total current output.
that is why wave wound generators used in **high voltage, low current** outputs.

$\boxed{\text{8. Q}}$ — What decides what type of armature winding to use?

A — The required voltage and current output
if high current, low voltage output ⇒ Lab winding
if low current, high voltage output ⇒ Wave winding

$\boxed{\text{9. Q}}$ — Does the number of the brushes is always two ?

A — No, number of brushes is equal to number of poles
Note that extra brush arms are used to limit the current in each brush arm[10]

6 EMF Generated In An Armature Winding

let :

Z = Number of armature conductors.
ϕ = Useful flux per pole, in Webers (Wb)

[10]Each brush have its own current capacity, handle a limited amount of current, so we divide the current among several brushes, not two

P = Number of poles

N = Armature speed in rpm (revolution per minute)

a = Number of armature parallel paths.(either 2 or P)

Z/a = Number of conductor per path

[11]

[11] In LaTeX by Taha Ahmed