22-DC Machine Construction

ECEGR 450
Electromechanical Energy Conversion

Overview

- Introduction
- Physical Construction
- Armature Winding

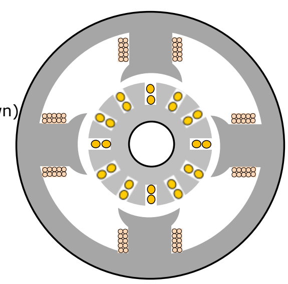
DC Generators

- Magnetic flux is established by poles within the generator <u>stator</u> (stationary part)
  - flux is produced by permanent magnets or field windings (electromagnets)
- emf is induced in a coil that rotates called the *armature*

In AC generators, the emf is induced in a stationary coil. The term "armature" refers to the windings in which the emf is induced and current flows when connected to a load.

Physical Construction

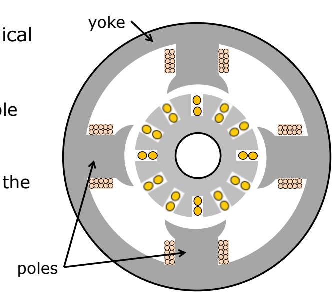
- Main Components:
  - Stator
  - Field Winding
  - Armature
  - Commutator (not shown)
  - Brushes (not shown)
- See book Fig 5.1, 5.2 for more detailed drawings
- <u>DC motors have same construction</u>



cross section

Stator

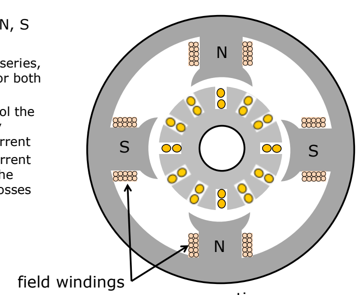
- Provides mechanical support
- Yoke
  - Highly permeable material
- Poles
  - Mounted inside the yoke



cross section

Field Winding

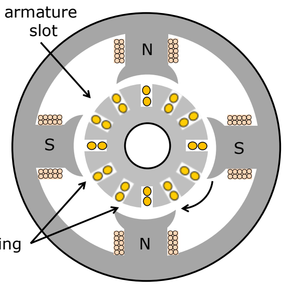
- Polarity alternates N, S
- Either PM or coils:
  - Can be wound in series, parallel (shunt), or both (compound)
  - Advantage: control the amount of flux by controlling the current
  - Disadvantage: current flowing through the windings create losses



cross section

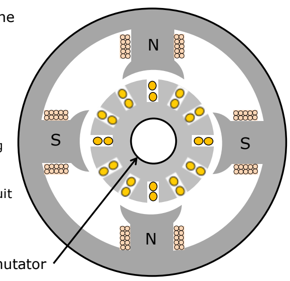
Armature

- Rotates in a dc machine
- Made of highly permeable material
- Armature coils usually made from copper with insulation
- Circular cross section with slots to accommodate the armature coils (armature windings)
- Armature winding can be lap or wave wound



Commutator

- Key component of DC machine
- Rotates with rotor
- Functions like a mechanical rectifier
- Armature windings are connected to it
  - Configuration depends on whether lap or wave winding was used in the armature
  - Allows for connection of generator with external circuit through the brushes

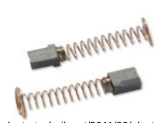


Commutator

- Stationary brushes connect machine to circuit through commutator
- 2 or more commutator segments (odd numbers possible)
- Commutator rotates with rotor
- Segments are insulated from each other
- One or more coils connected to each segment

Brushes

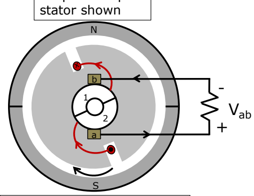
- Connect the rotating commutator to the circuit
- Usually made of carbon or carbon-based mixture
- Spring-loaded to ensure good connection with commutator
- Require maintenance and replacement



Source://www.electrotechnik.net/2011/02/electric-brushes.html

Commutator and Brushes

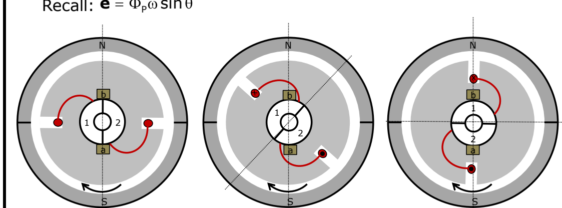
simplified 2-pole stator shown



Recall: current into paper under N pole for CW rotation

Armature Winding

Recall: $\mathbf{e} = \Phi_p \omega \sin\theta$



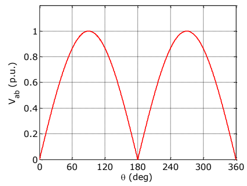
$\theta = 0$, $v_{ab} = 0$
zero emf and segments are shorted

$\theta = 45^o$, $v_{ab} = 0.7$

$\theta = 90^o$, $v_{ab} = 1.0$

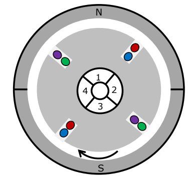
Armature

- Output voltage in dc generator with single coil
- Large ripple
- Pulsating current, torque, power
- How can ripple be reduced?
- How can the induced voltage be increased?



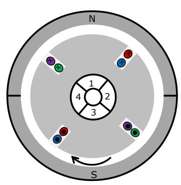
Armature Winding

- Consider 4 armature coils
  - Red, blue, green, purple
- Each coil:
  - Has two ends
  - Full pole pitch
- Indicate the polarity of the induced current in each conductor if each coil is connected to an external circuit



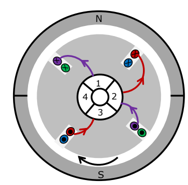
Armature Winding

- Current in conductors near N pole flow into paper
- Current in conductors near S pole flow out of paper



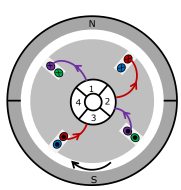
Armature Winding

- Current flows from segment 1:
  - into purple coil by N pole
  - out of purple coil by S pole
  - into segment 2
  - into red coil by N pole
  - out of red coil by S pole
  - into segment 3



Armature Winding

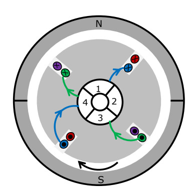
- Draw coil-to-segment connections to make blue and green coils in series
- Do not short any coil (e.g. connect both ends of red coil to same segment)
- Respect polarity of current



Current will flow into "x" and out of ●

Armature Winding

- Current flows from segment 1:
  - into blue coil by N pole
  - out of blue coil by S pole
  - into segment 4
  - into green coil by N pole
  - out of green coil by S pole
  - into segment 3



Armature Winding

- Let brushes be positioned along N-S axis
- Two parallel paths
- Each path has two series coils

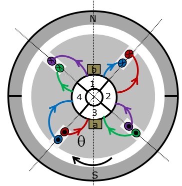
$\theta = 45°$

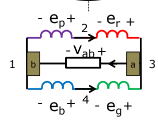
$|\mathbf{e}_p| = |\mathbf{e}_g| = |\Phi_p \omega \sin\theta|$

$|\mathbf{e}_r| = |\mathbf{e}_b| = |\Phi_p \omega \sin(\theta - 90°)|$

$v_{ab} = |\mathbf{e}_p| + |\mathbf{e}_r| = |\mathbf{e}_b| + |\mathbf{e}_g|$

Polarity already accounted for.





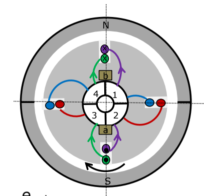
Armature Winding

$\theta = 90°$

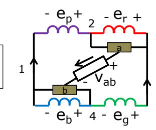
$|\mathbf{e}_p| = |\mathbf{e}_g| = \Phi_p \omega \sin\theta = \Phi_p \omega$

$|\mathbf{e}_r| = |\mathbf{e}_b| = \Phi_p \omega \sin(\theta - 90°) = 0$

$v_{ab} = |\mathbf{e}_p| + |\mathbf{e}_r| = |\mathbf{e}_b| + |\mathbf{e}_g| = \Phi_p \omega$

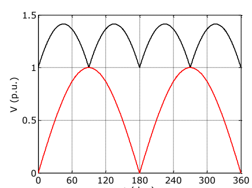


shorted windings have 0 emf



Armature Winding

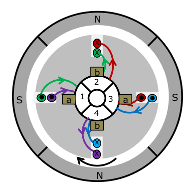
- Effects of adding armature windings
  - Reduce ripple
  - Higher peak voltage
  - Higher average voltage

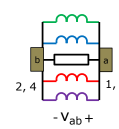


4 coils: black
1 coil: red

Armature Windings

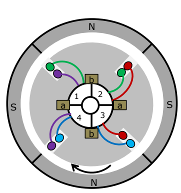
4 pole, 4 armature winding machine



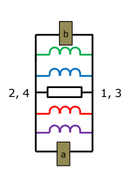


Armature Windings

4 pole, 4 armature winding machine



No current flow, $V_{ab} = 0$



Lap Winding

- Discussed winding method known as *Lap Winding*
- Very common
- Used in low-voltage, high-current machines
  - High number of parallel paths for current
  - Low number of coils in series
- Ends of a coil are connected to adjacent segments on the commutator
  - Number of commutator segments equals the number of armature slots

Lap Winding

- Number of brushes = number of parallel paths = number of poles
  - Must be even number
- Number of segments = number of armature windings
  - Possible for odd number of armature windings

Wave Winding

- Used in high-voltage, low-current machines
  - Connect armature windings in series to obtain high voltage
    - Those under N pole are connected together
    - Those under S pole are connected together
  - Armature windings are connected almost 360º electrical apart (can be more, can be less)
- Always 2 brushes
- Number of commutator segments = number of slots
- Windings are the same as in Lap wound machines, but the commutator pitch is different

Armature Winding

- Recall that maximum emf occurs in a full-pitch coil (180º electrical)
- May not be easy to wind using full-pitch, so fractional pitch may be used
  - Reduces emf by a value known as the pitch factor

Example

How many brushes and commutator segments does a 6-pole dc machine with 31 armature windings have?

Example

How many brushes and commutator segments does a 6-pole dc machine with 31 armature windings have?

6 brushes
31 commutator segments

Summary

- DC machines are composed of: stators, rotors, field windings (or PMs), armature windings, brushes and commutator
- Increasing # of armature winding improves output waveform
- Armature windings may be lap or wave wound
- Lap winding: # of poles = # of brushes
  # of armature windings = # of commutator segments
  - Winding ends connected to adjacent segments