DC Machines—Part 3

Losses. Construction.

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Electrical Losses

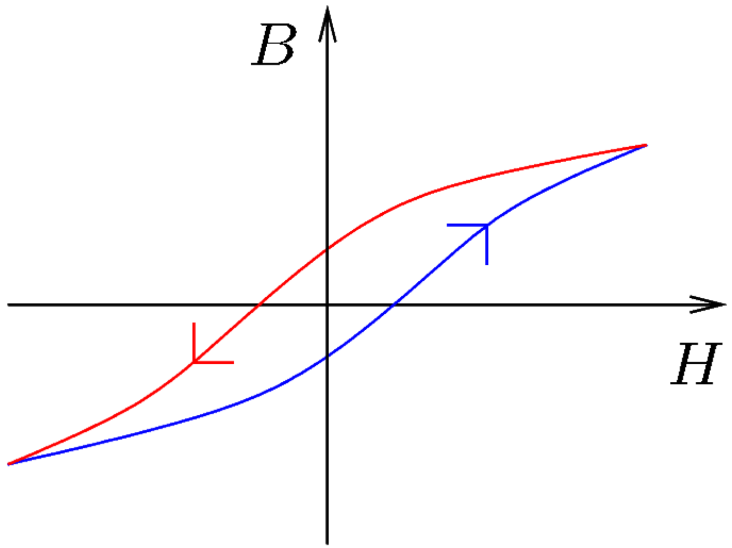
- Copper losses: due to the resistance of the windings.
- Brush contact losses: the resistance between the brushes and the commutator segments is not zero and not constant.

- Let I_a and I_f be the armature and field currents.
- Let R_a and R_f be the armature and field resistances.
- Copper losses equal to the power dissipated by R_a and R_f:

$$P_c = I_a^2 R_a + I_f^2 R_f$$

Magnetic Losses

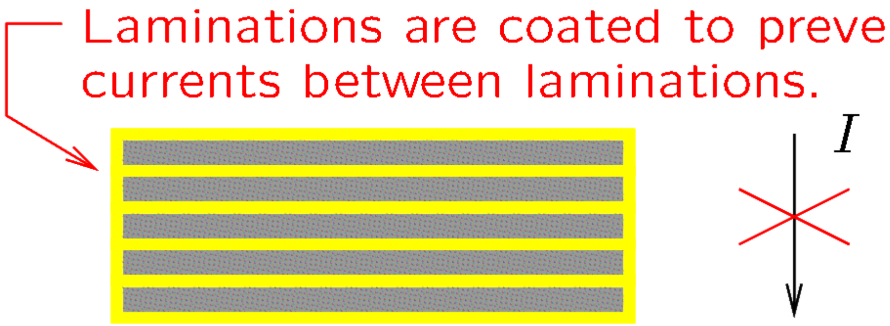
- Magnetic losses appear in the core of the coils of the motor.
- They are also known as iron losses, because the core is commonly made of steel.
- Hysteresis losses appear for core materials in which the dependence of the flux density B on the intensity of the magnetic field H has a hysteresis.
  - When current increases, H increases, and B follows the lower curve.
  - When current decreases, H decreases, and B follows the upper curve.



- Steel has hysteresis, so hysteresis losses are common in motors.
- The lost power is proportional to frequency and the area between the lower and upper curves.
- So there are no losses in constant magnetic field.

Magnetic Losses

- Eddy current losses are significant when the core conducts well electricity.
  - A time-varying magnetic field induces currents in the core.
  - Since the resistivity of the core is not zero, power will be dissipated in the core due to the Eddy currents.
- In constant magnetic field there are no Eddy currents, and thus no losses.
- To reduce Eddy currents, cores are made of sheet-steel laminations.
  - Laminations are insulated one from the other.
  - There are Eddy currents in each sheet, but no currents from one sheet to another.



Other Losses

- Mechanical losses are due to friction.
  - Bearing friction.
  - Brush friction (friction between the brush and the commutator).
  - Windage (friction with the air).
- Stray load: Any other loss not covered before.
  - In the textbook, stray load losses are taken as 1% of the output as a rule of thumb.

Example

A $10\ hp$ $200\ V$ shunt DC motor operates at the rated power. The line current is $48\ A$, the field resistance is $200\ \Omega$, the armature resistance is $0.5\ \Omega$, the brush contact drop is $2\ V$, mechanical losses are $400\ W$, and stray losses 1% of output. Find the efficiency and the core losses. (See problem 4.24 in the textbook for a similar example.)

- *The line current is the total current. The input power is* $P_{in} = 48 \cdot 200 = 9.6\ kW$.
- *The output power is* $P_{out} = 10\ hp = 7457\ W$.
- *The efficiency is* $\eta = \frac{P_{out}}{P_{in}} = 77.68\%$.
- *The field current is* $I_f = \frac{200\ V}{200\ \Omega} = 1\ A$.
- *The armature current is* $I_a = I_L - I_f = 48 - 1 = 47\ A$.
- *The brush contact losses are* $P_{bc} = 2 \cdot I_a = 94\ W$.

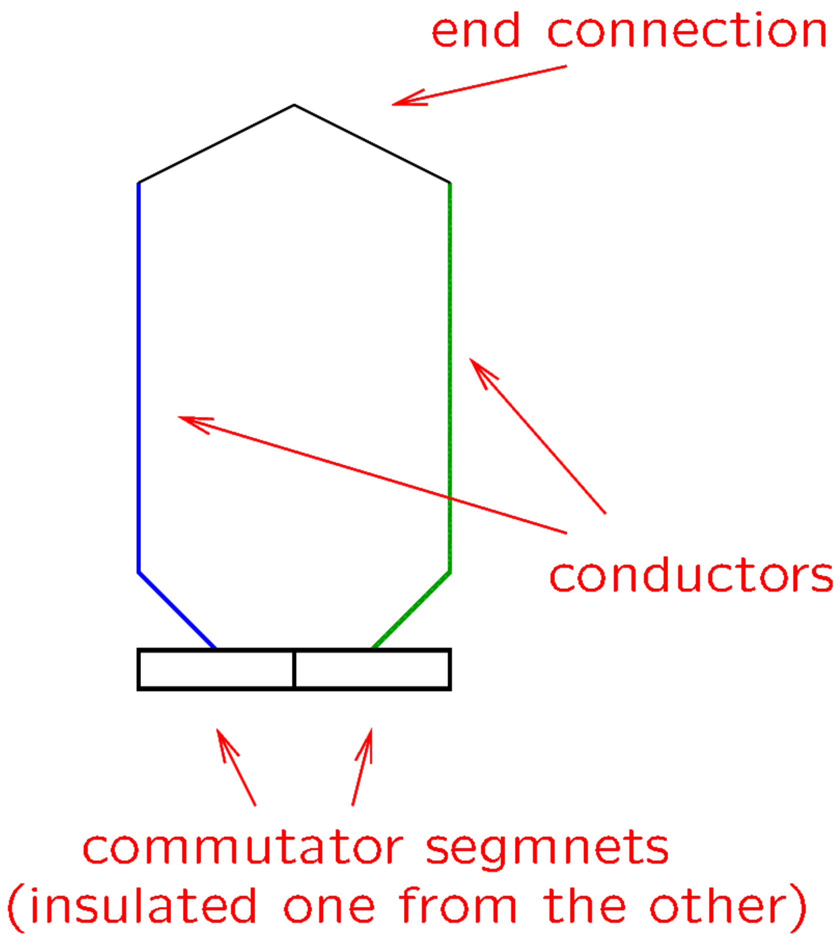
Example (Continued)

- *The copper losses are* $P_c = I_a^2 R_a + I_f^2 R_f = 47^2 \cdot 0.5 + 1^2 \cdot 200 = 1304.5\ W$.
- *The stray losses are* $P_s = 0.01 \cdot P_{out} = 74.57\ W$.
- *The mechanical losses are given:* $P_m = 400\ W$.
- *The core losses are the magnetic losses.*

$$P_{iron} = P_{in} - P_{out} - P_{bc} - P_c - P_s - P_m = 269.93\ W.$$

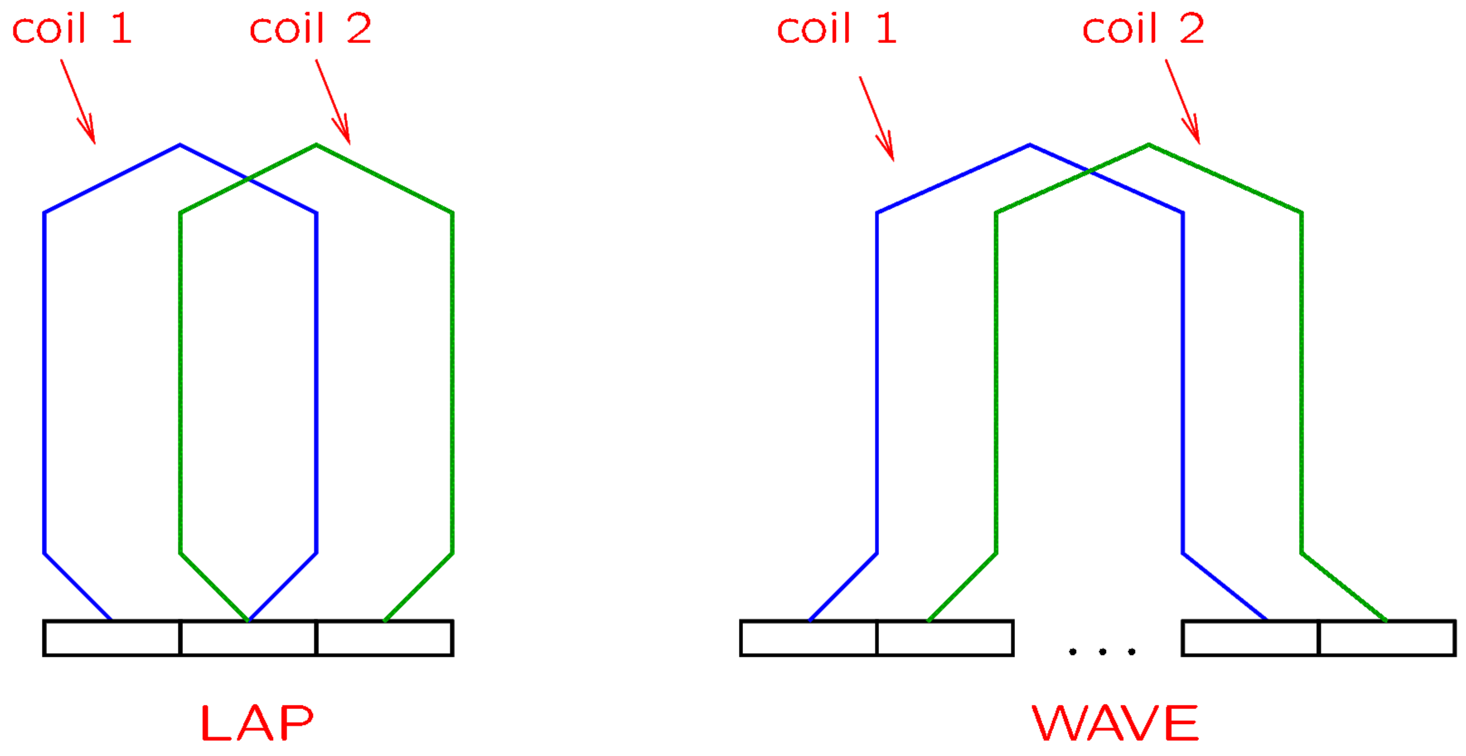
Construction of DC Motors

- The coils of large motors consist of many turns connected in series, where each turn has two conductors.



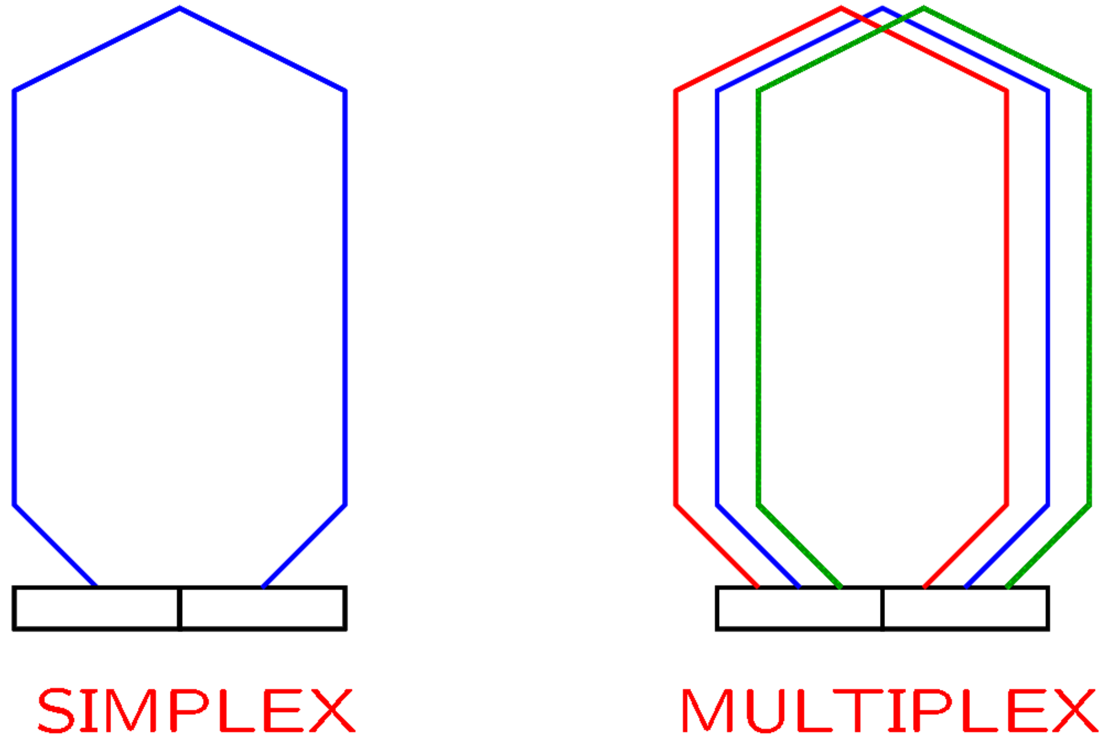
Construction of DC Motors

- There are two types of windings:
  - Lap windings: Each armature coil connected to adjacent commutator segments.
  - Wave windings: The armature coils are <u>not</u> connected to adjacent segments.



Construction of DC Motors

- Windings may be:
  - Simplex: no parallel coils.
  - Multiplex: several parallel coils.



Construction of DC Motors

- Let $PLEX$ be the number of parallel coils.
  - $PLEX = 1$ for simplex windings.
  - $PLEX > 1$ for multiplex windings.
- A machine with wave windings has:
  - $p \geq 2$ stator poles
  - 2 brushes
  - $2 \cdot PLEX$ current paths.
- A machine with lap windings has:
  - $p \geq 2$ stator poles
  - p brushes
  - $p \cdot PLEX$ current paths.

Construction of DC Motors

- Let
  - p be the number of stator poles.
  - z be the total number of conductors.
  - a be the number of current paths.
- The back electromotive force has the equation

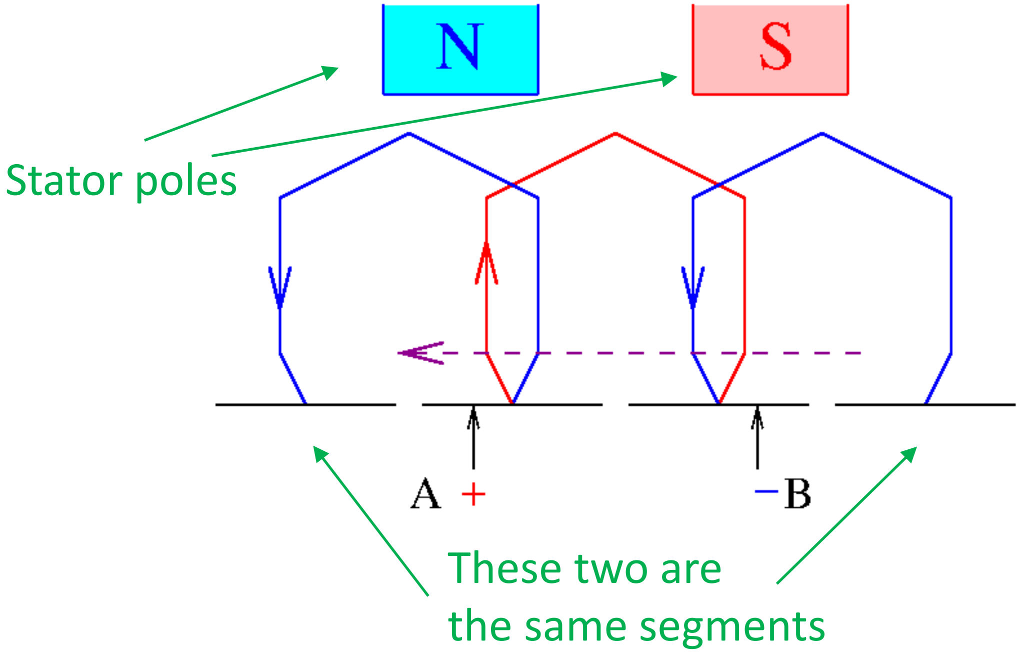
$$E = k_a \Phi \omega$$

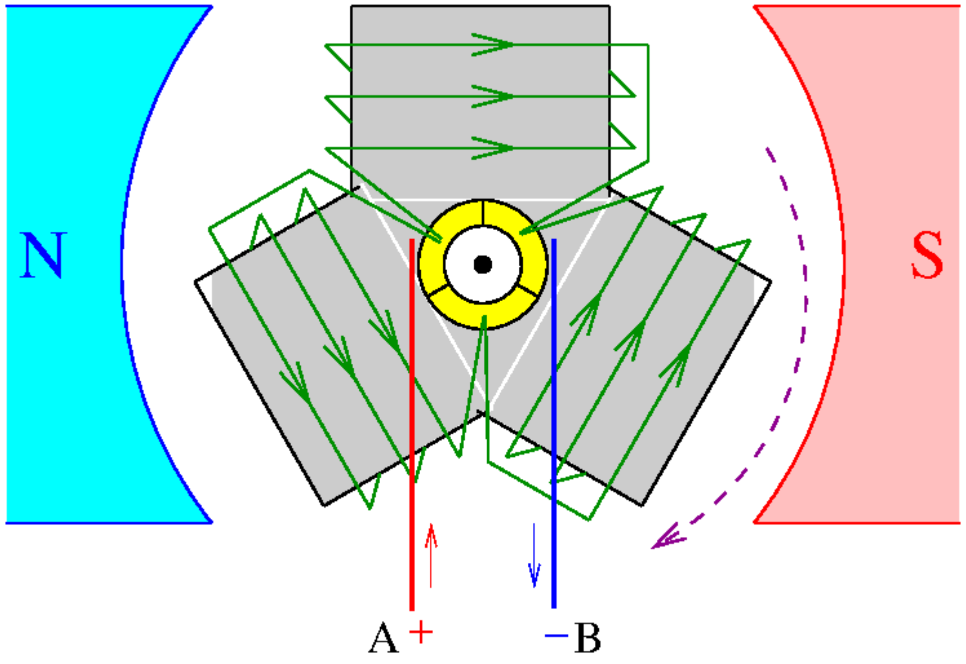
where Φ is the flux per pole and

$$k_a = \frac{zp}{2\pi a}$$

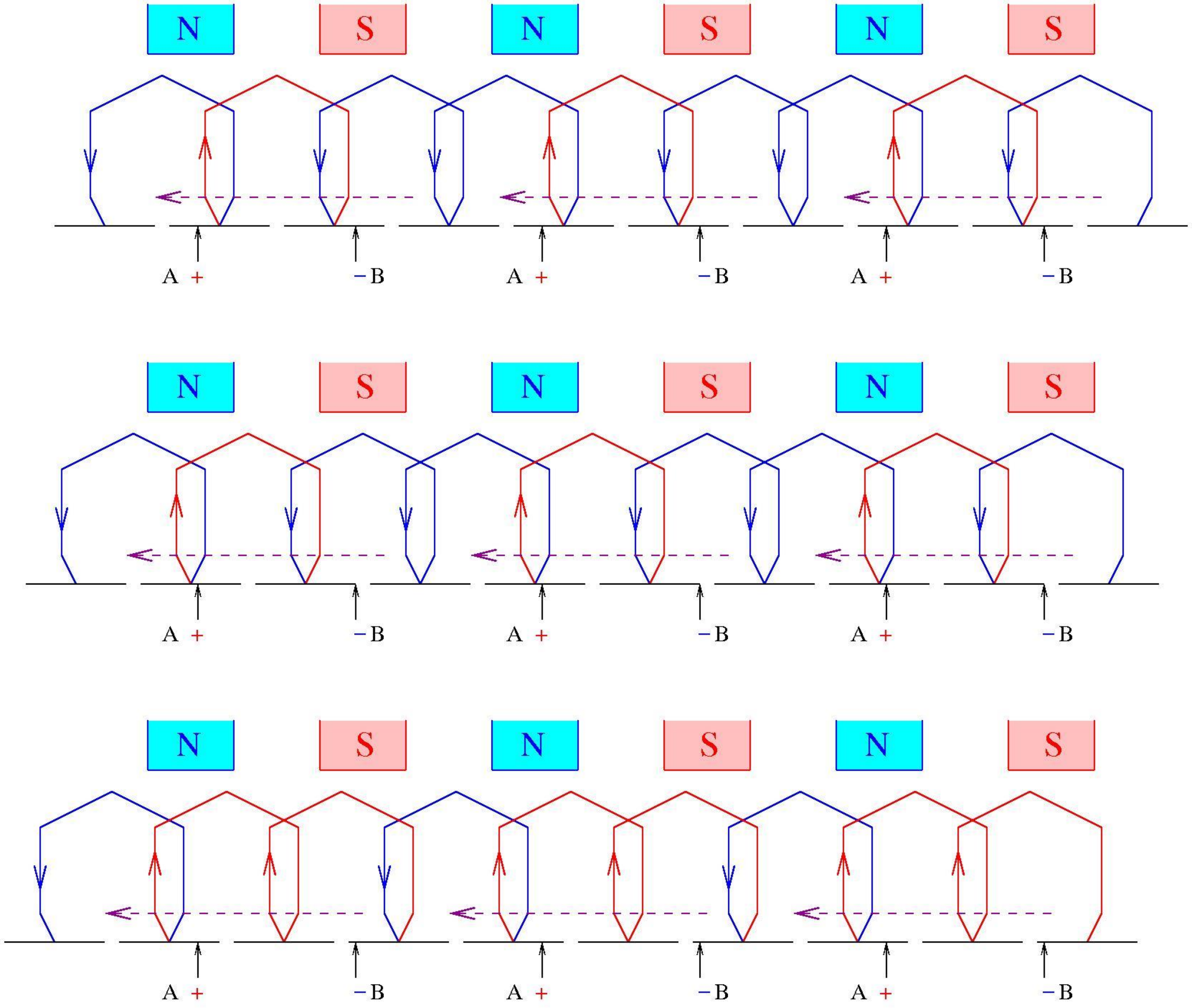
Examples

- To describe a motor more easily, it is convenient to “flatten” it and draw it flat.
- A *developed diagram* “is obtained by imagining the armature surface to be removed and then laid out flat” (Quoting from http://machineryequipmentonline.com/electric-equipment/two-layer-winding-and-multiplex-winding/ , as of April 18, 2020.)
- Below, there are two current paths ($a = 2$) between the two brushes, one shown in red and one in blue.



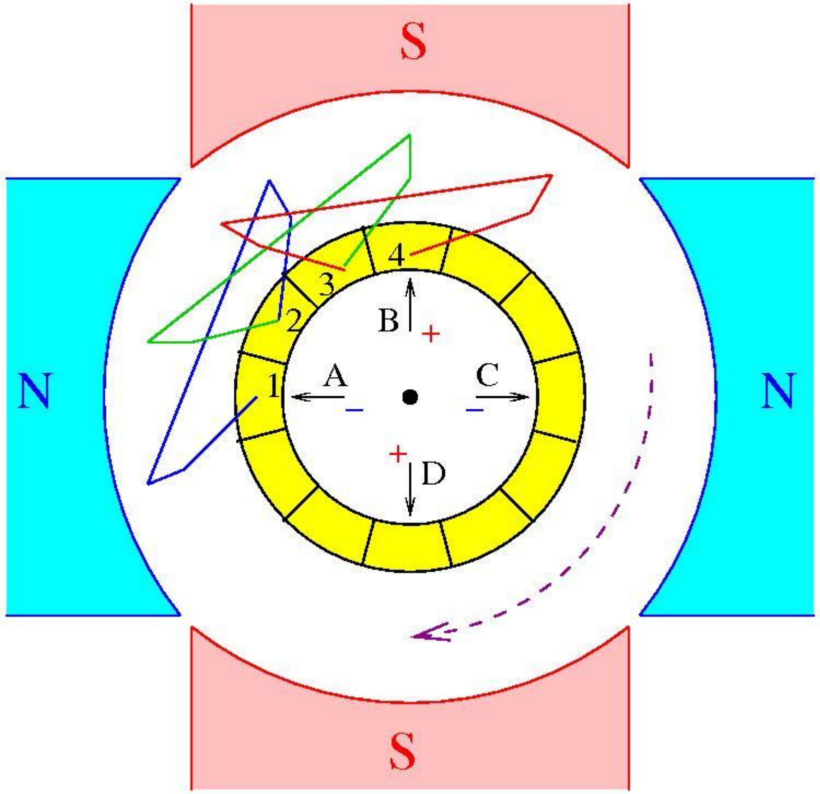


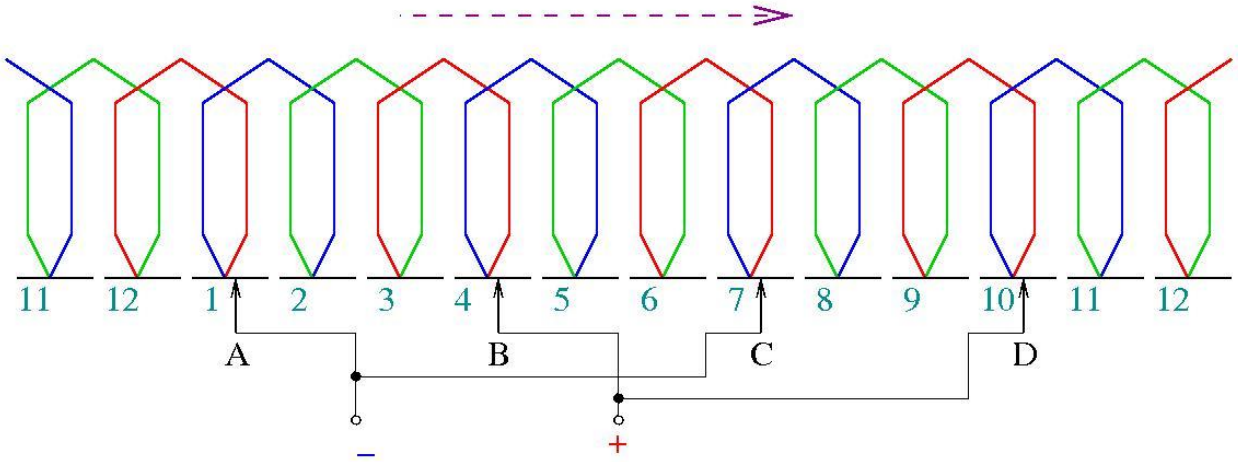
- A red coil has the south polarity and a blue coil the north polarity.
- So a south stator pole repels a red coil and attracts a blue coil.
- The brushes and the stator poles are fixed.
- The armature moves from right to left.
- As it moves, the polarity of the current is switched by the commutator, so that the force is consistently from right to left.



DC Machine with Lap Windings and 4 Stator Poles

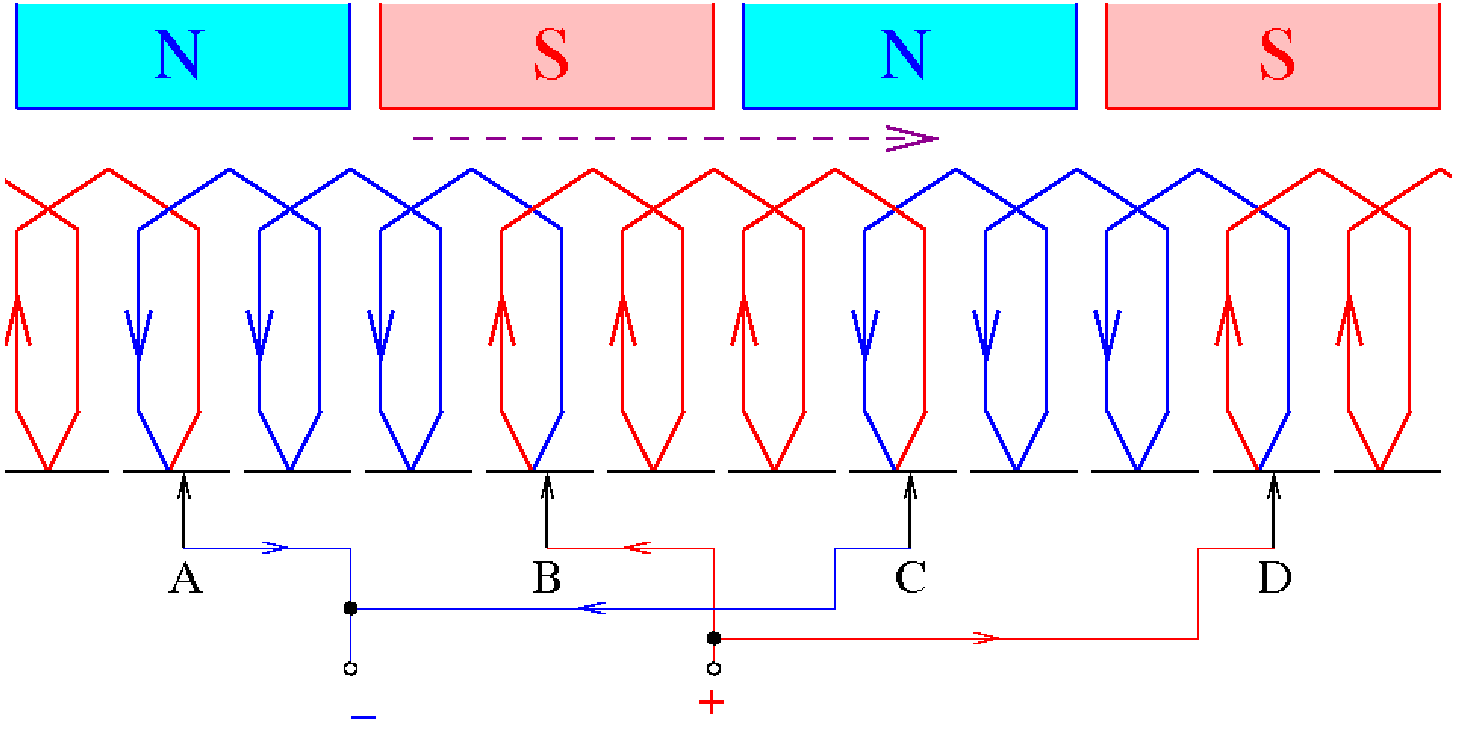
- Note that $p = 4$ and $a = 4$.
- There are four current paths:
  - One between brush A and brush B
  - One between brush B and brush C
  - One between brush C and brush D
  - One between brush D and brush A





DC Machine with Lap Windings and 4 Stator Poles

- Note that $p = 4$ and $a = 4$.
- Two current paths marked in red and two marked in blue.



DC Machine with Wave Windings and 4 Stator Poles

- Note that $p = 4$ and $a = 2$.
- There are two current paths between the brushes A and B.
- One path is marked in red and one in blue.