ME133 Lecture 13 2/28/23

Last time:

> Timing Diagrams

> Boolean Algebra

Today:

> DC Motors

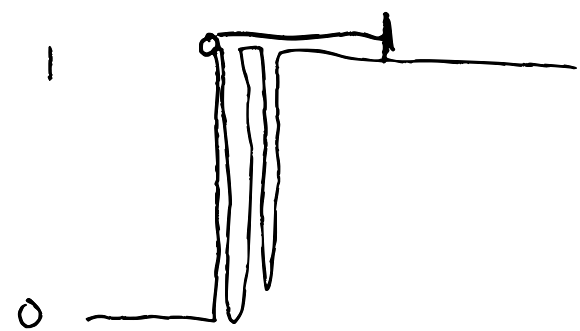
Notes on Simon Says

```
play-sequence ( seq ) {
  digital write . . .
      - . .
       - . .
}
```

millis()

button ⟶ debounce

tone ⟶



Finite State Machine

play(n, seq) {

setup

→ set pins

⋮

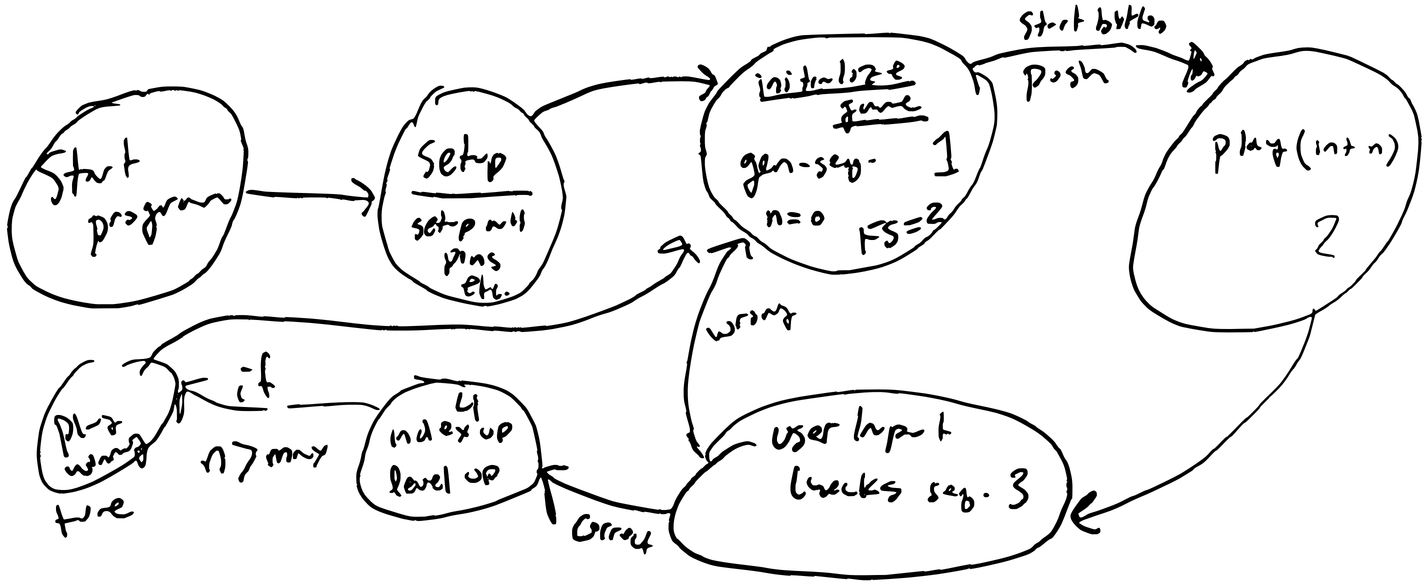
int * generate Seq(int l) {

array seq.

for l

seq[i] = rand (4)

}



Correct
or
wrong

$\begin{pmatrix} 0 \\ 1 \end{pmatrix}$

user_seq.

```
userInput( seq, n )
while
  a = digitalread(pin1)
  b = digitalread (pin 2)
  c = digitalread (pin 3)
  d = digitalread (pin 4)

  if (a==1) || (b==1)
       break.
```

polling

Monday 3/4

```
// check the sequence.
{ for 0:n
  seq(n) == user_seq(n);
```

FS = 1

Switch FS

Case : 1

intialize game() .

Case : 2

play Sequen()

case : 3

getuser lnpt ()

Case : 4 nextleve().

Example: Designing a logic network

Let's design a home alarm system using only logic gates

What we want:

1. Alarm to sound only if windows or doors are disturbed (sleeping - mode 1)
2. Alarm to sound if windows or doors are disturbed or motion in the house is detected (vacation - mode 2)
3. A disable state where the alarm can be turned off completely (off - mode 3)

Assumptions:

1. Sensors are binary (motion - 1, no motion -0, door/window disturbed - 1, no disturbance - 0)

Example: Designing a logic network

- A: state of the door and window sensors
- B: state of the motion detector
- Y: output used to sound the alarm
- $C\,D$: 2-bit code set by the user to select the operating state defined by

$$C\,D = \begin{cases} 0\,1 & \text{operating state 1} \\ 1\,0 & \text{operating state 2} \\ 0\,0 & \text{operating state 3} \end{cases}$$

Quasi-logic Statement

Activate alarm (Y=1) if A=1 and CD = 01 or activate the alarm if A = 1 or B = 1 and CD = 10

Example: Designing a logic network

Translate Quasi-logic Statement into Boolean Expression

Activate alarm (Y=1) if A=1 and CD = 01 or activate the alarm if A = 1 or B = 1 and CD = 10

$$Y = A \cdot \left(\overline{C} \cdot D\right) + (A + B) \cdot \left(C \cdot \overline{D}\right)$$

Example: Designing a logic network

Simplify $Y = A \cdot (\overline{C} \cdot D) + (A + B) \cdot (C \cdot \overline{D})$

C	D	$(\overline{C} \cdot D)$	$(C \cdot \overline{D})$
0	1	1	0
1	0	0	1
0	0	0	0

$\overline{C} \cdot D = D$ $\quad C \cdot \overline{D} = C$

$Y = (A \cdot D) + (A + B) \cdot C$

Example: Designing a logic network

Convert to single gate: $Y = (A \cdot D) + (A + B) \cdot C$

You can only use AND-gates

de Morgan's Law: $A \cdot B \cdot C \cdots = \overline{\bar{A} + \bar{B} + \bar{C}}$

$A + B + C \cdots = \overline{\bar{A} \cdot \bar{B} \cdot \bar{C}}$

$(A+B) = \overline{(\bar{A} \cdot \bar{B})} \Rightarrow Y = (A \cdot D) + \overline{(\bar{A} \cdot \bar{B})} \cdot C$

$= \overline{\overline{(A \cdot D)} \cdot \overline{\overline{(\bar{A} \cdot \bar{B})} \cdot C}}$ ✓

verify next time.

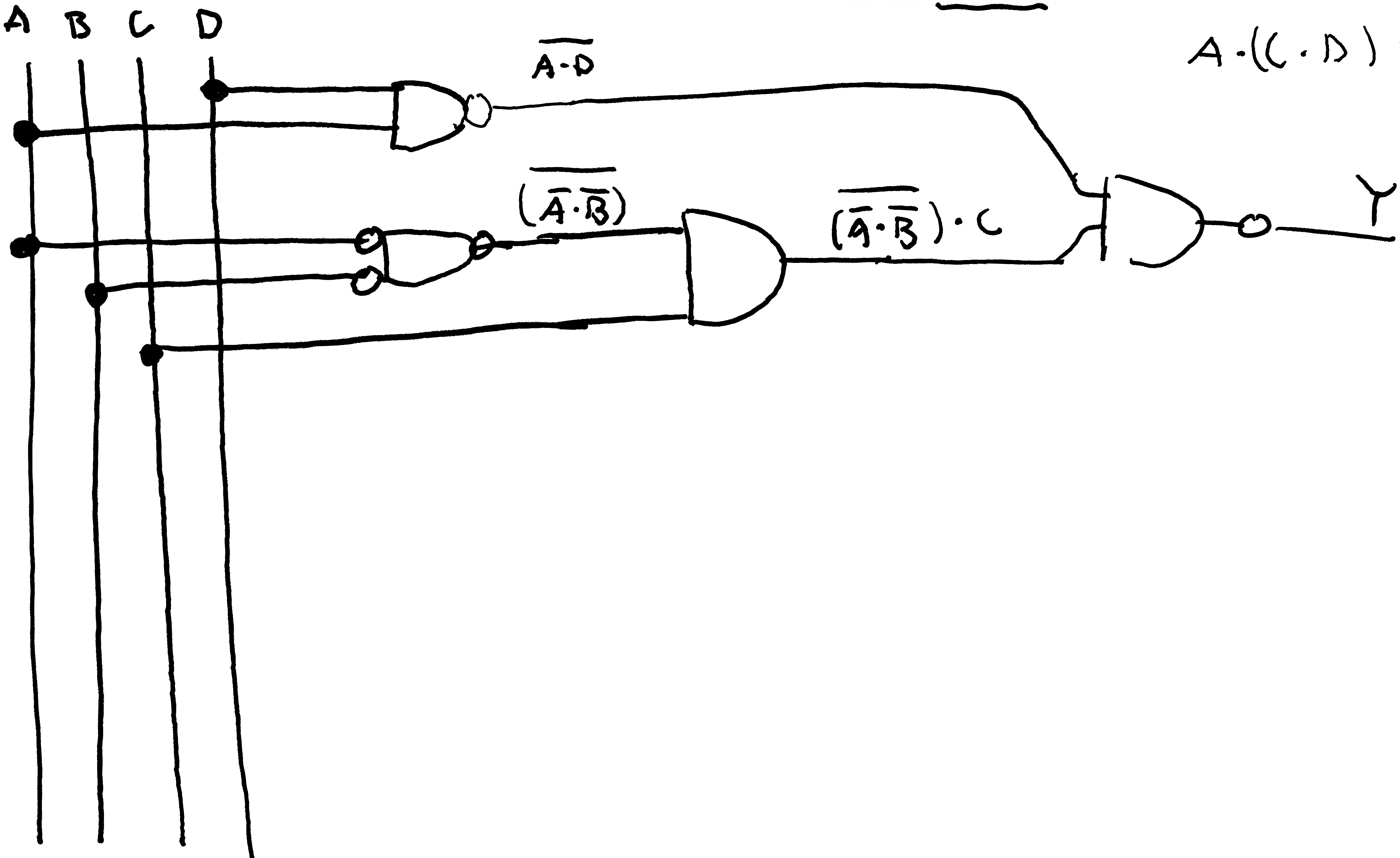
Example: Designing a logic network

Now we can draw logic circuit: $Y = \overline{\overline{A \cdot D} \cdot \overline{(\overline{A} \cdot \overline{B})} \cdot C}$ ✓

$A \cdot (C + D)$

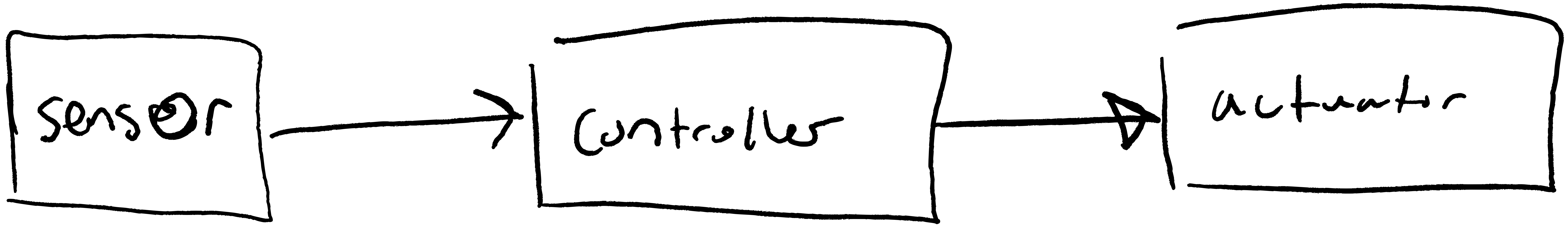
$(A \cdot C) + (A \cdot B)$

$A \cdot (C \cdot D) = (A \cdot C) \cdot D)$



What is an actuator?

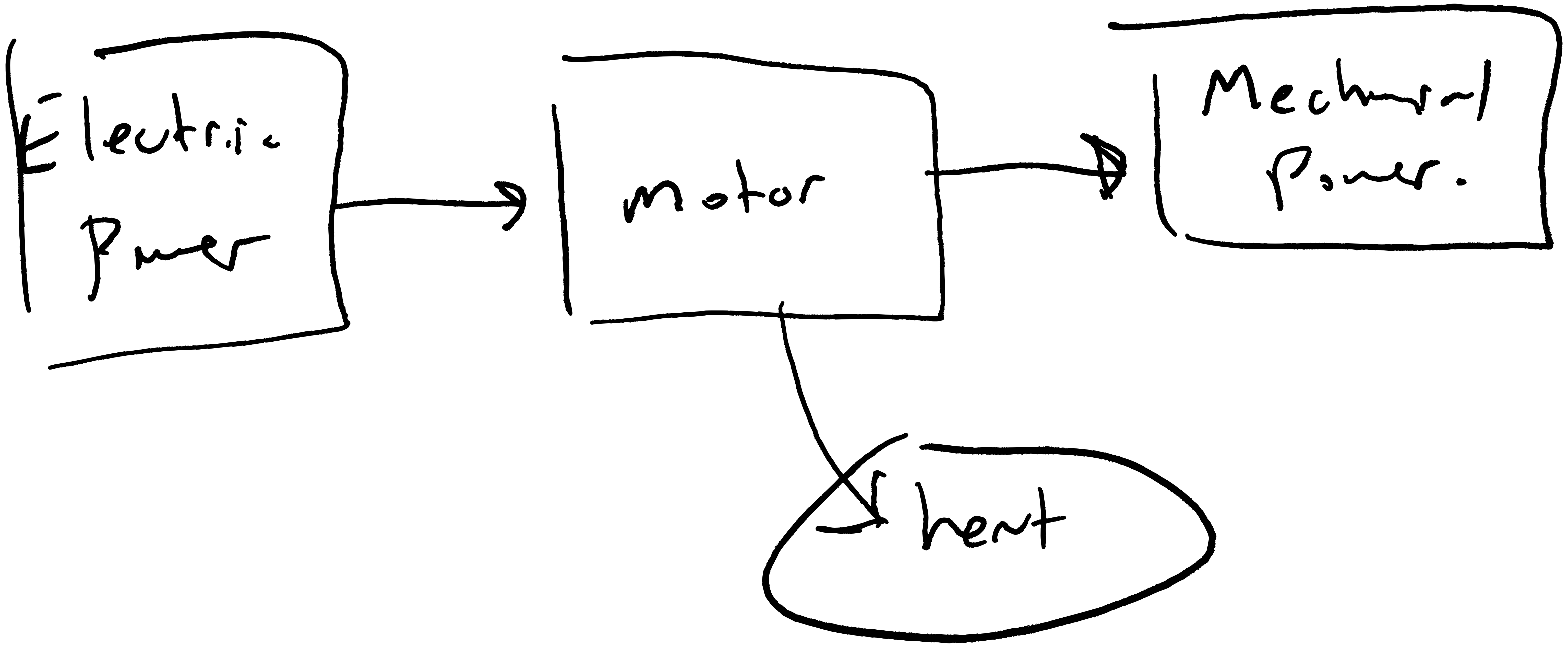
Actuators are the devices used to produce ~~this~~ motion or action.



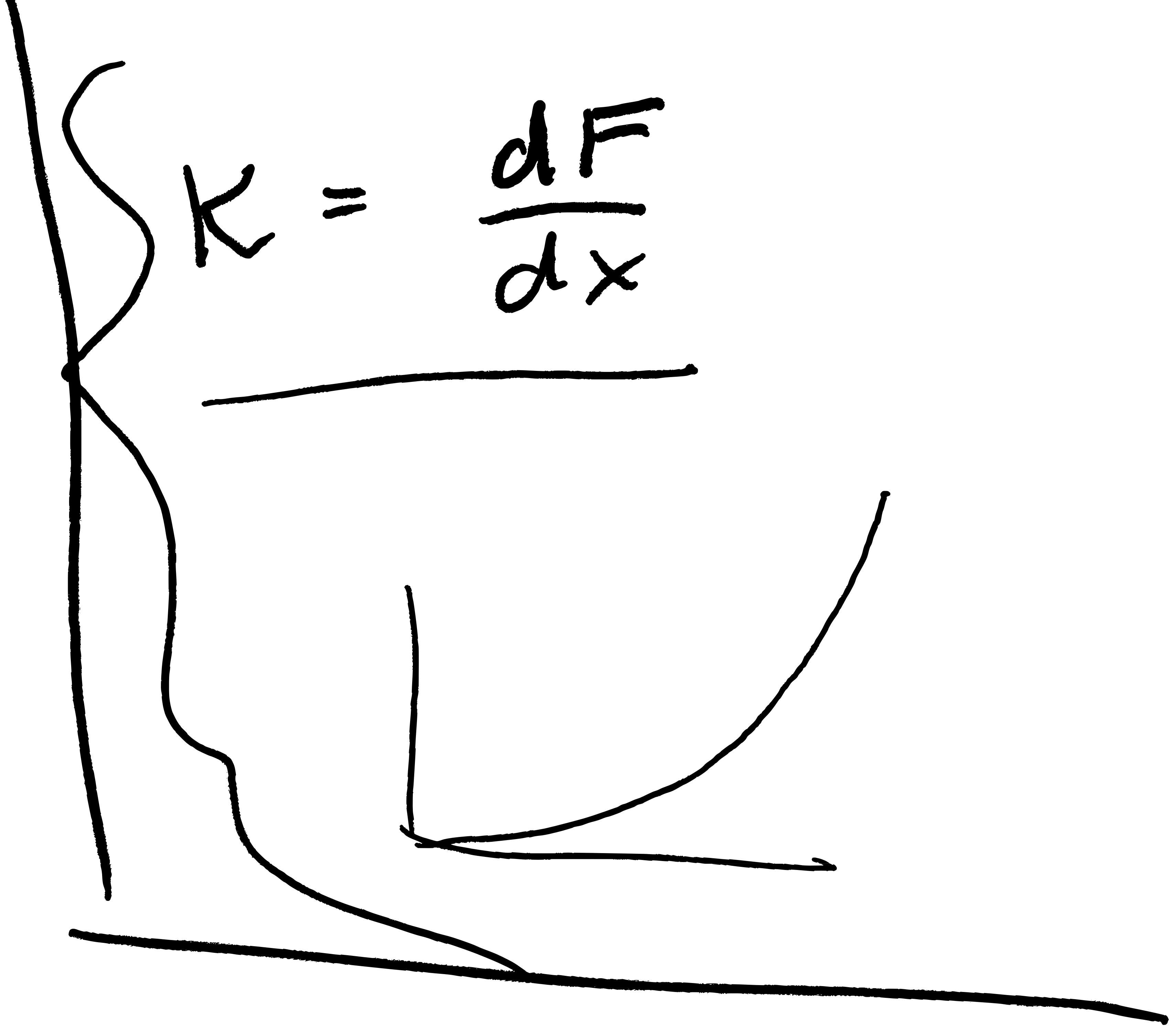
- electric motor
  - → tons
- solenoid
- Hydraulics
- Piezo-actuators
- smart materials
  - → shape memory alloys
- pneumatic
  - piston
  - soft actuators

Fundamental Principle of Electric (Motors) Actuators

Hookes law?



$$K = \frac{dF}{dx}$$



$$P_{in} = P_{out}$$

$$V \cdot I = \tau \cdot \omega \quad \text{(Ideal)}$$

$$\tau \cdot \omega = \eta \cdot V \cdot I$$

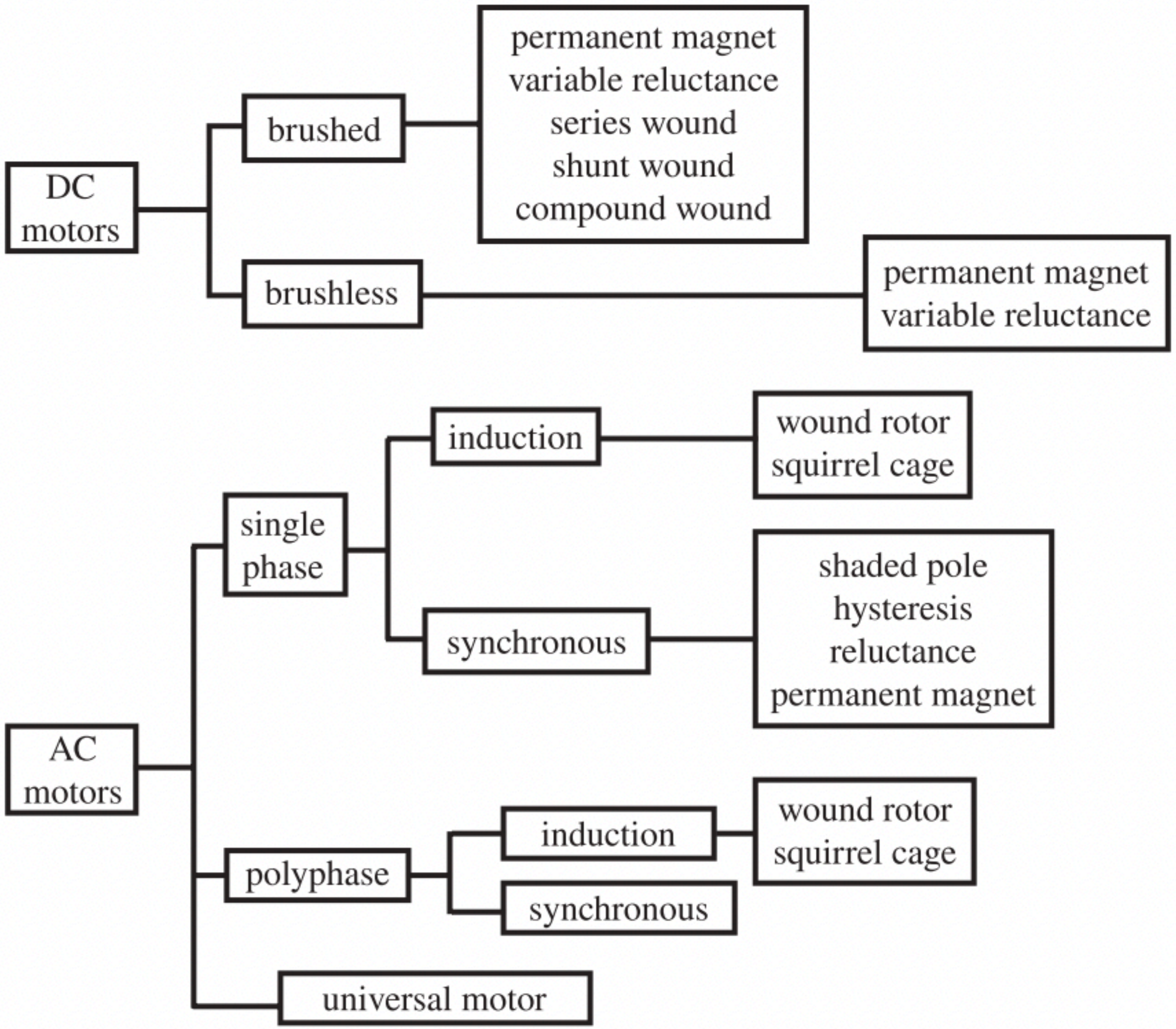
η ← efficiency

Brushless DC Motor $\quad \eta = 70-90\%$

AC vs DC Motor

AC	DC
Pros: simple design.	**pros:** simple to control
high power	inexpensive,
long life	variable speed.
fixed speed	
Cons: poor speed performance	**cons:** short life span
poor position control	high maintenance
	low power.

AC vs DC Motor



Lorentz's Principle : Basis for electronic actuators
→ solenoids, motors.

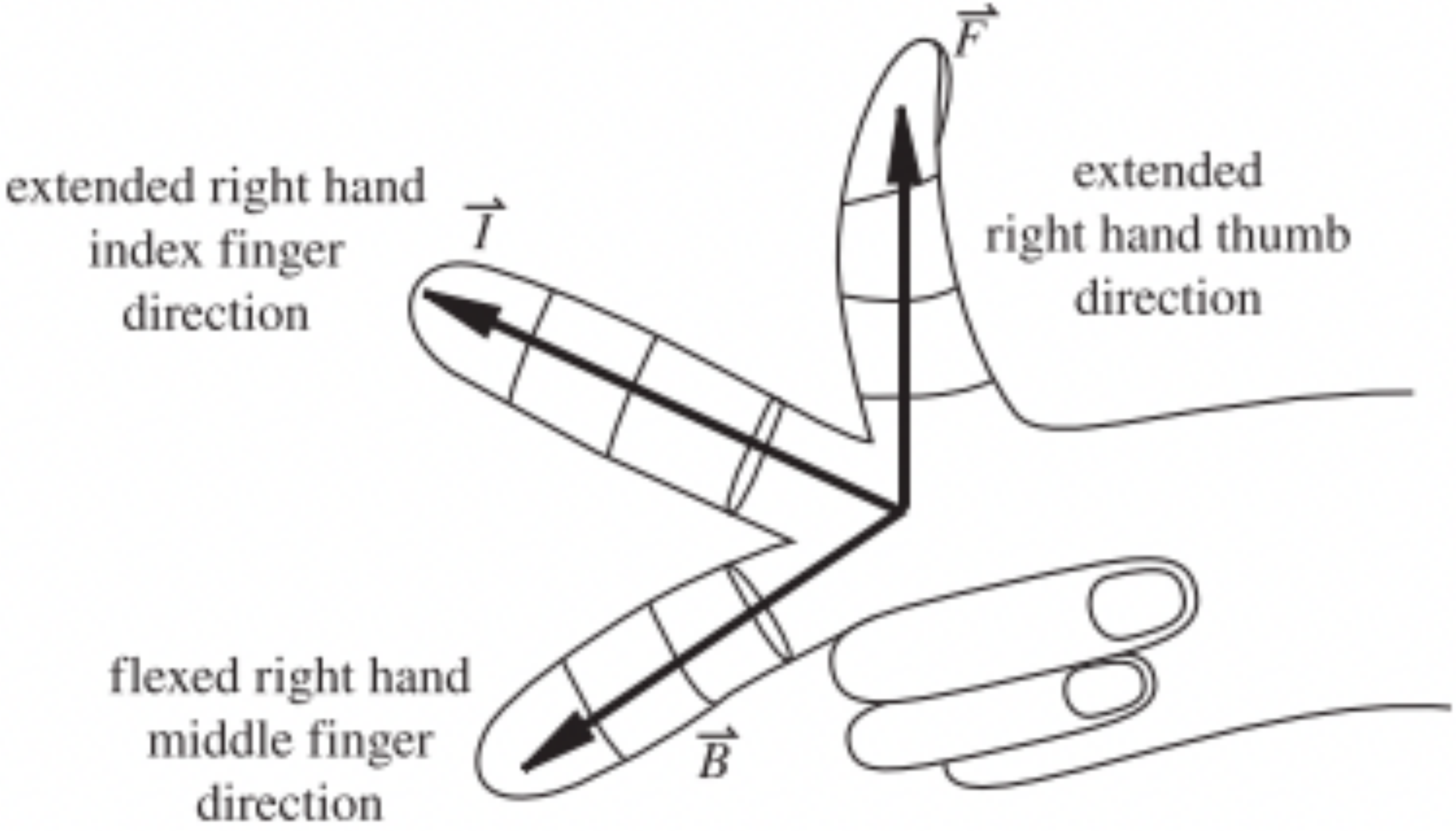
Lorentz Force

relates force on a conductor
to the current through conductor
& the external magnetic field

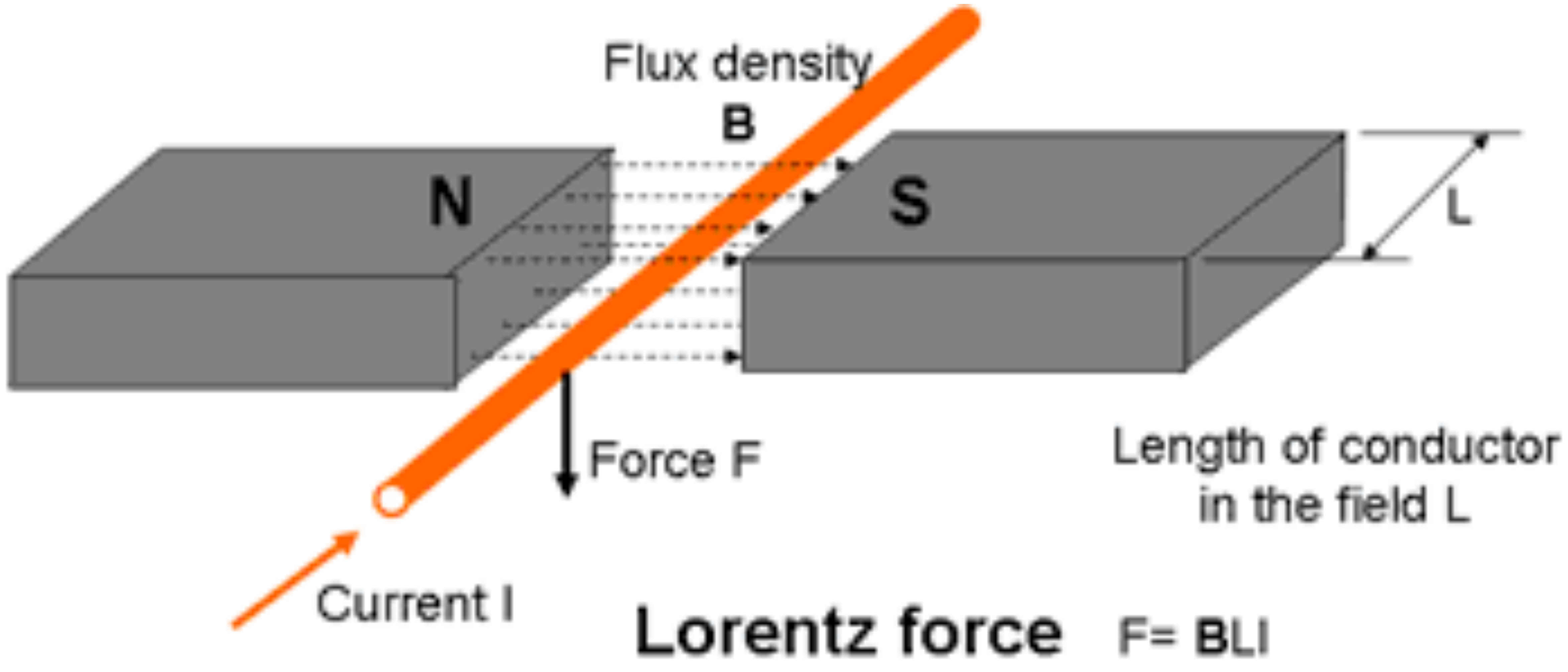
$$\vec{F} = \vec{I} \times \vec{B}$$

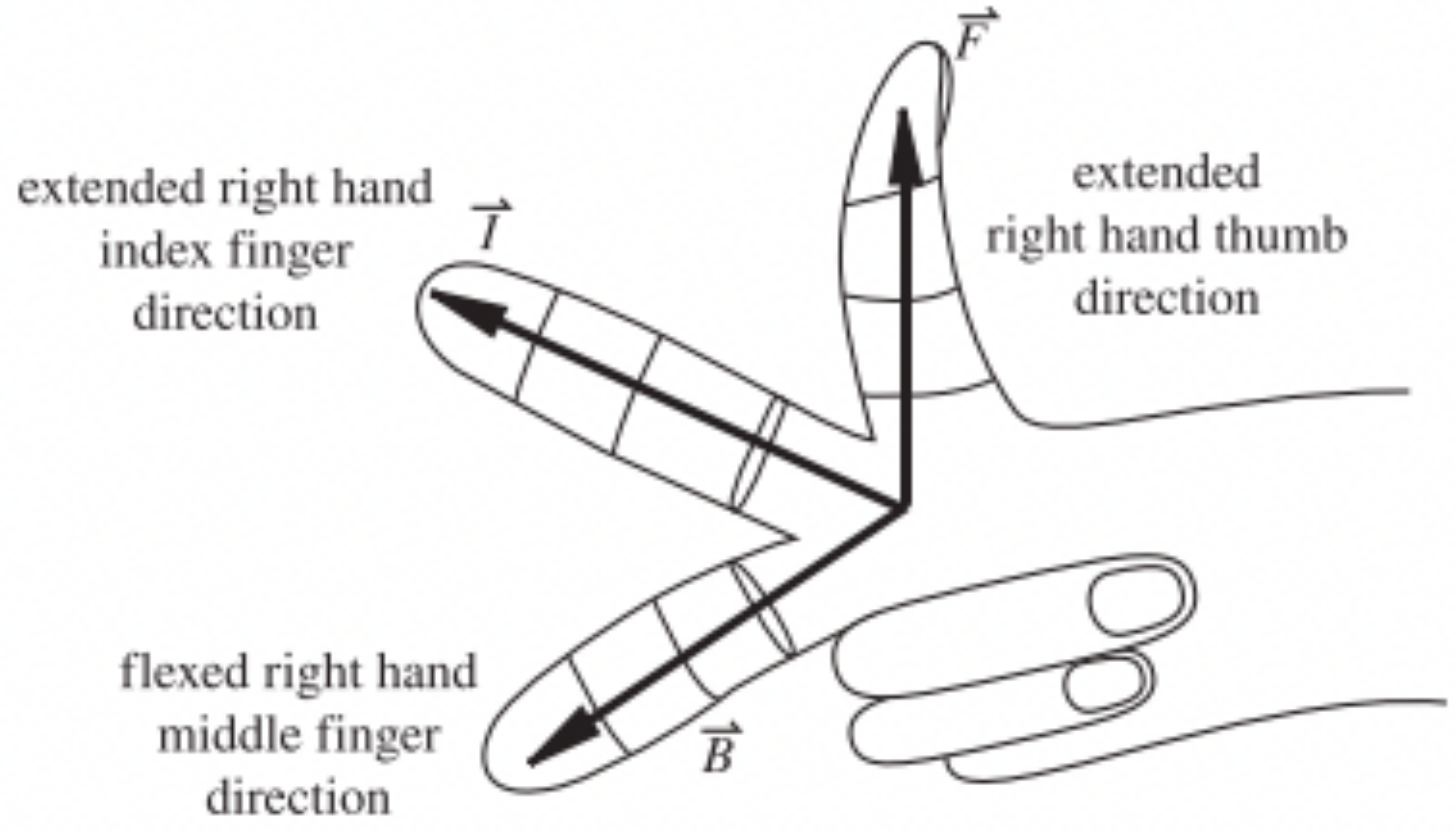
↗ force
↑ current vector
↙ magnetic field vector

Right Hand Rule

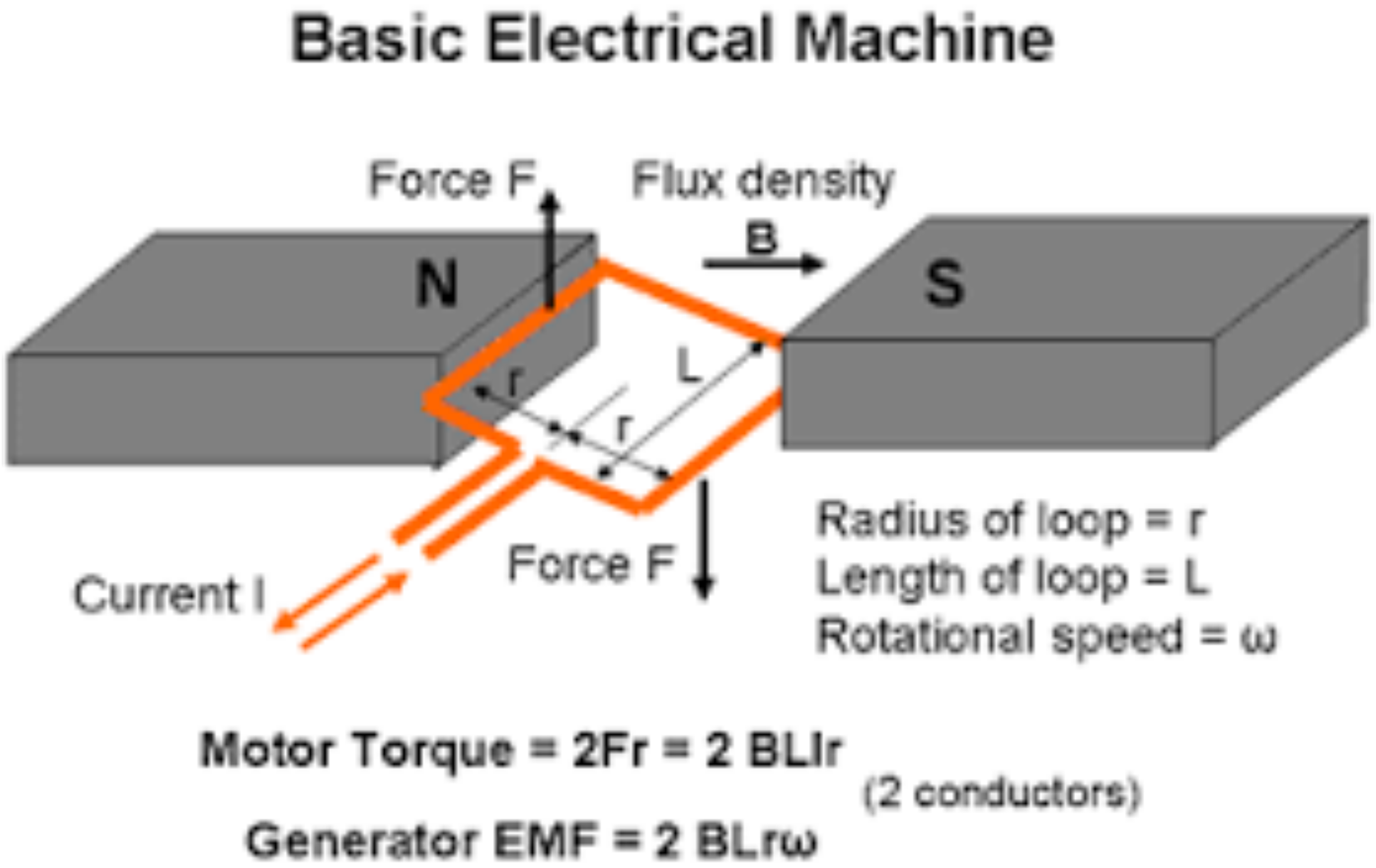


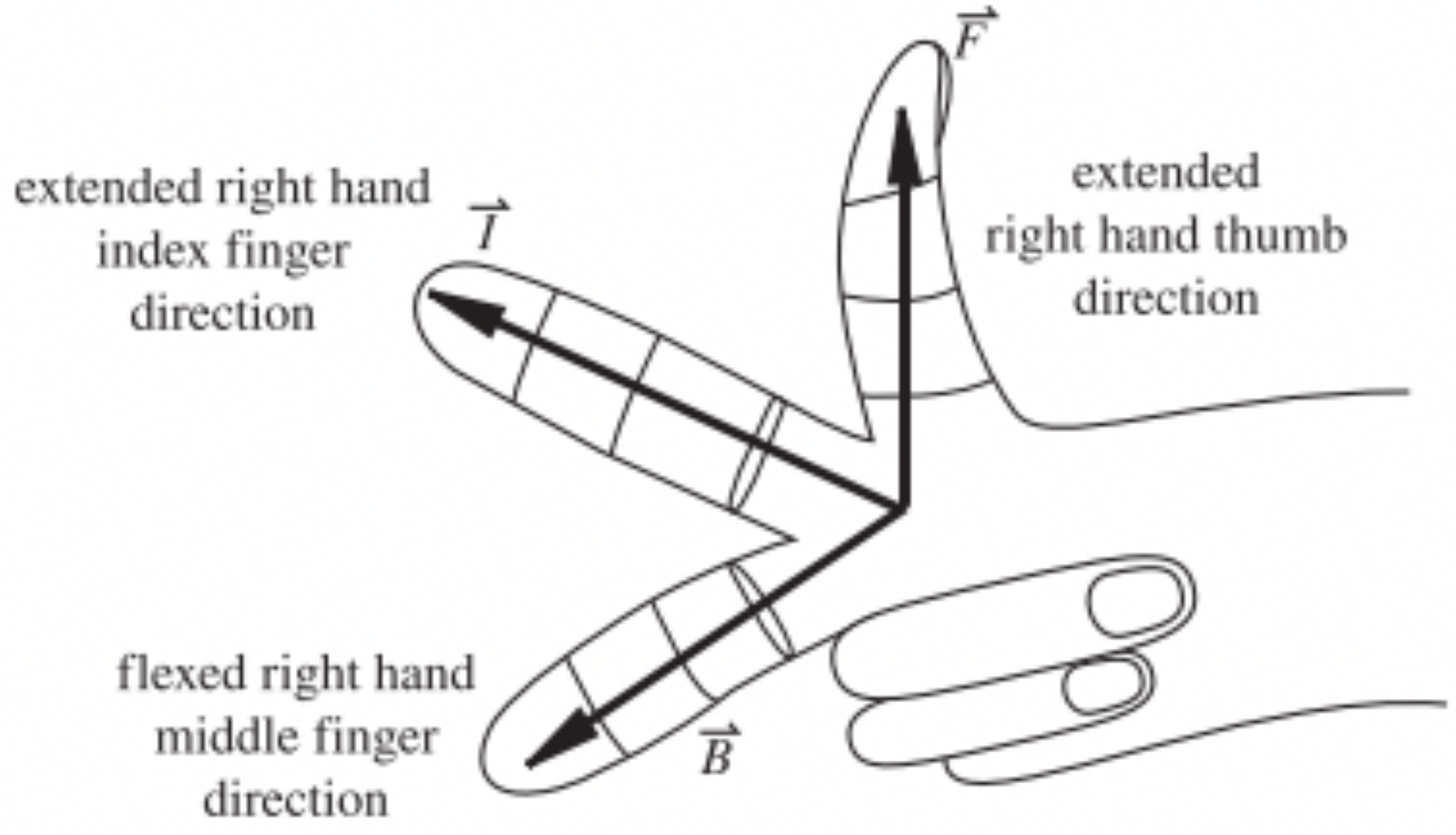
Right Hand Rule





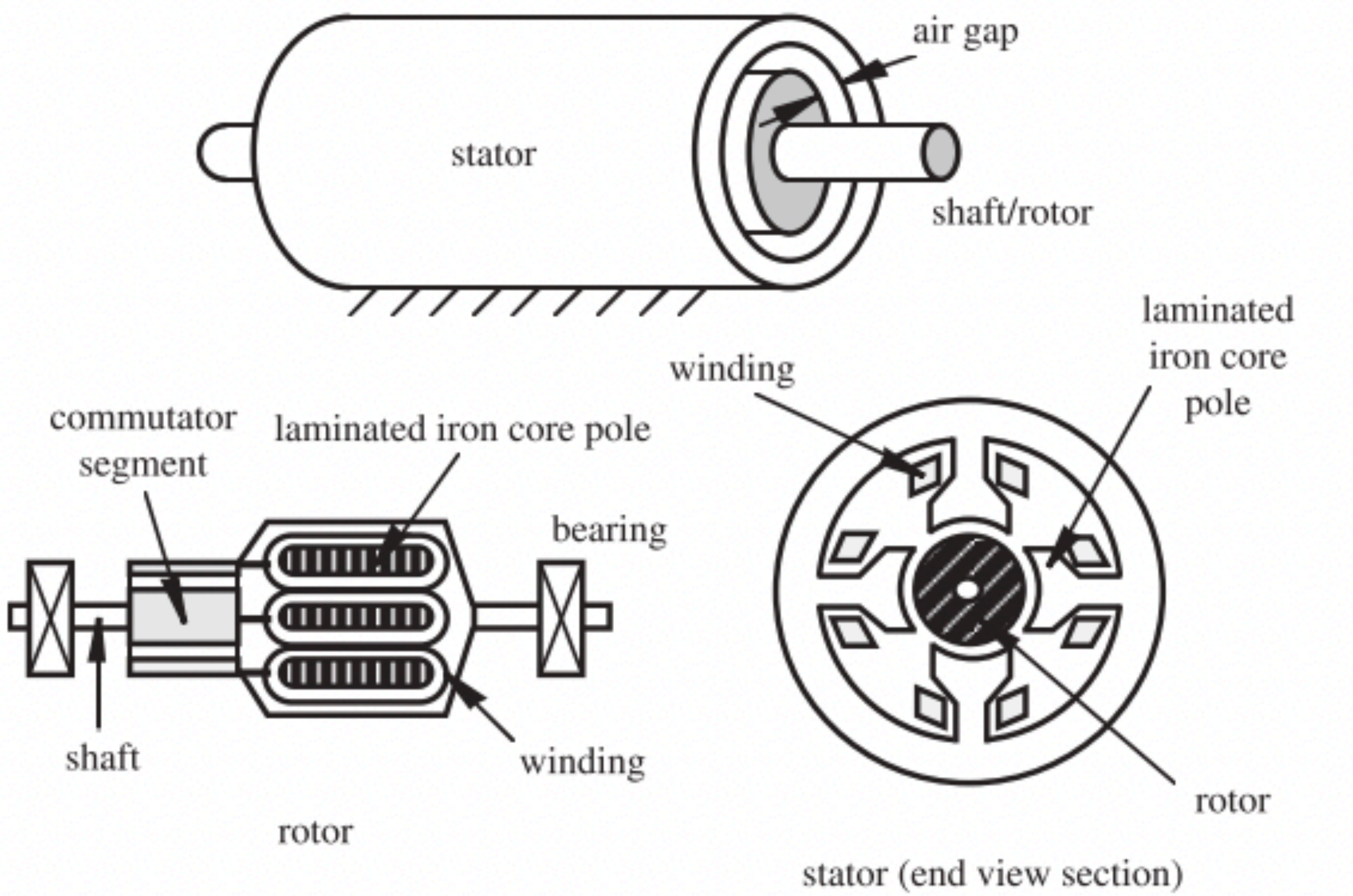
Right Hand Rule





Videos

(Brushed) DC Motor Terminology



Stator - stationary

it house **poles** : permanent magnets or coils - provides radial magnetic fields

rotor - rotates!

→ supported with shaft bearings

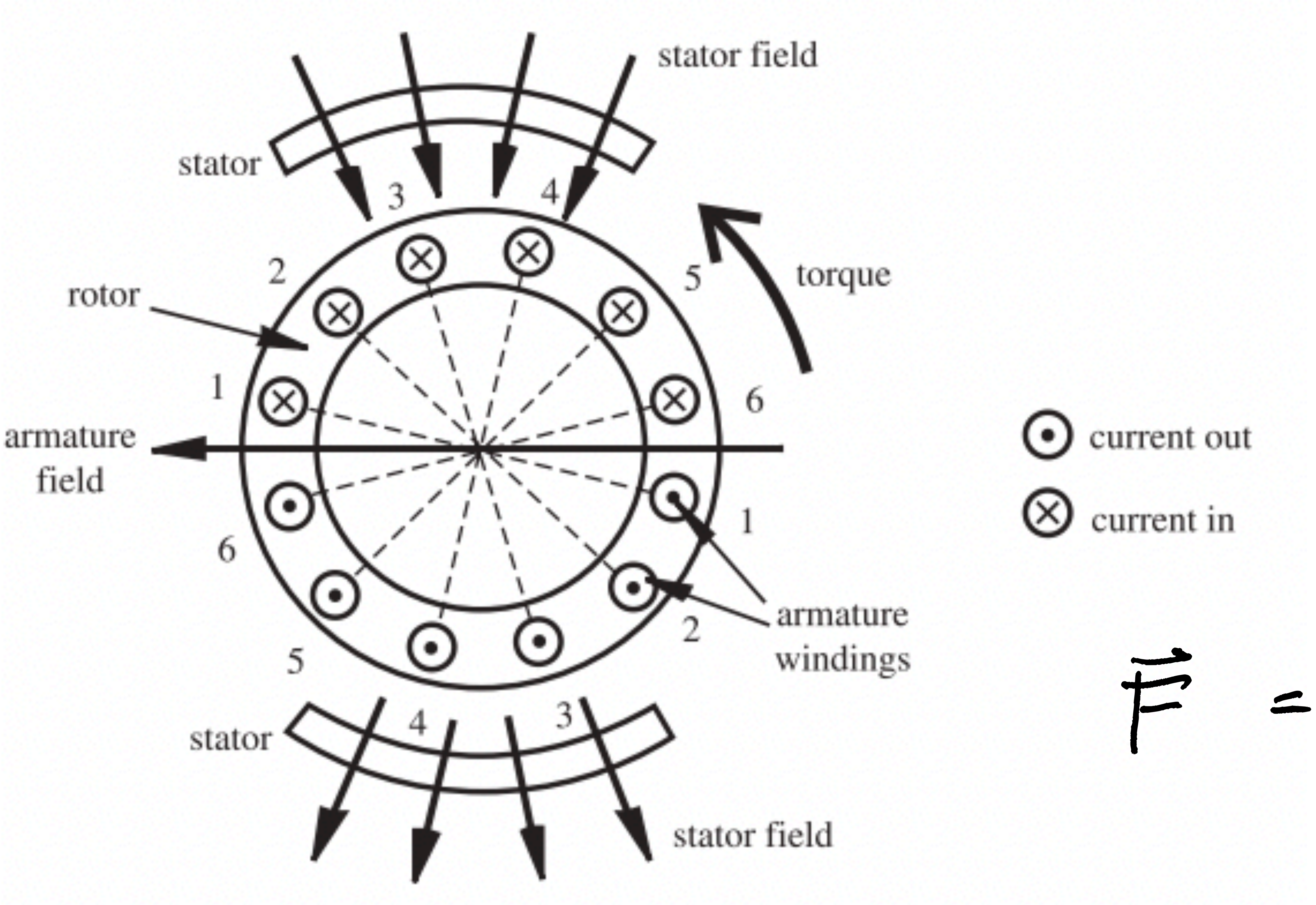
→ has conducting coils armature windings

brushes : provide stationary electrical contact to the moving commutator.

commutator : delivers i

controls the direction of current

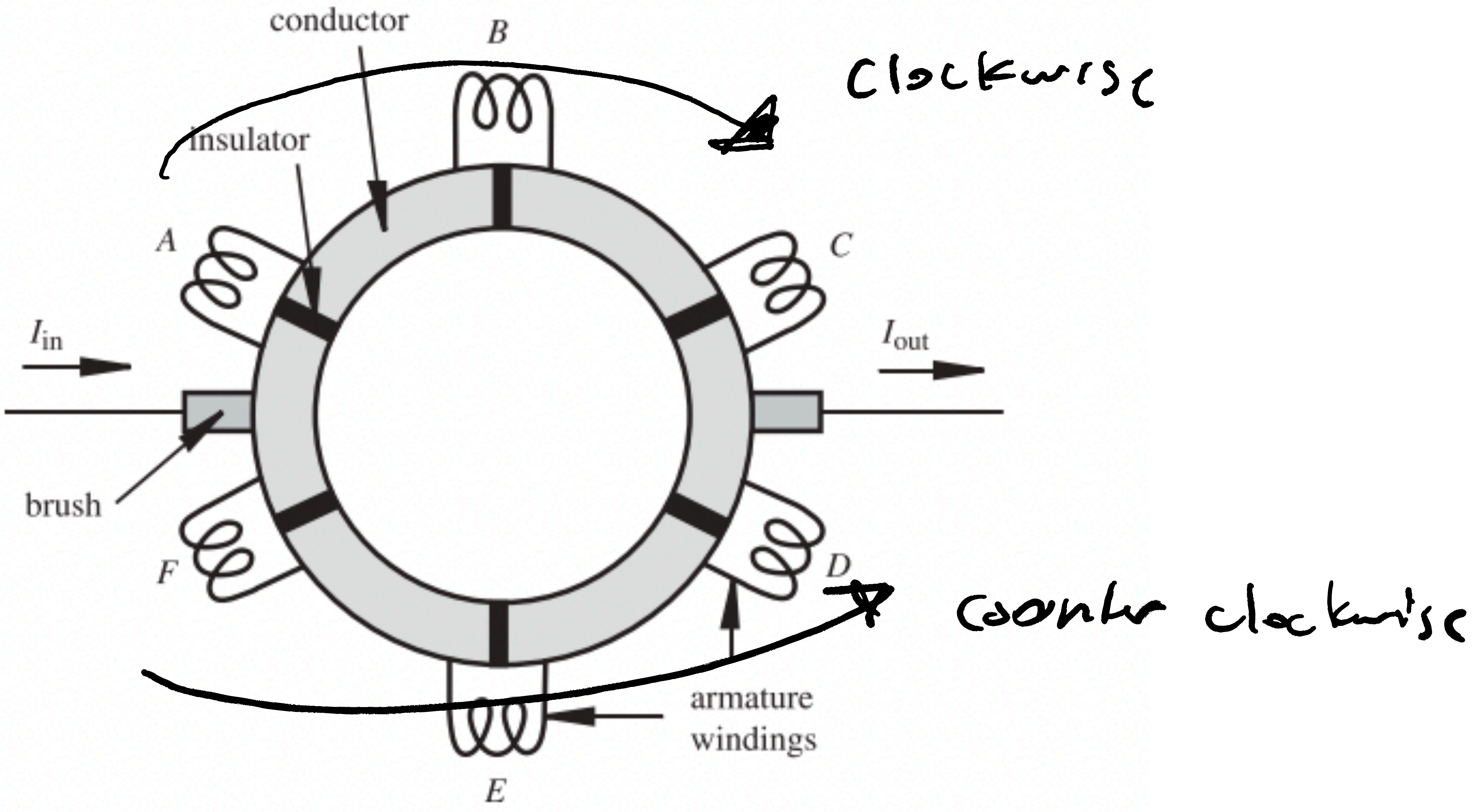
DC Motors: Working Principle - stator field/armature currents



$$\vec{F} = \vec{I} \times \vec{B}$$

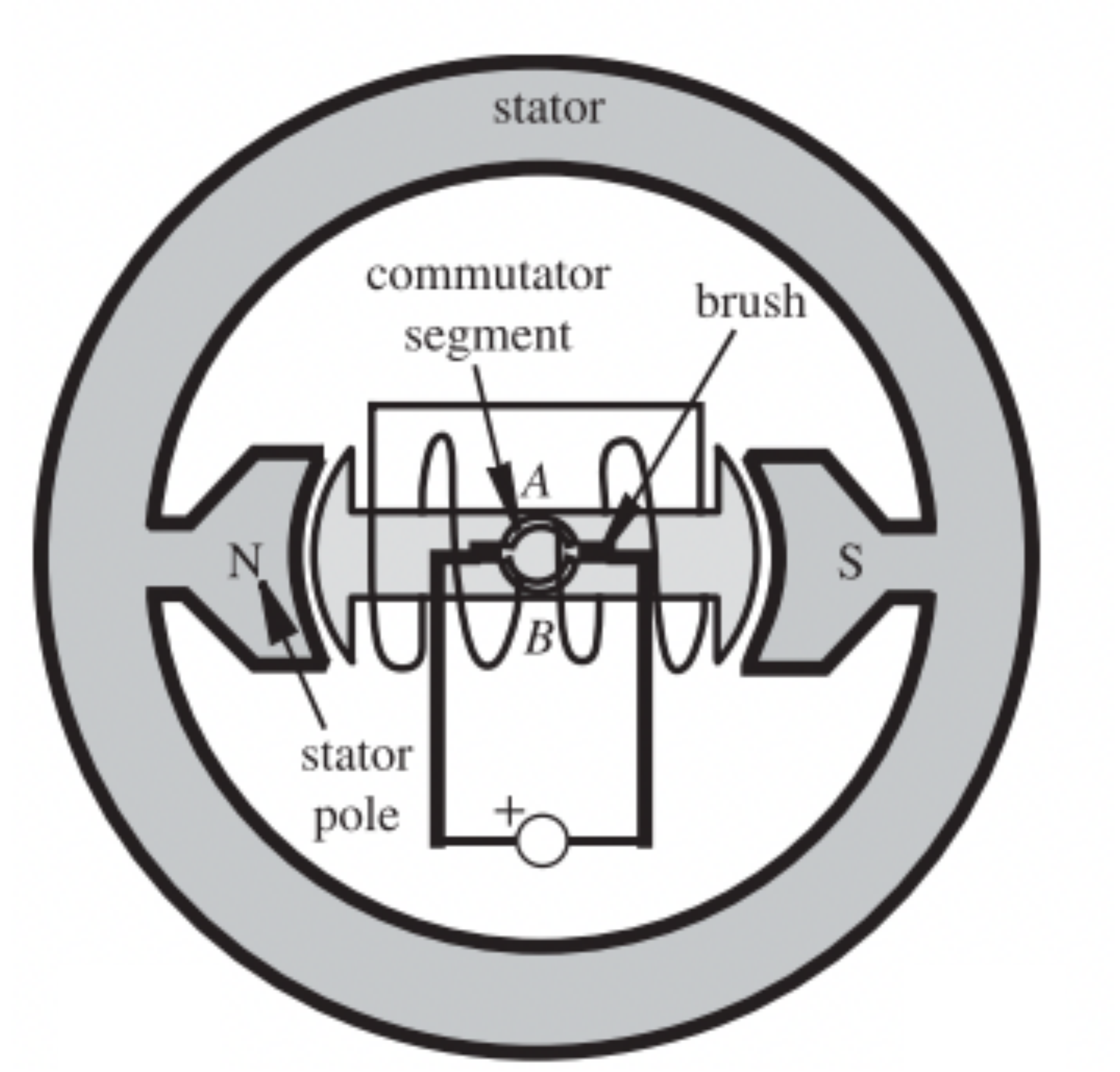
DC motor with six armature windings

DC Motors: Working Principle - stator field/armature currents



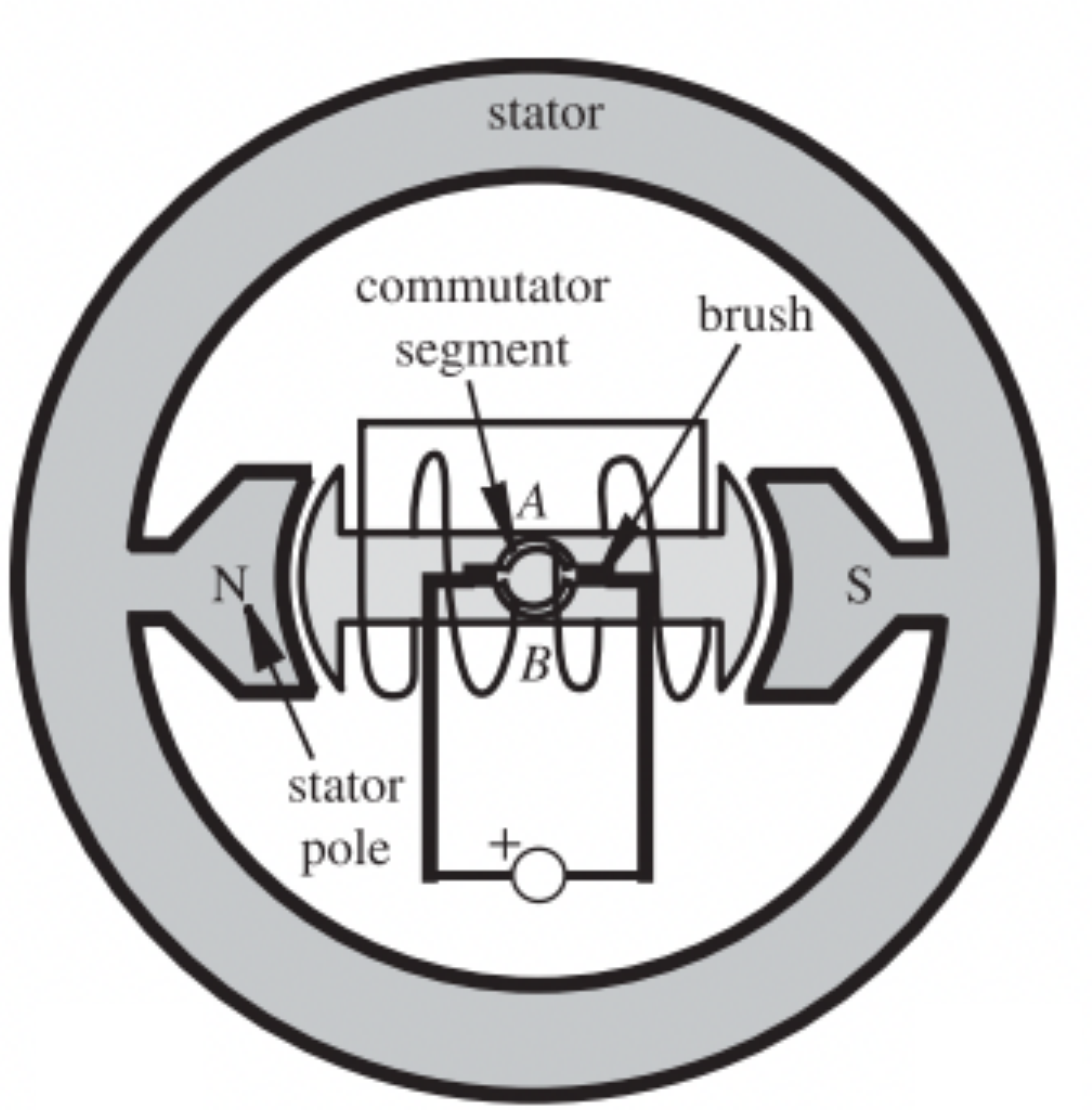
Electric motor six-winding commutators

DC Motors: Working Principle - stator/rotor magnetic fields

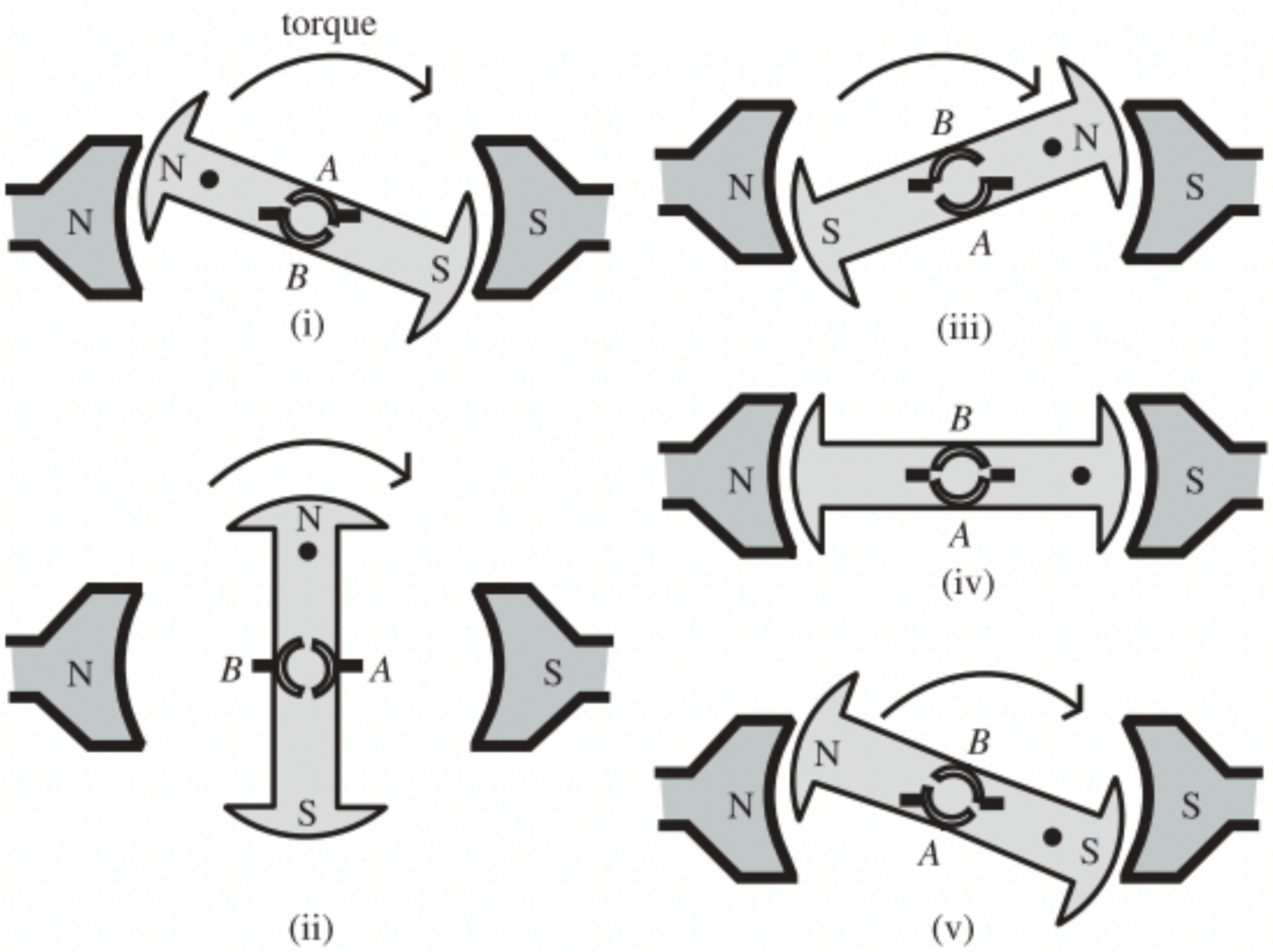


DC Motors: Working Principle - stator/rotor magnetic fields

The torque is produced by the fact that like field poles attract and unlike poles repel.



Two Pole
Brushed DC motor



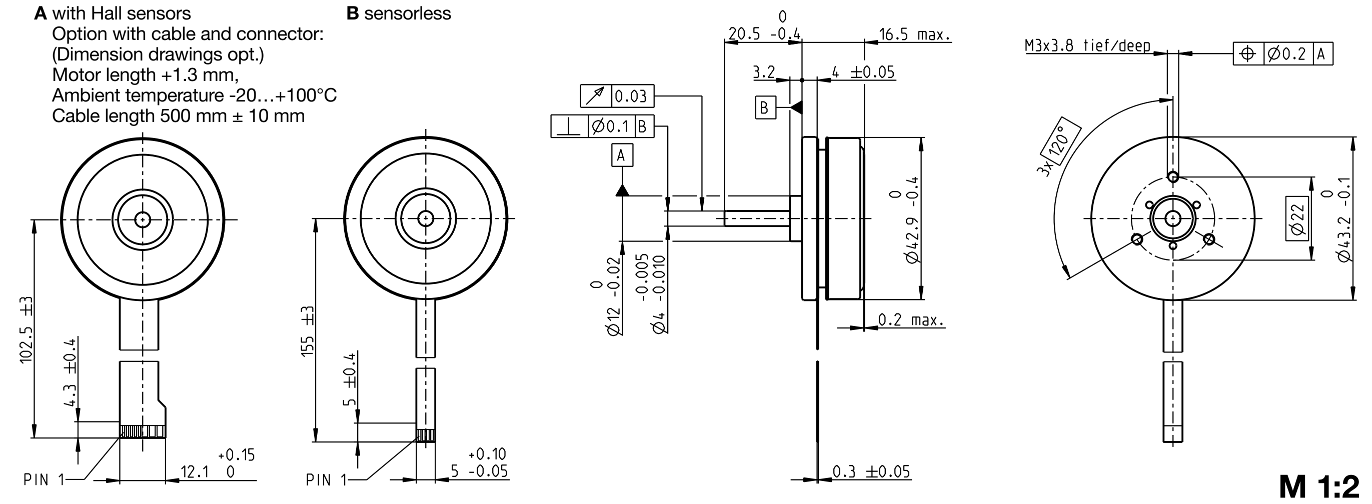
DC Motors: You can have many poles!

EC 45 flat ∅42.9 mm, brushless, 30 Watt

maxon flat motor

A with Hall sensors
Option with cable and connector:
(Dimension drawings opt.)
Motor length +1.3 mm,
Ambient temperature -20…+100°C
Cable length 500 mm ± 10 mm

B sensorless



M 1:2

Stock program
Standard program
Special program (on request)

Part Numbers							
A with Hall sensors		200142		339281		339282	
Option with Cable and Connector		387266		400527		400580	
B sensorless			200189		339283		339284
Motor Data							
Values at nominal voltage							
1 Nominal voltage	V	12	12	24	24	36	36
2 No load speed	rpm	4370	4350	4360	4380	4750	4760
3 No load current	mA	163	163	81.4	73	61.6	55.3
4 Nominal speed	rpm	2940	2800	2940	2900	3290	3270
5 Nominal torque (max. continuous torque)	mNm	55	54.7	54.8	55.2	66	66.6
6 Nominal current (max. continuous current)	A	2.02	2.02	1.01	1.01	0.847	0.849
7 Stall torque[1]	mNm	255	219	253	243	380	369
8 Stall current	A	10	8.58	4.97	4.77	5.38	5.22
9 Max. efficiency	%	76	75	76	77	80	81
Characteristics							
10 Terminal resistance phase to phase	Ω	1.2	1.4	4.83	5.03	6.69	6.89
11 Terminal inductance phase to phase	mH	0.56	0.56	2.24	2.24	4.29	4.29
12 Torque constant	mNm/A	25.5	25.5	51	51	70.6	70.6
13 Speed constant	rpm/V	374	374	187	187	135	135
14 Speed/torque gradient	rpm/mNm	17.6	20.5	17.7	18.5	12.8	13.2
15 Mechanical time constant	ms	17.1	19.9	17.2	17.9	12.4	12.8
16 Rotor inertia	gcm^2	92.5	92.5	92.5	92.5	92.5	92.5

Specifications

Thermal data

17	Thermal resistance housing-ambient	6.69 K/W
18	Thermal resistance winding-housing	3.92 K/W
19	Thermal time constant winding	11.4 s
20	Thermal time constant motor	295 s
21	Ambient temperature	-40…+100°C
22	Max. winding temperature	+125°C

Mechanical data (preloaded ball bearings)

23	Max. speed	10000 rpm
24	Axial play at axial load < 5.0 N	0 mm
	> 5.0 N	typ. 0.14 mm
25	Radial play	preloaded
26	Max. axial load (dynamic)	4.8 N
27	Max. force for press fits (static)	53 N
	(static, shaft supported)	1000 N
28	Max. radial load, 5 mm from flange	18 N

Other specifications

29	Number of pole pairs	8
30	Number of phases	3
31	Weight of motor	75 g

Values listed in the table are nominal.

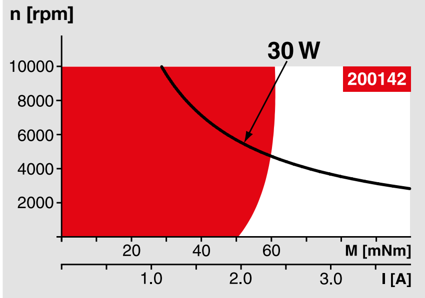
Connection	with Hall sensors	sensorless
Pin 1	V_{Hall} 4.5…18 VDC	Motor winding 1
Pin 2	Hall sensor 3*	Motor winding 2
Pin 3	Hall sensor 1*	Motor winding 3
Pin 4	Hall sensor 2*	⅄ neutral point
Pin 5	GND	
Pin 6	Motor winding 3	
Pin 7	Motor winding 2	
Pin 8	Motor winding 1	

*Internal pull-up (7…13 kΩ) on V_{hall}
Wiring diagram for Hall sensors see p. 43

Adapter	Part number	Part number
see p. 471	220300	220310
Connector	**Part number**	**Part number**
Tyco	1-84953-1	84953-4
Molex	52207-1133	52207-0433
Molex	52089-1119	52089-0419

Pin for design with Hall sensors:
FPC, 11-pol, Pitch 1.0 mm, top contact style
[1]Calculation does not include saturation effect (p. 53/164)

Operating Range



Comments

Continuous operation
In observation of above listed thermal resistance (lines 17 and 18) the maximum permissible winding temperature will be reached during continuous operation at 25°C ambient.
= Thermal limit.

Short term operation
The motor may be briefly overloaded (recurring).

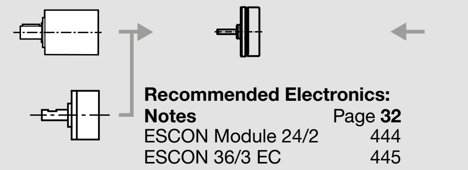
Assigned power rating

maxon Modular System

Overview on page 28–36

Planetary Gearhead
∅42 mm
3 - 15 Nm
Page 356

Spur Gearhead
∅45 mm
0.5 - 2.0 Nm
Page 358



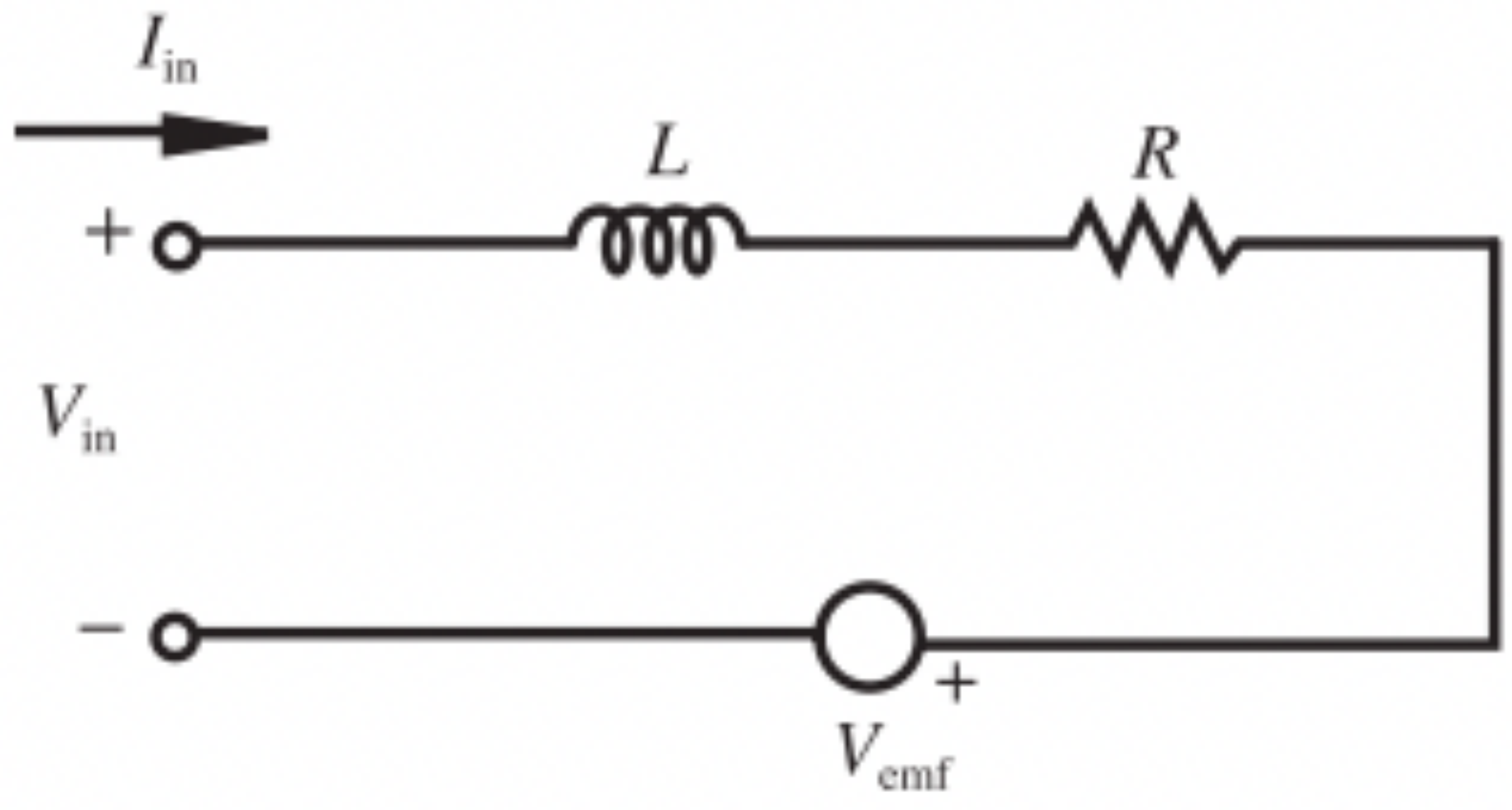
for motor type A:
Encoder MILE
256 - 2048 CPT,
2 channels
Page 402

Recommended Electronics:

Notes	Page 32
ESCON Module 24/2	444
ESCON 36/3 EC	445
ESCON Mod. 50/4 EC-S	445
ESCON Module 50/5	445
ESCON 50/5	447
DEC Module 24/2	449
DEC Module 50/5	449
EPOS4 Mod./Comp. 24/1.5	452
EPOS4 50/5	453
EPOS4 Mod./Comp. 50/5	453
EPOS2 P 24/5	464
MAXPOS 50/5	468

Motor Equivalent Circuit

Back EMF Voltage



Motor Mechanical Model (permanent magnet DC motor)

Steady state response

Steady state response

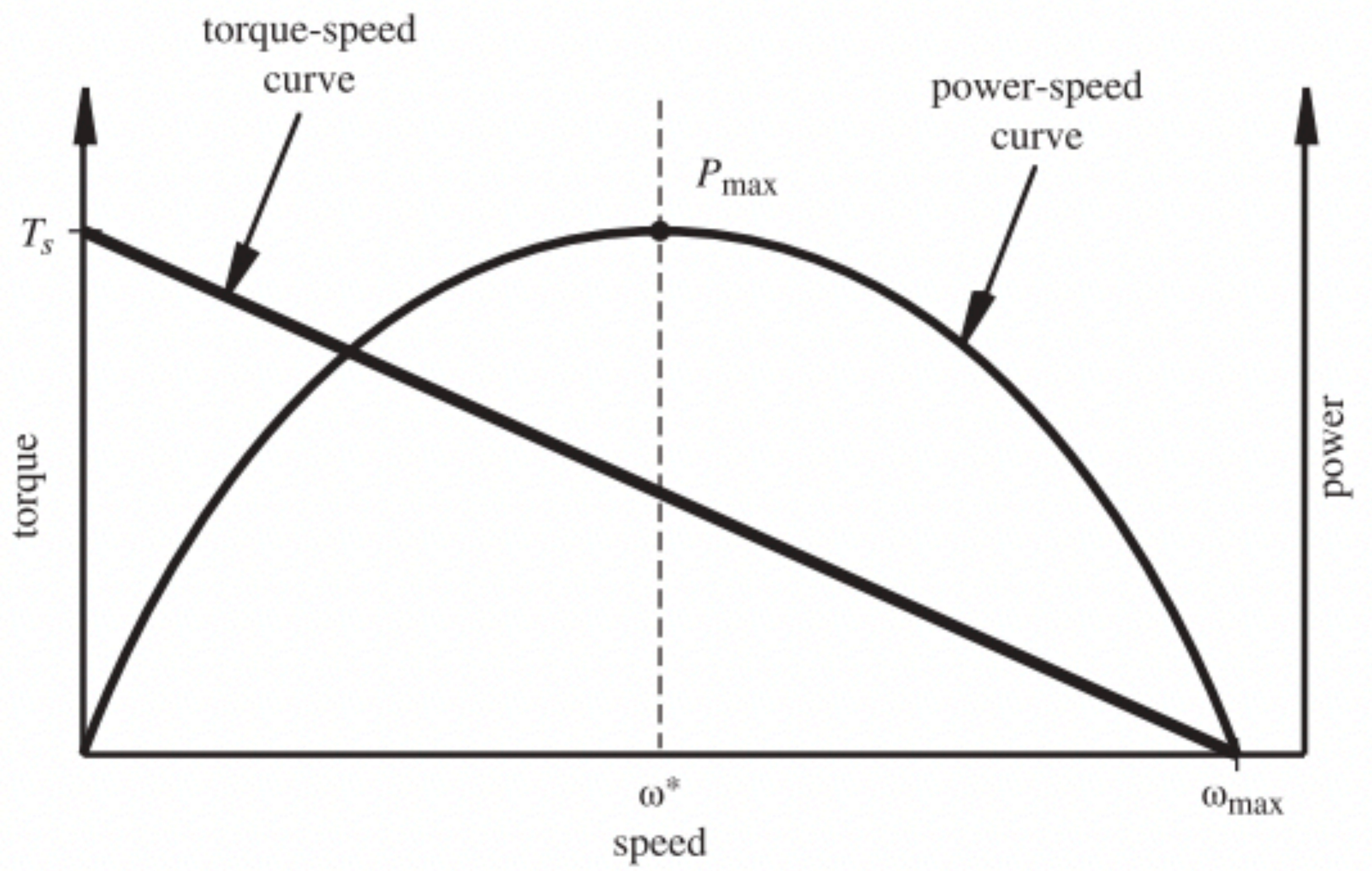
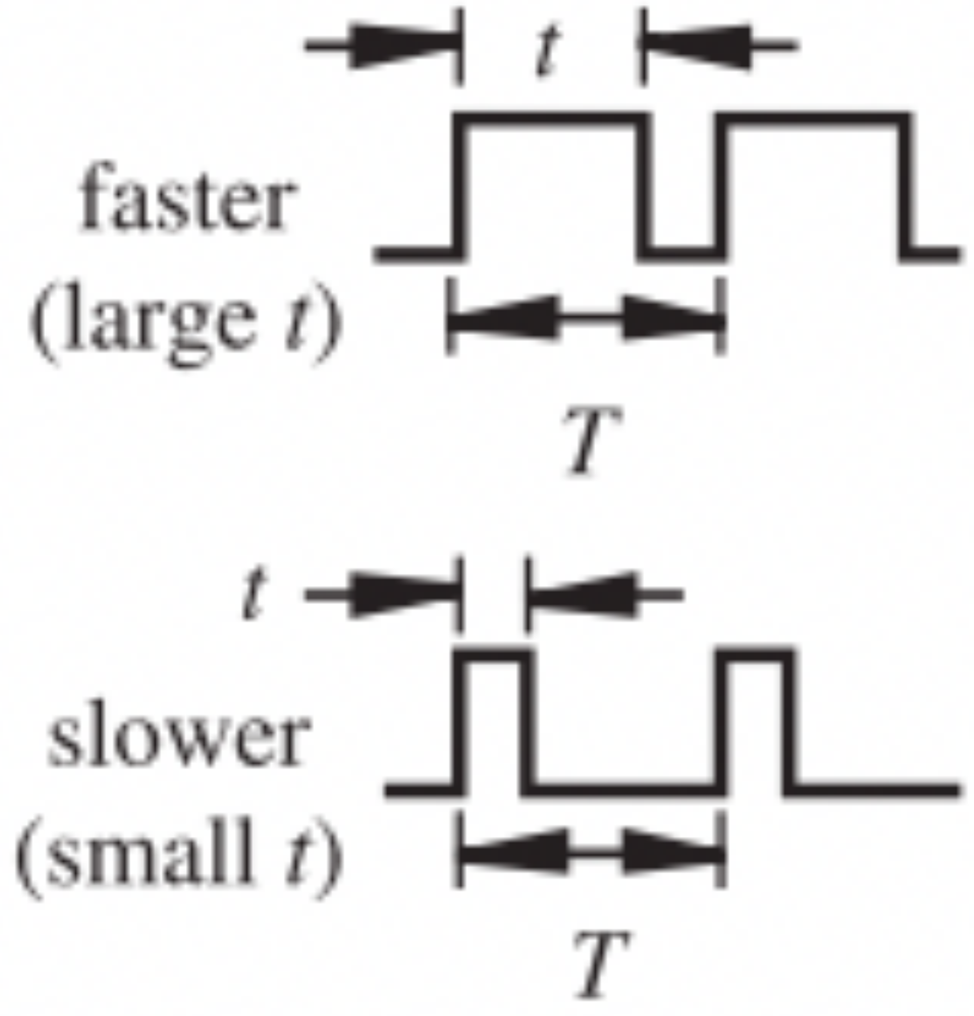


Figure 10.17 Permanent magnet DC motor characteristics.

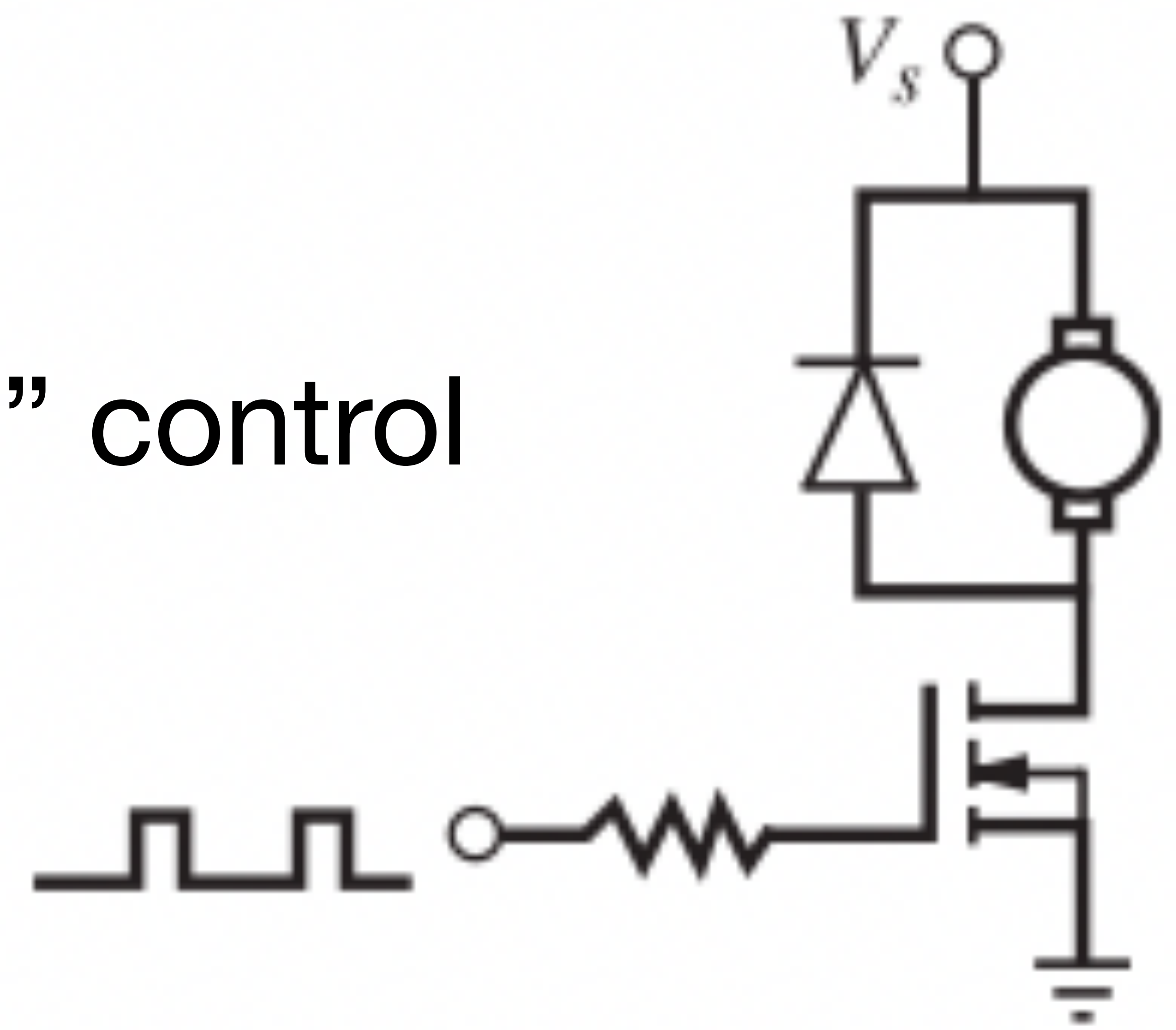
Basic Control

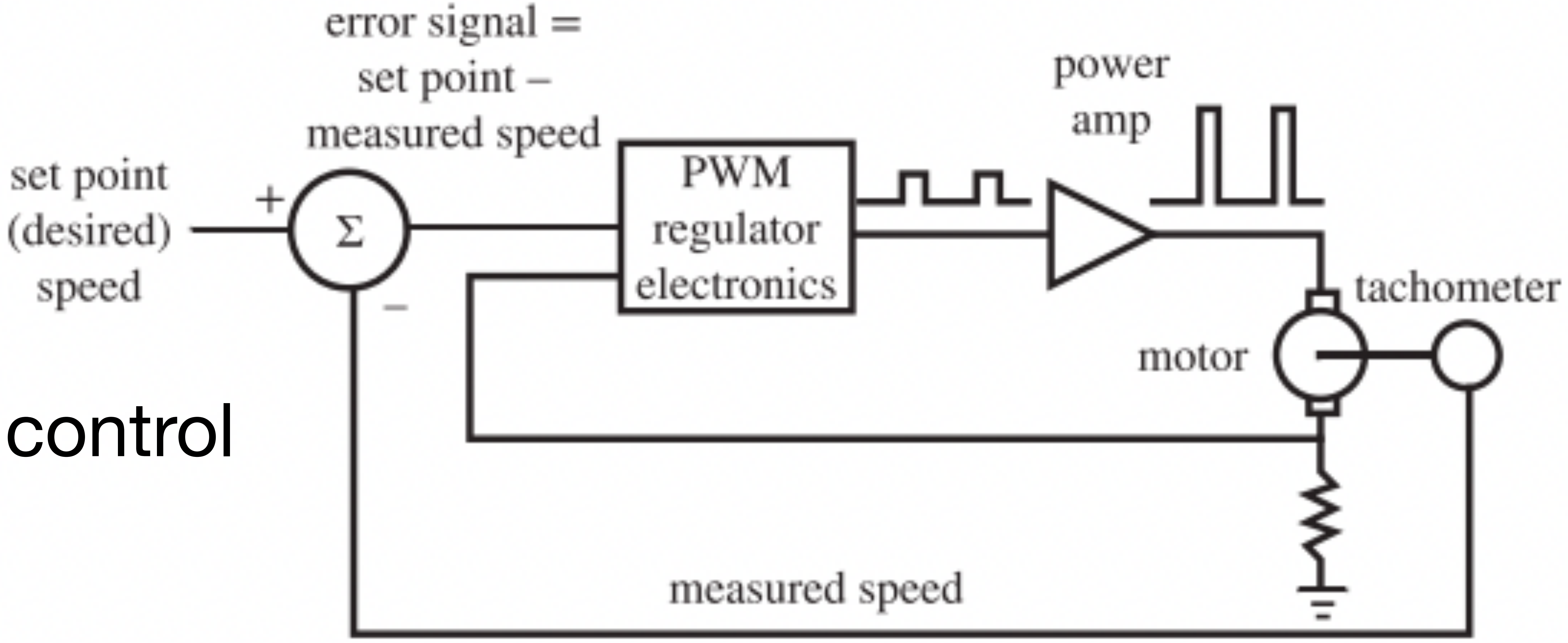
PWM: Pulse Width Modulation



"Open Loop" control

PWM





"Closed Loop" speed control