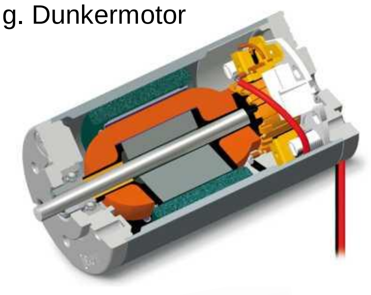
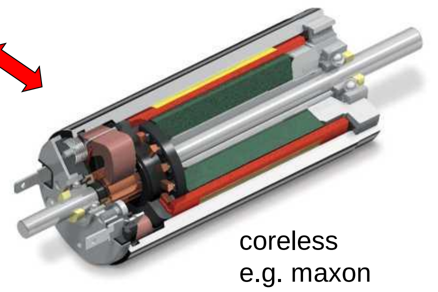
maxon DC motor
Permanent magnet DC motor with coreless winding

- Design, Characteristics
- Stator: Magnetic circuit
- Rotor: Winding and current flow
- Operation principle
- Commutation: Graphite brushes, precious metal brushes
- Service live, bearings

Part 1: DC motor designs

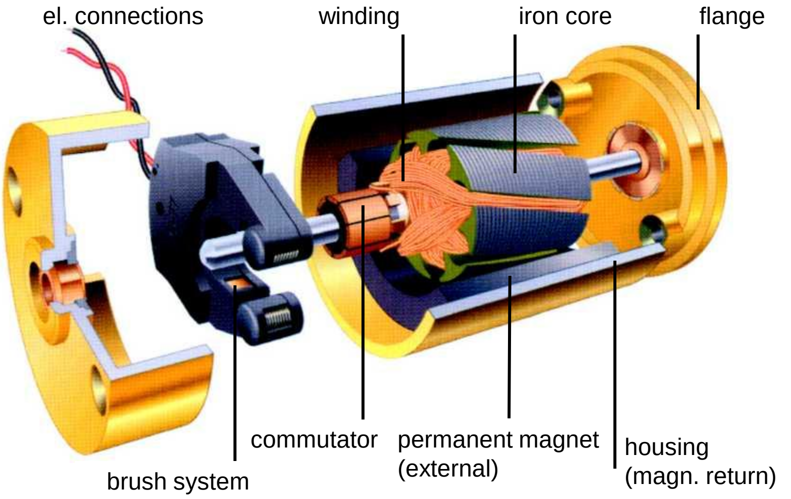
conventional, slotted
e.g. Dunkermotor



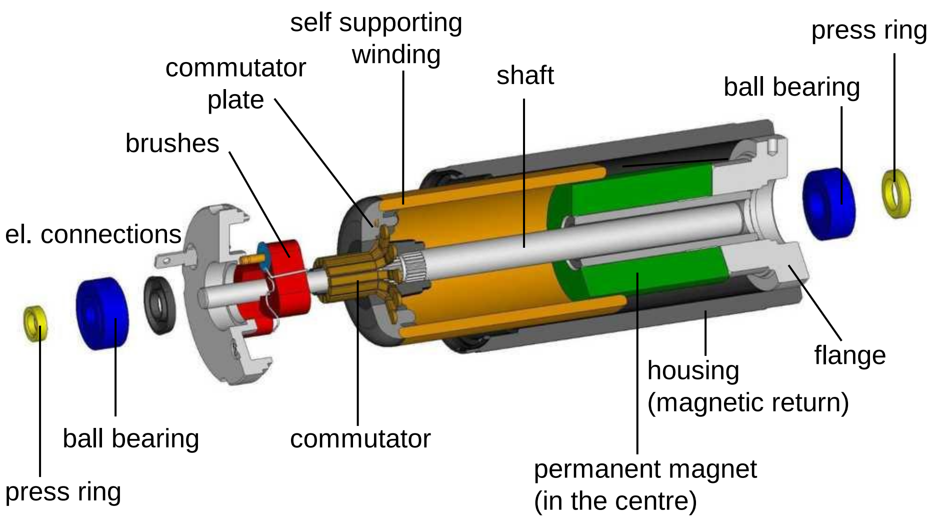


coreless
e.g. maxon

Conventional DC motor



Coreless maxon DC motor (RE 35)



Advantage coreless: no cogging

- no soft magnetic teeth to interact with the permanent magnet
- smooth motor running even at low speed
- less vibrations and audible noise

- any rotor position can easily be controlled
- no nonlinearities in the control behavior

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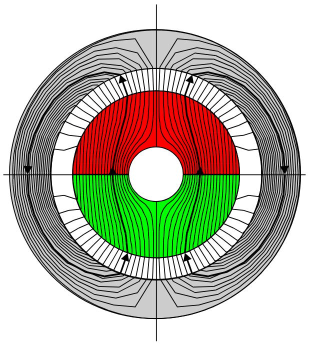
Advantage coreless: no iron losses

- no iron core - no iron losses
- constantly impressed magnetization
- high efficiency, up to over 90%
- low no-load current, typically < 50 mA
- does not apply to EC motors



- no saturation effects in the iron core
- Even at the highest currents the produced torque is proportional to the motor current.
- stronger magnets = stronger motors

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Advantage coreless: compact design

- more efficient design of the magnetic circuit
  (even with a larger air gap)
  - compact magnet in the centre
  - high power density
- small rotor mass inertia
  - hollow cylinder vs. plain cylinder
  - high dynamics
  - typical acceleration times: 5 - 50 ms

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Advantage coreless: low inductance

- less brush fire
  - Commutation: Closing and opening of a contact over an inductive load
- longer service life
- less electromagnetic emissions
- easier to suppress interferences:
  - capacitor between connections
  - ferrite core at motor cable
- fast current reaction
  - might cause problems with pulsed supply (pulse width modulation PWM)
  - motor choke needed?

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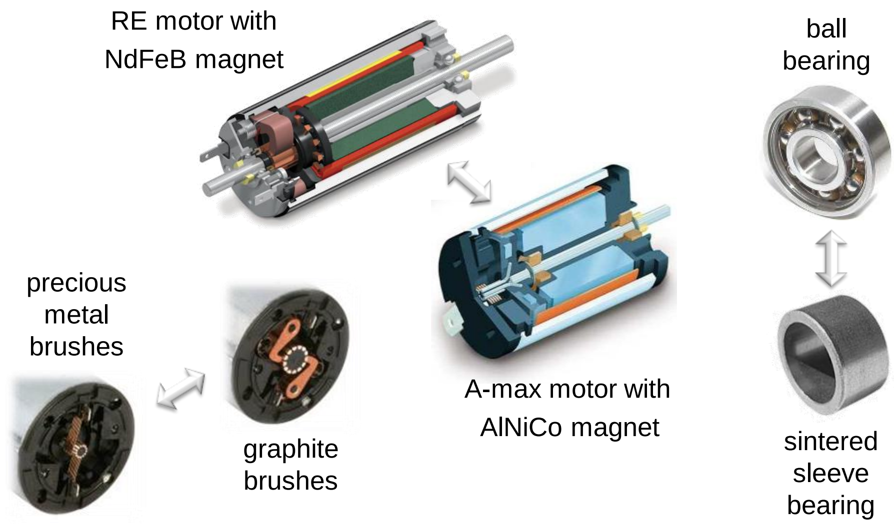
maxon DC motor variants



maxon DC motor families

- RE motor range
  - power optimized
  - high performing DC motor with NdFeB magnet
  - high torques and speeds
- A-max motor range
  - attractive price-performance ratio
  - DC motor with AlNiCo magnet
- RE-max motor range
  - performance between RE and A-max

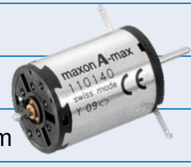
Ø 6 - 65mm

Ø 12 - 32mm

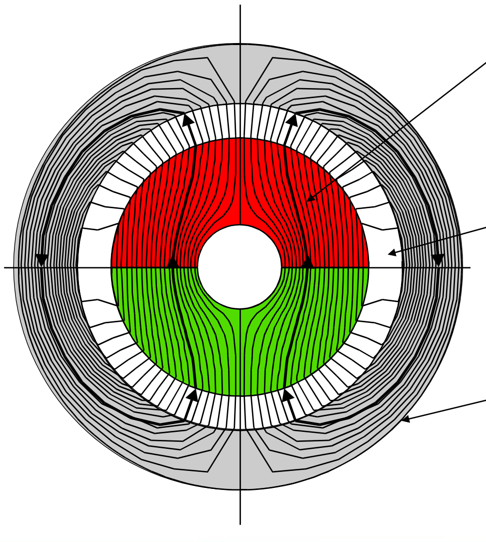
Ø 13 - 29mm

maxon DC motor families comparison

permanent magnet motor range	AlNiCo A-max, S, A	NdFeB RE, RE-max
example	A-max 19 GB	RE 13 GB
speed / torque gradient	1150 min^{-1}/mNm	1250 min^{-1}/mNm
rated power	2.5 W	3 W
diameter	19 mm	13 mm
length	31.5 mm	34.5 mm
motor dimension	8.9 cm^3	4.6 cm^3
cont. torque	3.8 mNm	2.4 mNm
approximate price	≈ 50.- CHF	≈ 100.- CHF



Part 2: Stator - the magnetic circuit

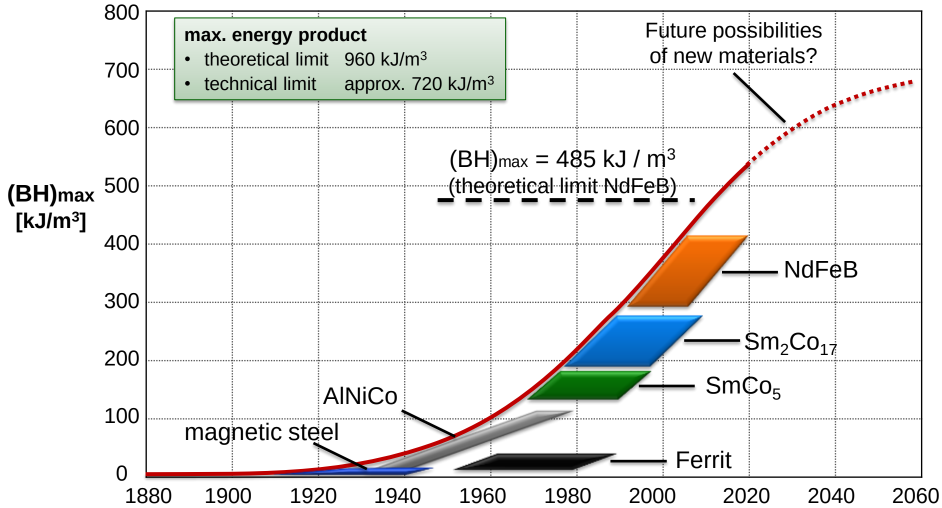


Permanent magnet:
produces the magnetic field with north and south pole on opposite sides.

Air gap:
the larger the air gap the weaker the magnetic field

Housing:
magnetic return path made of magn. steel (iron) guides magnetic field

History of permanent magnets

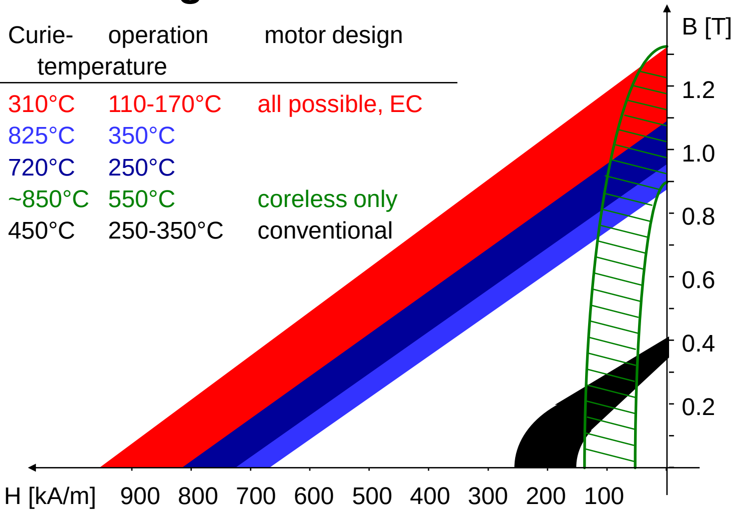


Source: http://www.vacuumschmelze.de/

magnets maxon motor driven by precision

Permanent magnets

magnet	Curie-temperature	operation	motor design
$Nd_2Fe_{14}B$	310°C	110-170°C	all possible, EC
Sm_2Co_{17}	825°C	350°C	
$SmCo_5$	720°C	250°C	
AlNiCo	~850°C	550°C	coreless only
ferrites	450°C	250-350°C	conventional



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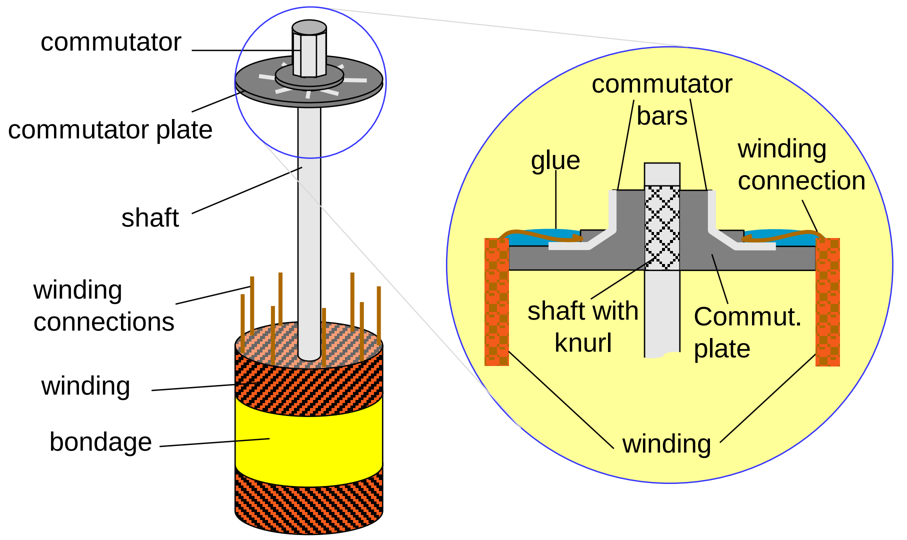
Part 3: Rotor and winding



DC motors – stator / rotor interaction

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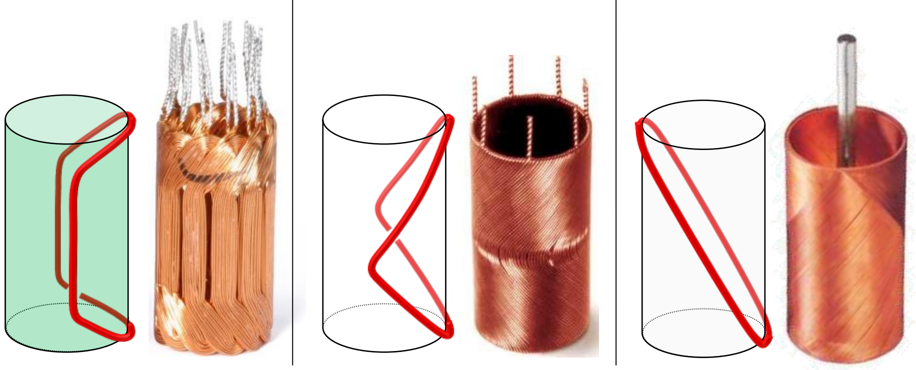
Coreless winding systems

coreless (DC) - slotless (EC)

maxon and others	maxon	Faulhaber Portescap



Source: Portescap

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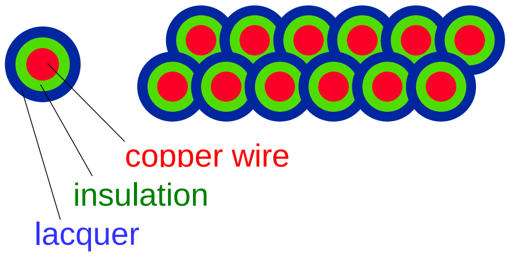
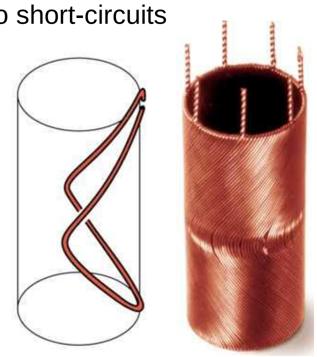
Winding: Enameled wire



copper core:
- good electrical conductor

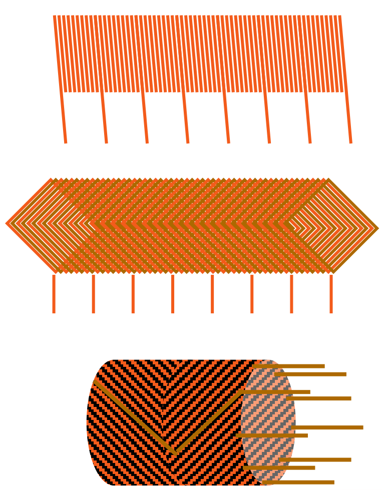
insulation:
- no short-circuits



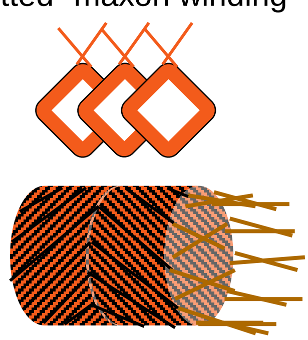
lacquer: plastic with solvent
- at higher temperatures (130-150°C):
  - lacquer of neighboring wires melts together
  - pressing forms the winding in narrow tolerances
  - out gassing of solvent: plastic hardens
  - baking of the winding

maxon winding: Standard and knitted

standard maxon winding

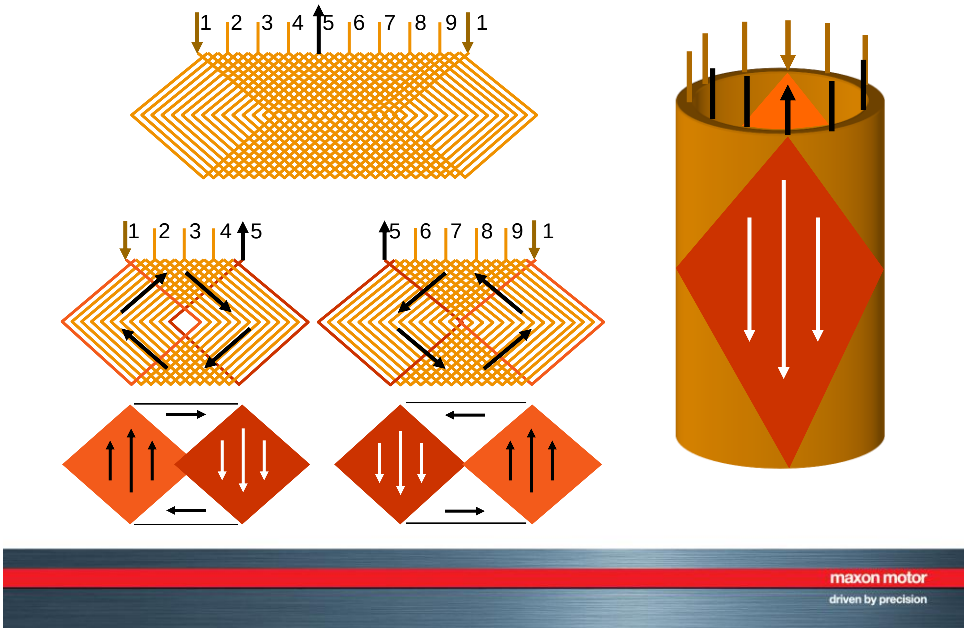


"knitted" maxon winding

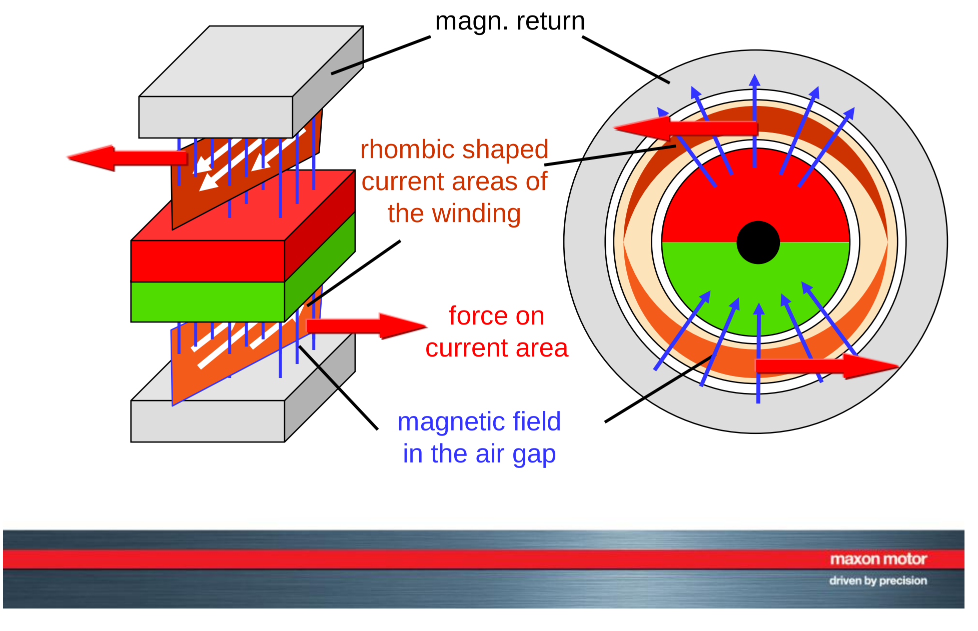


"knitted" winding for
- large motors with NdFeB magnet
- RE motors, EC motors
- thick-walled windings

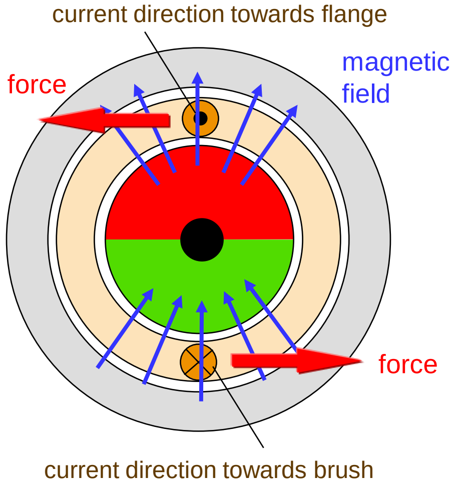
Current flow through the maxon winding



Part 4: Force and torque generation



Torque and current: k_M



forces:
force on current conducting wire in magnetic field

torque:
sum of all the forces at a distance to the rotation axis

influencing parameter:
geometry
flux density
number of winding turns } **design**

=> k_M = torque constant

$$M = k_M \cdot I$$

I = current } **application**

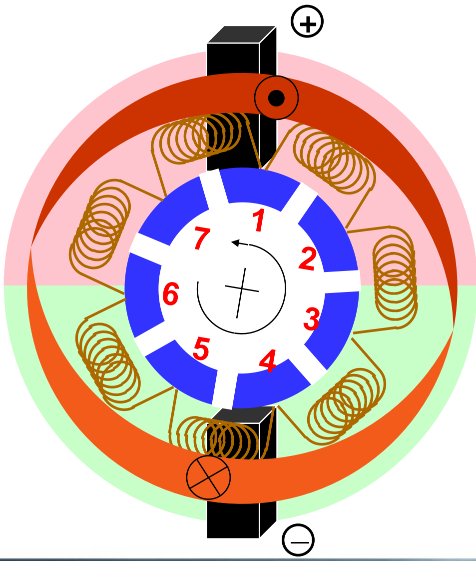
Speed and voltage: speed constant

- rotating winding in the air gap
  - in an inhomogeneous magnetic field
  - induced voltage U_{ind} (EMF) depends on
    - geometry
    - magnetic flux density
    - number of winding turns } **design**
    - speed n } **application**

$$n = k_n \cdot U_{ind}$$

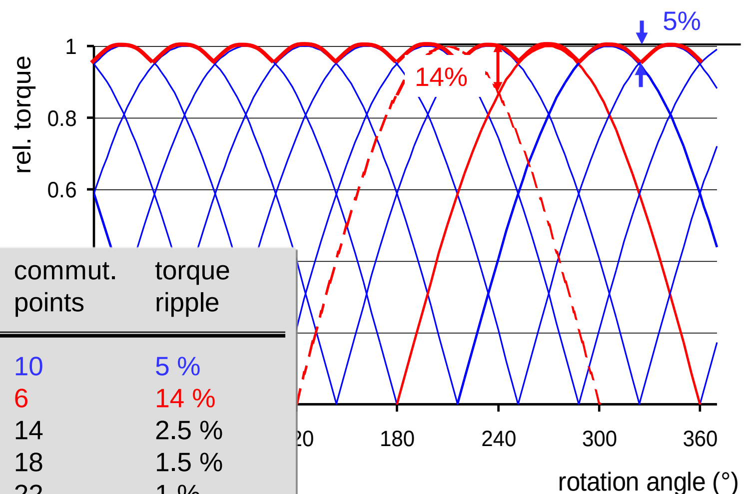
- speed constant k_n
  - inversely proportional to k_M
  - inversely proportional to generator constant (V/1000 rpm)

Part 5: Commutation with brushes



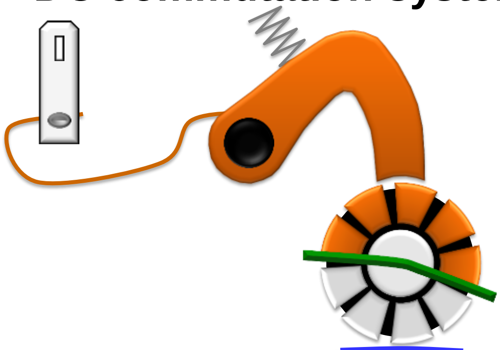
+	−
1	4
1	5
2	5
2	6
3	6
3	7
4	7
4	1
5	1
5	2
6	2
6	3
7	3
7	4
1	4

DC commutation: torque ripple

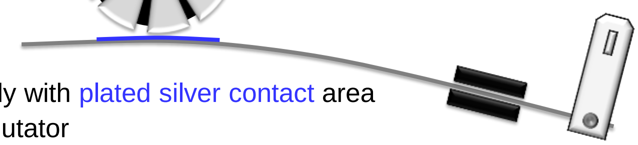


commutator segments	commut. points	torque ripple
5	10	5 %
6	6	14 %
7	14	2.5 %
9	18	1.5 %
11	22	1 %
13	26	0.75 %

DC commutation systems



Graphite
- graphite brush with 50% copper
- copper reduces the contact and brush resistance
- copper commutator
- graphite serves as lubricant
- spring system (schematic)



Precious metal
- bronze brush body with plated silver contact area
- silver alloy commutator
- smallest contact and brush resistance (50 mΩ)
- CLL for high service life

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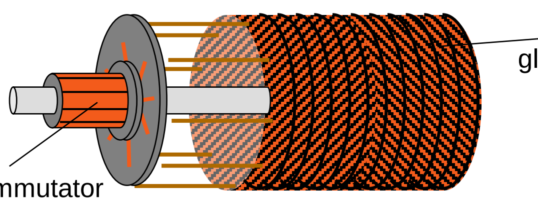
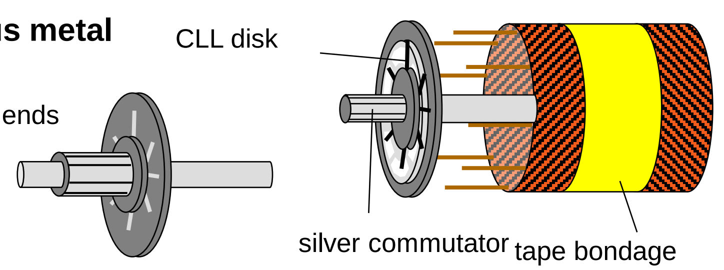
DC commutation: rotors

graphite



precious metal



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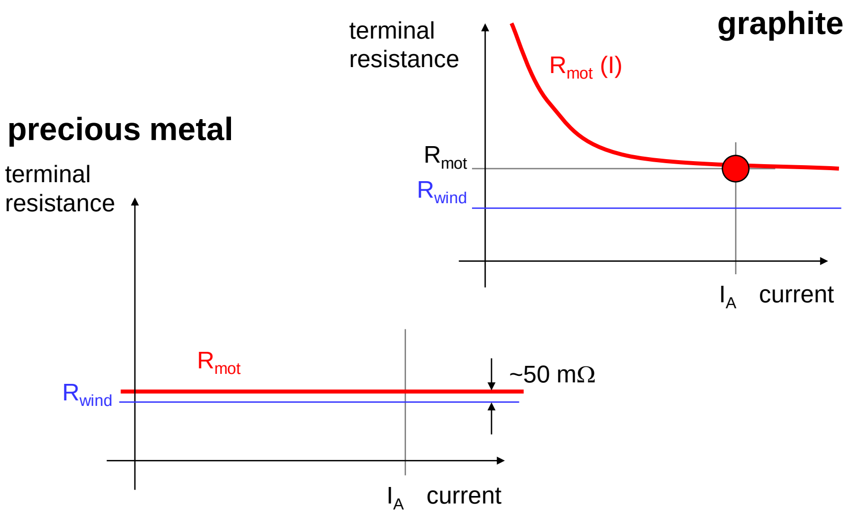
DC commutation: terminal resistance



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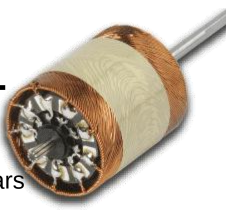
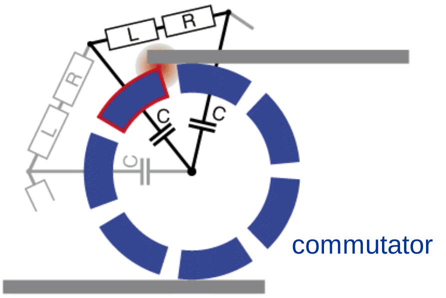
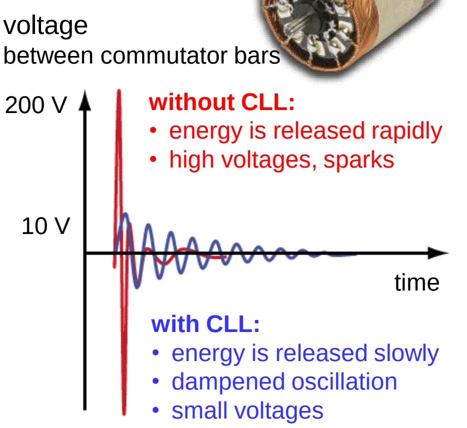
Precious metal commutation: CLL



Problem

– Brush fire => Reduced life





Solution

– capacitors and resistors between neighbouring commutator segments
– energy is deviated into capacitor: no arcs produced

DC motors – commutation
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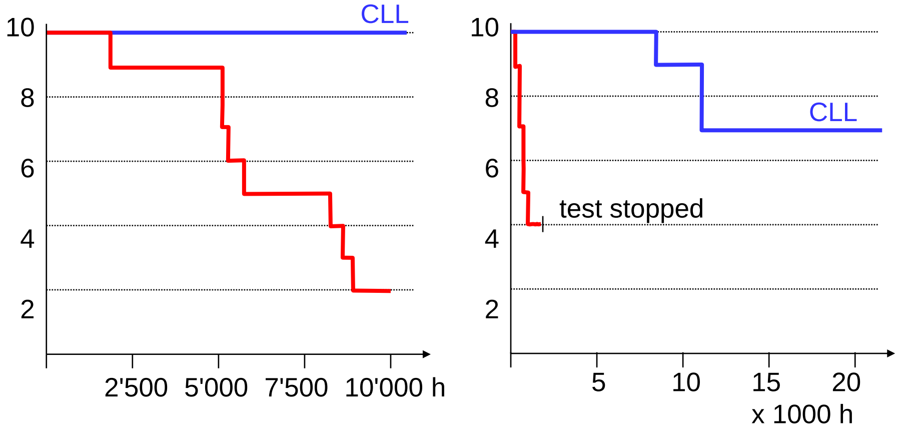
Service life and CLL (examples)

Motor 1
I = 50 mA n = 13'000 rpm
U = 24 V

Motor 2
I = 250 mA n = 1'500 rpm
U = 10 V



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DC commutation: Characteristics

Graphite

- well suited for high currents and peak currents
- well suited for start-stop and reversing operation
- larger motors (>approx. 10 W)

- higher friction, higher no-load current
- not suited for small currents
- higher audible noise
- higher electromagnetic emissions
- higher costs

Precious metal

- well suited for smallest currents and voltages
- well suited for continuous operation
- smaller motors
- very low friction
- low audible noise
- low electromagnetic interference
- cost effective

- not suited for high current and peak currents
- not suited for start-stop operation

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Part 6: Service life, bearings

service life

- no general statement possible
- average conditions: 1'000 - 3'000 hours
- under extreme conditions: less than 100 hours
- under favorable conditions: more than 20'000 hours

influencing factors

- electrical load:
  higher currents = higher electro erosion (brush fire)
- speed:
  higher speed = higher mechanical wear
- operation mode:
  continuous operation
  start-stop operation
  reverse operation = reduced service life
- temperature
- humidity of the air
- load on the shaft (bearing)

use graphite brushes and ball bearing for extreme requirements

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Ball and sleeve bearings: characteristics

Ball bearing

- well suited for high radial and axial loads
- well suited for all operating modes, for start-stop and reversing operation
- on larger motors

- more audible noise if not preloaded
- when preloaded higher friction
- more expensive

Sintered sleeve bearings

- suited for low radial and axial loads
- suited for continuous operation at higher speeds
- smaller motors
- low friction and noise
- cost effective

- not suited for start-stop operation

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