maxon EC motor
An introduction to brushless DC motors

- **Design variants: maxon EC motor families**
- **Common features**
  - operating principle
  - winding connections, iron losses
- **Electronic commutation systems**
  - block commutation with and without Hall sensors
  - sinusoidal commutation
- **Comparison to DC motors with brushes**

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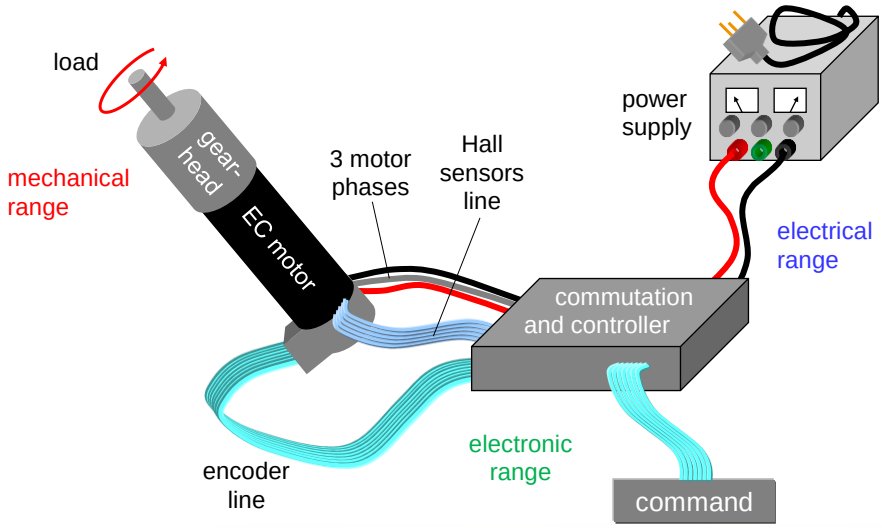
Components of an EC drive system



EC motors - overview

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Brushless DC motor

- names: EC motor, BLDC motor
- motor behavior similar to DC motor
  - design similar to synchronous motor (3 phase stator winding, rotating magnet)
  - the powering of the 3 phases according to rotor position
- main advantages: higher life, higher speeds
- slotless windings
  - similar advantages as coreless DC motors
  - no magnetic detent, less vibrations
- becomes more attractive: costs, size, magnets

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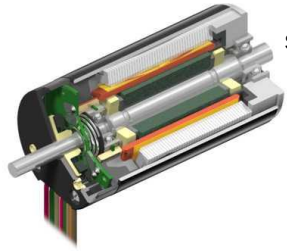
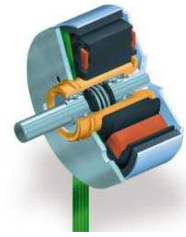
Part 1: maxon EC motor design variants

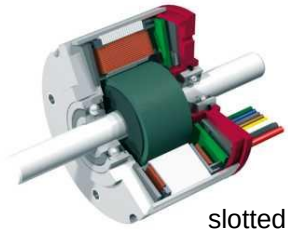


slotless



slotted
external rotor

- features in common
  - 3 phase winding in the stator (3 winding connections)
  - rotating permanent magnet made of NdFeB
  - preloaded ball bearings
  - electronic commutation



slotted
internal rotor

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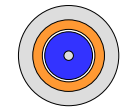
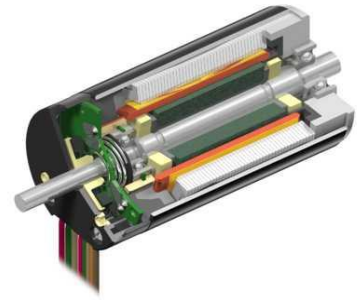
maxon EC motor: Coreless design



- design with coreless maxon winding
  - internal rotor with 1 or 2 pole pair



- maxon EC motor
  - many types: e.g. short – long, sterilisable, integrated electronics, …
  - typically for high speeds
- maxon EC-max
  - Philosophy: reliable EC motor at reasonable price
- maxon EC-4pole
  - Philosophy: the strongest possible motor

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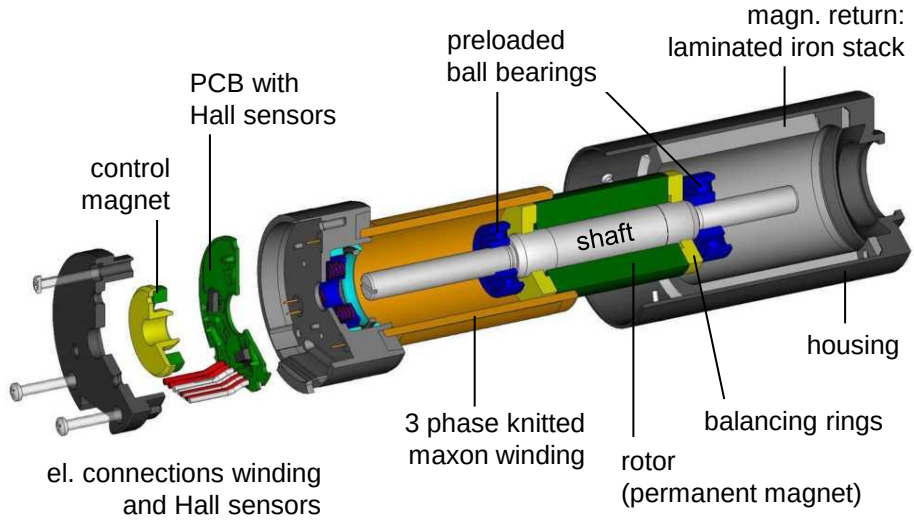
maxon EC motor



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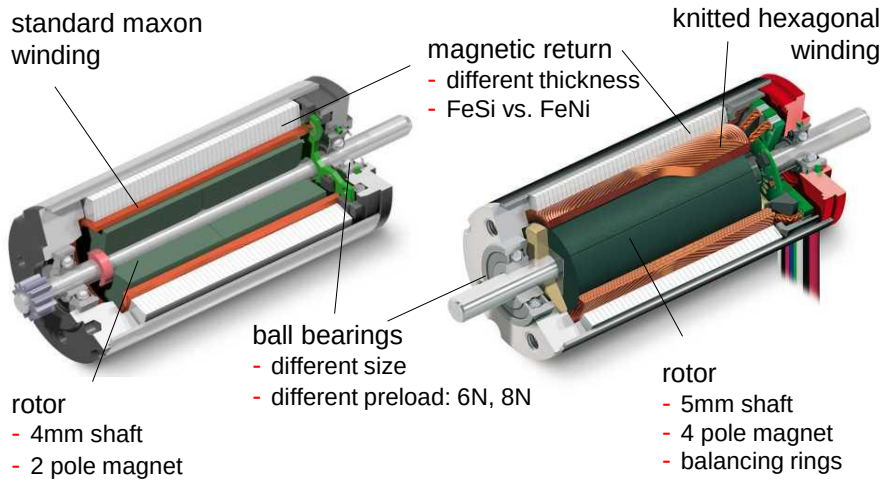
EC-max 30 vs. EC-4pole 30



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EC-max: design characteristics

Philosophy: reliable EC motor at reasonable price

- standard maxon winding
  - only star circuit possible
  - not optimized with respect to performance (power)
- Hall sensors monitor directly the power magnet
  - no control magnet
  - special orientation process of Hall sensors to winding
- no balancing rings
  - very high speeds are not possible (up to 12 - 20'000 rpm)
- preloaded ball bearings
- long and short versions per diameter

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EC-4pole: design characteristics

Philosophy: the strongest possible EC motor

- very high torque and acceleration
  - knitted maxon winding
  - hexagonal winding on long versions
  - 4-pole permanent magnet
- moderate speeds up to 25'000 rpm
  - higher commutation frequency
  - higher iron losses
- special orientation process of Hall sensors to winding
- preloaded ball bearings

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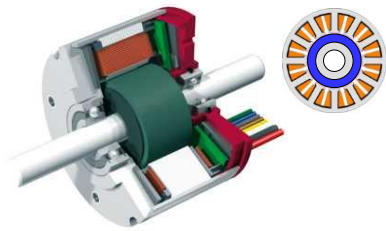
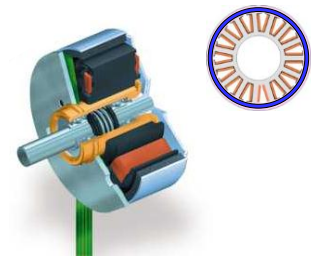
maxon EC motor: Slotted design

- maxon EC-i
  - Philosophy: strong EC Motor at an attractive price
  - dynamic motor, cogging torque
  - slotted winding, internal rotor
  - several magnetic pole pairs



- flat maxon EC motor
  - Philosophy: flat EC Motor at an attractive price
  - slotted winding, external rotor
  - more than 4 magnetic pole pairs
  - relatively high torque but limited speed and dynamics



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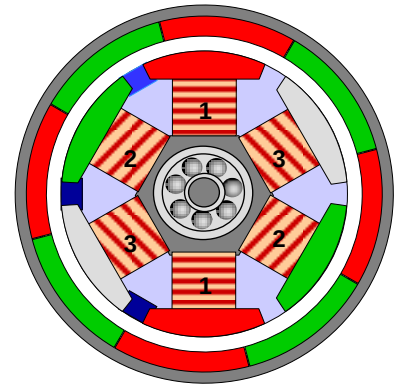
EC flat motor: design characteristics

Philosophy: flat design with attractive price

rotor:
- external rotor => high torque
- multi-pole magnetic ring of NdFeB
  => higher commutation frequency,
  => not very high speeds

stator:
- 3 phases, several teeth per phase

further characteristics:
- Hall sensors detect magnetic ring
- but also often sensorless
- preloaded ball bearings



e.g. EC 32 flat:
- 8 magnetic poles
- 2 teeth per winding phase

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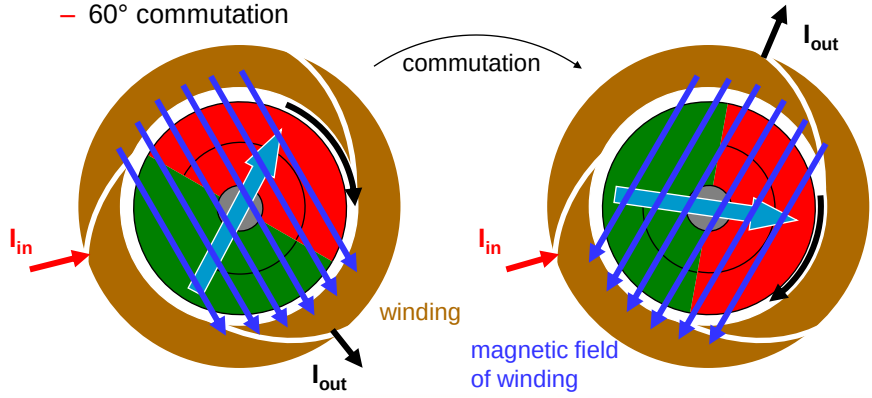
Part 2: Interaction of rotor and stator

- current distribution in phases
  - 3 phases: 6 possible current distributions
  - 6 winding magnetic field directions rotated by 60°
  - 60° commutation



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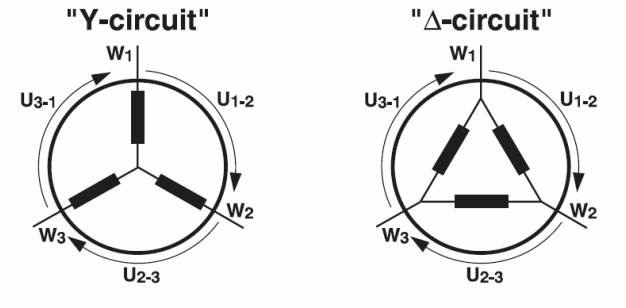
Winding connections



- high resistance
- low currents
- higher torque constant

$$R_Y = 3 \cdot R_\Delta$$

$$k_{M,Y} = \sqrt{3} \cdot k_{M,\Delta}$$

$$k_{n,Y} = \frac{1}{\sqrt{3}} \cdot k_{n,\Delta}$$

- low resistance
- low voltages
- higher speed constant
- possibility of induced circular winding currents

internal connection of the 3 phases: no practical consequences

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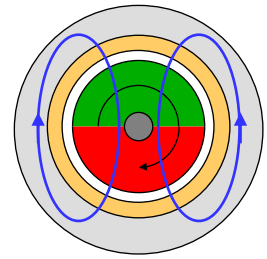
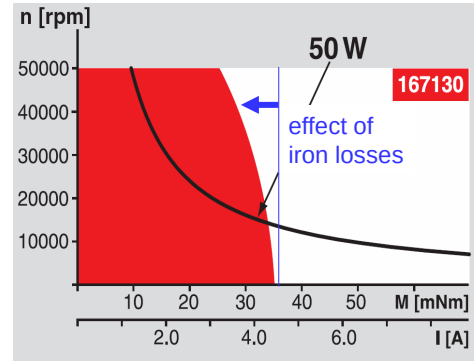
Iron losses

- origin: rotating magnet
- hysteresis losses
  - changing the direction of magnetization needs energy
- eddy current losses
  - rotating magnetic field causes eddy currents
- effects: additional motor heating
  - at high speeds less current for torque generation is allowed
  - see operation range diagram





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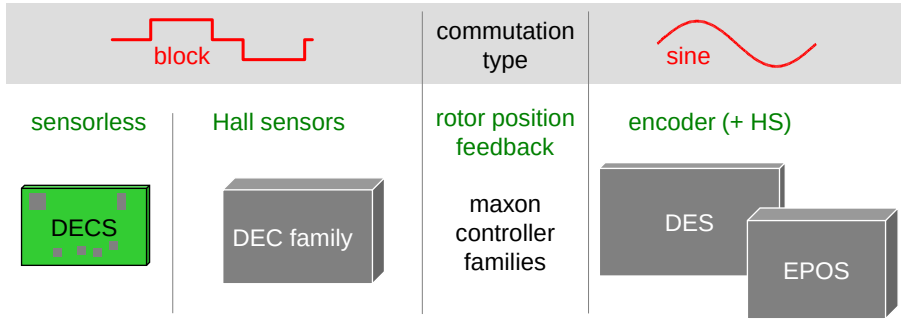
Part 3: Electronic commutations systems

- common goal: applying the current to get the maximum torque
- perpendicular magnetic field orientation of
  - rotor (permanent magnet)
  - and stator (winding)
- knowledge of rotor position with respect to winding



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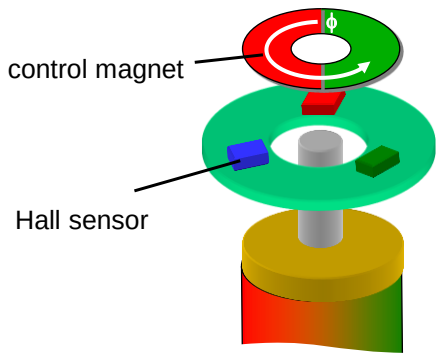
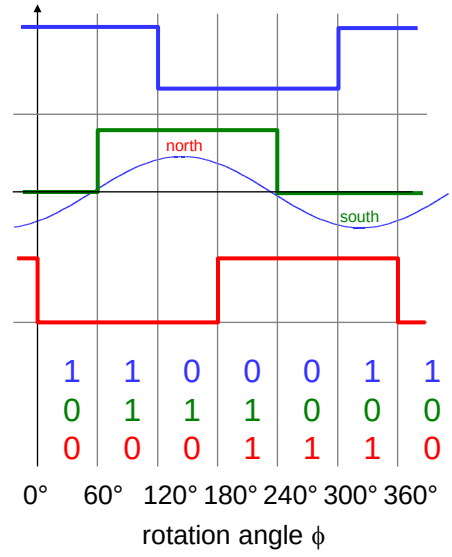
Block commutation

rotor position from Hall sensor signals





EC-max and EC flat:
Power magnet is probed directly

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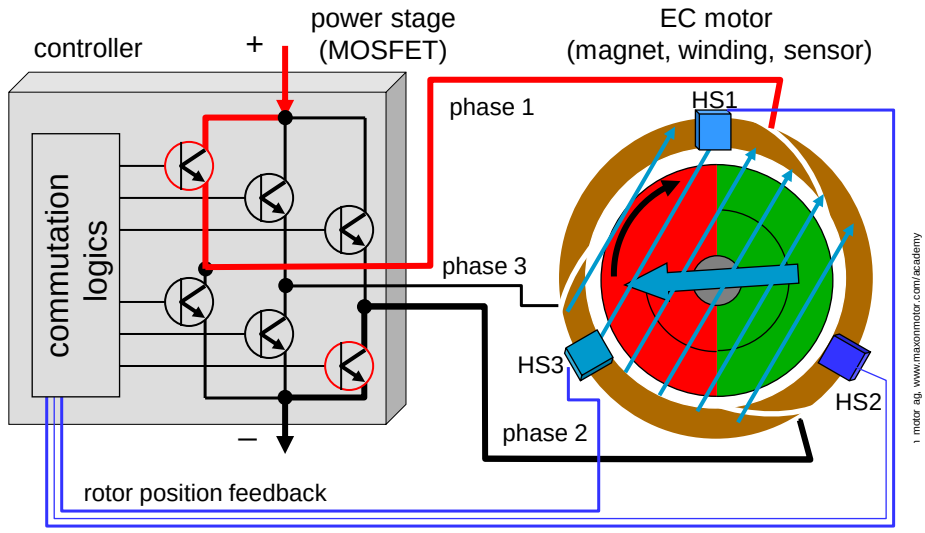
Block commutation



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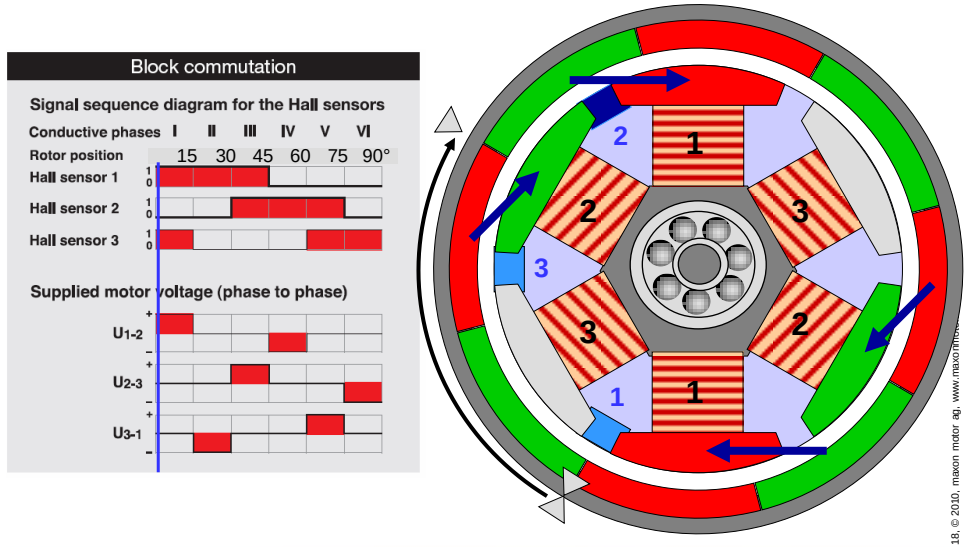
Multi-pole EC motor: commutation



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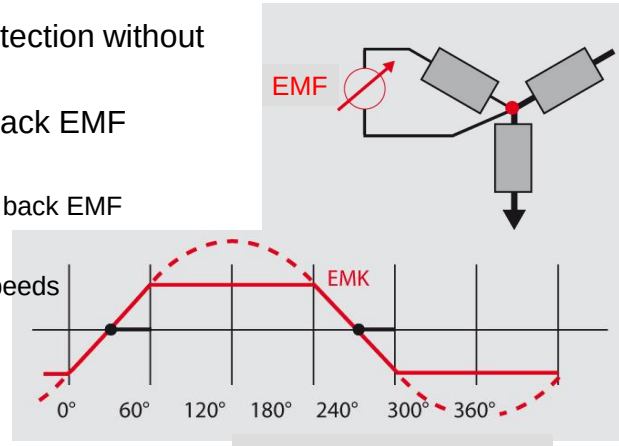
Sensorless block commutation

- rotor position detection without (Hall) sensors
- measuring the back EMF
  - star point
  - zero crossing of back EMF
  - time delay 30°
    difficult at low speeds



- special starting procedure similar to stepper motor

→ sensorless commutation only for continuous operation at high speeds

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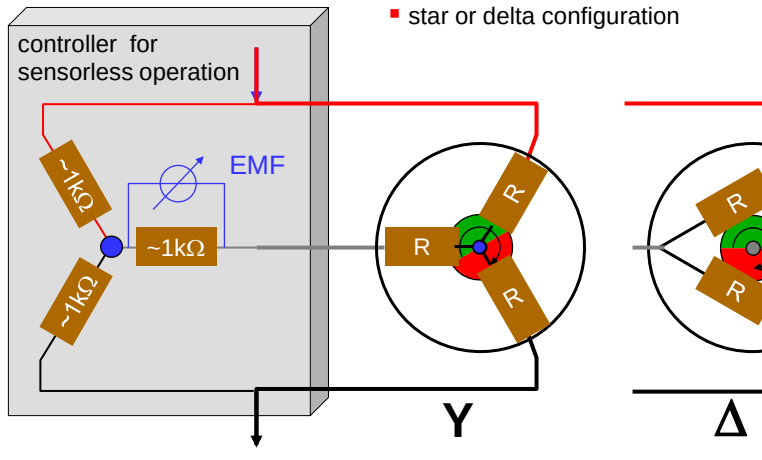
Sensorless block commutation

virtual star point

- virtual star point in the electronics
- star or delta configuration



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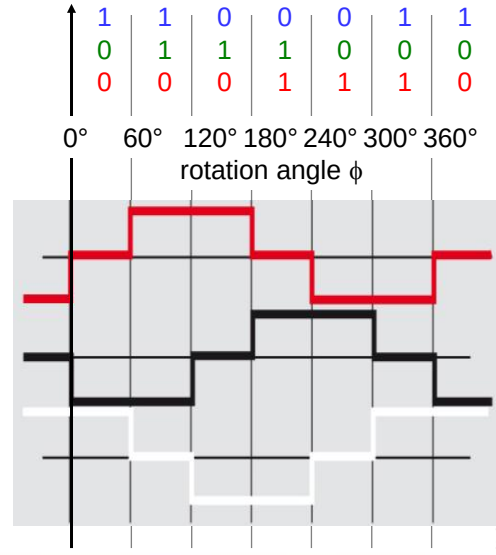
Block commutation

- motor with 1 pole pair
  - position known within 60°
  - commutation every 60°
- motor with P pole pairs
  - position known within 60°/ P
  - commutation every 60°/ P
- block shaped phase currents
  - torque ripple
  - vibrations, humming



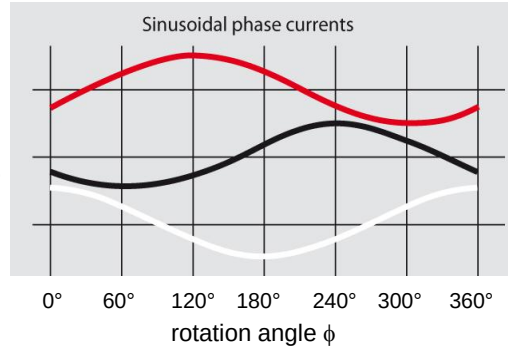
Sinusoidal commutation

rotor position

- must be known very accurately
- typical 2'000 points per rev.
- 500 pulse encoder
  (Hall sensors for start: absolute rotor position)
- resolver as an alternative

phase currents

- sinusoidal
- 120° phase shift
- similar to synchronous motor with variable frequency



Sinusoidal commutation for smooth running even at the lowest speeds

Part 4: DC and EC motor: Comparison

DC motor

- simple operation and control, even without electronics
- no electronic parts in the motor
- brush commutation system limits motor life
- max. speed limited by commutation system

EC motor

- long life, high speeds
  - preloaded ball bearings
- no brush fire
- iron losses in the magnetic return
- needs electronics to run
  - more cables
  - more expensive
- electronic parts in the motor (Hall Sensor)

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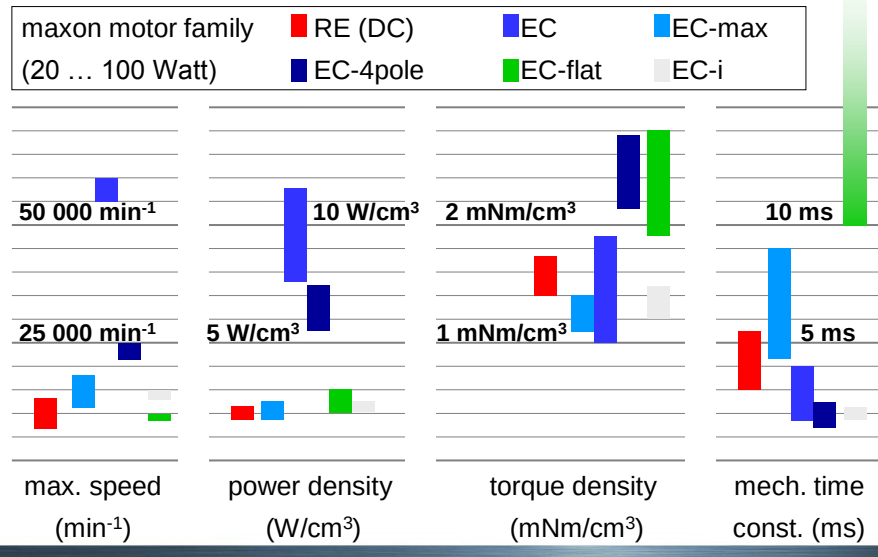
DC and EC motor: Comparison



Comparison DC and EC

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