DC and BLDC Motors with Permanent Magnets

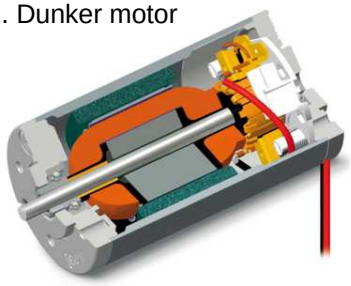
- **Design, design variants**
- **Commutation: Graphite and precious metal brushes**
- **Brushless commutation**

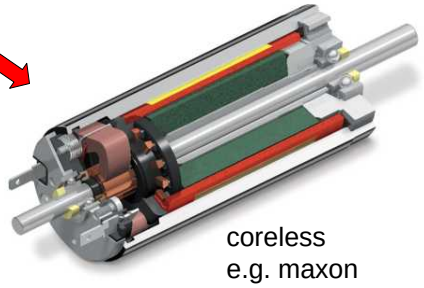
Seminar at Electromate

maxon motor
driven by precision

DC motor designs

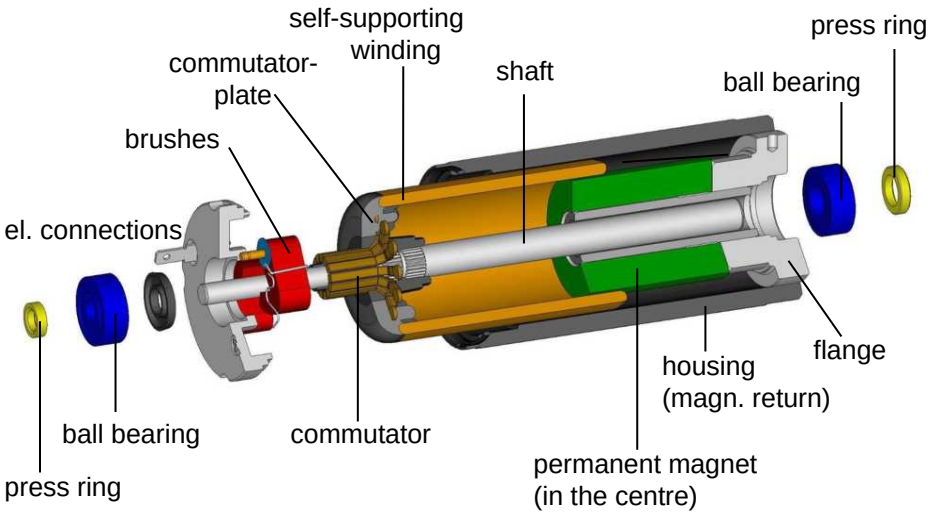
conventional, slotted
e.g. Dunker motor





coreless
e.g. maxon

Coreless maxon DC motor (RE 35)

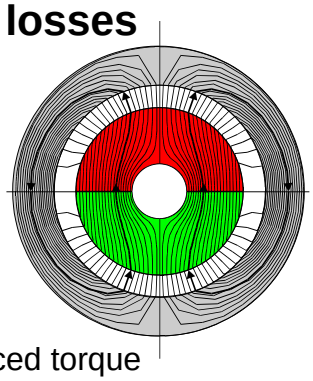


Advantage coreless: no cogging

- no soft magnetic teeth to interact with the permanent magnet
- smooth running even at small speeds
- less vibration and noise

- any rotor position can be controlled in a simple way
- no nonlinear control behaviour

Advantage coreless: no iron losses



- no iron – no iron losses
- constant magnetization
- high efficiency, up to above 90%
- low no load current, typical < 50 mA

- no saturation effects in the iron core
- Even at the highest currents the produced torque remains proportional to the motor current.
- stronger magnets = stronger motors
- compact design
- small rotor inertia

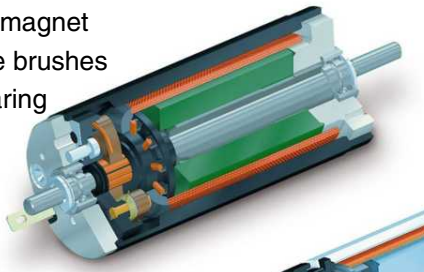
Advantage coreless: small inductance

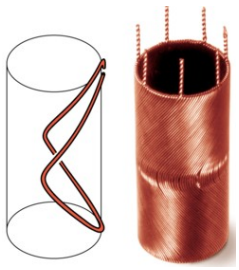
- less brush fire
  - commutation: open and close a contact on an inductive load
- higher live expectancy
- less electromagnetic emissions
- easier to suppress interferences:
  - capacity between connections
  - ferrite core at motor cable

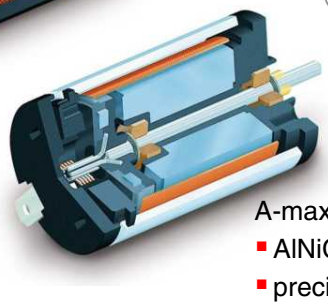
- but fast reaction of the current
  - problems in combination with pulsed supply (choke needed)

maxon DC motor: Variants

RE-Motor with
- NdFeB magnet
- graphite brushes
- ball bearing

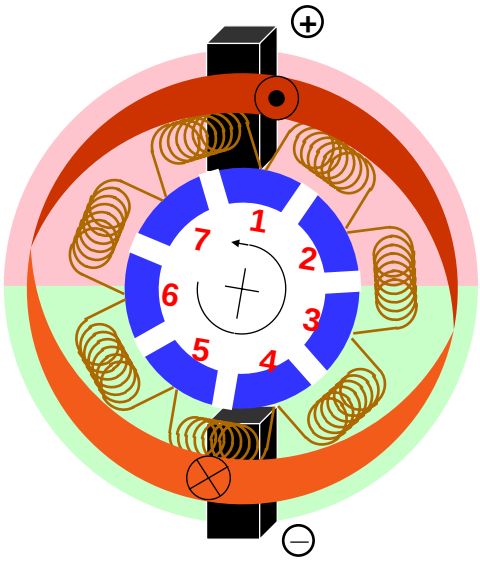






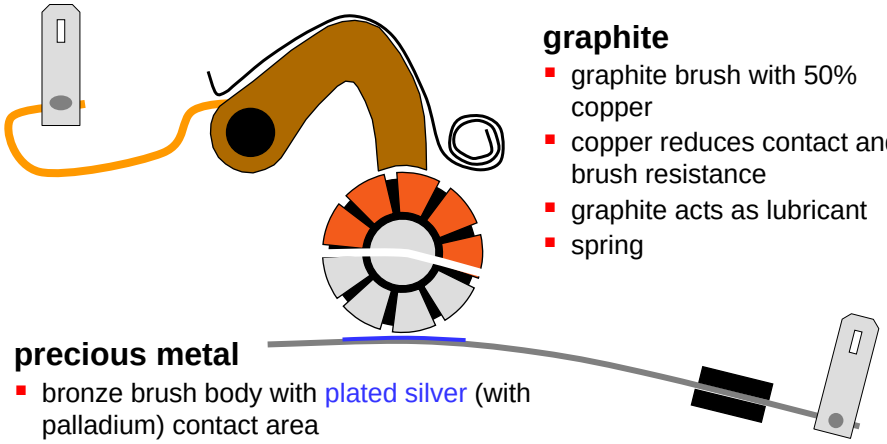
A-max-Motor with
- AlNiCo magnet
- precious metal brushes
- sintered sleeve bearing

Commutation process



⊕	⊖
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 systems

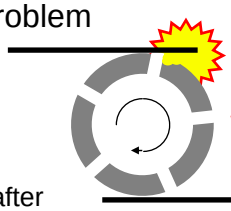


graphite
- graphite brush with 50% copper
- copper reduces contact and brush resistance
- graphite acts as lubricant
- spring

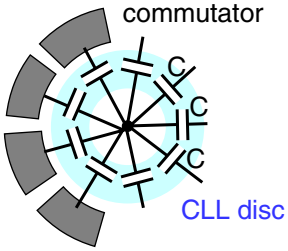
precious metal
- bronze brush body with plated silver (with palladium) contact area
- silver copper commutator
- small contact and brush resistance (50mΩ)
- CLL for extended service life

Precious metal brushes: CLL

the problem



solution
- capacitors between neighbouring commutator segments
- energy is deviated into capacitor: no arcs produced



R_S

DC commutation: pros and cons

graphite

- well suited for high currents and current peaks
- well suited for start-stop and reversed operation
- bigger motors
- higher friction, higher no-load currents
- not well suited for small currents
- more audible noise and electromagnetic emission
- more expensive

precious metal

- well suited for smallest currents and voltages
- well suited for continuous operation
- smaller motors
- very low friction and noise
- low electromagnetic emission
- favourable price
- not well suited for high currents and current peaks
- not well suited for start-stop operation

maxon DC motor: service life

service life

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

use graphite brushes and ball bearings for extreme operating conditions

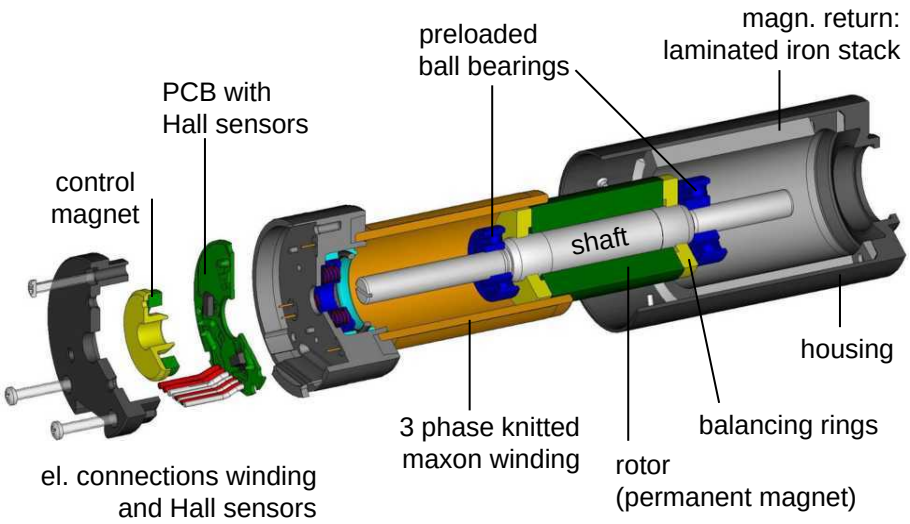
life influencing factors

- the electric load: higher currents = higher electric wear (arcing)
- speed: higher speed = higher mechanical wear
- type of operation: reversed operation = reduced service life
- temperature
- humidity with graphite brushes
- CLL (with precious metal brushes) enhances service life
- load on shaft (bearings)

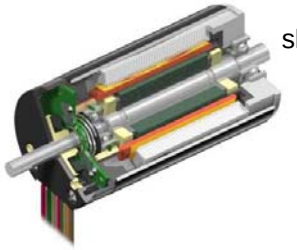
Brushless DC motor

- 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
- the more attractive, the smaller the costs and size of electronics

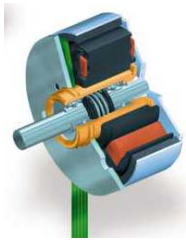
maxon EC motor / brushless DC motor



maxon EC motor design variants

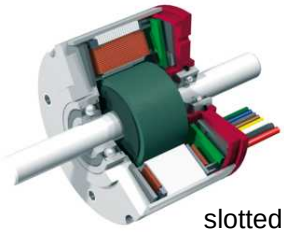


slotless



slotted
external rotor

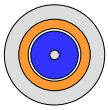
- features in common
  - rotating permanent magent made of NdFeB
  - 3 phase winding in the stator (3 winding connections)
  - preloaded ball bearings
  - electronic commutation



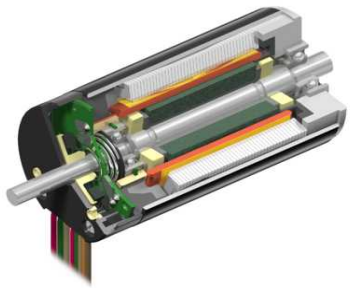
slotted
internal rotor

maxon EC motor: Coreless design

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

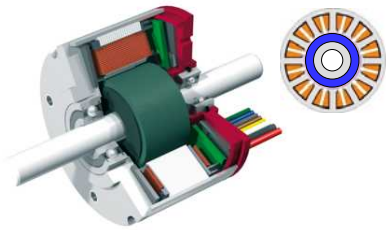


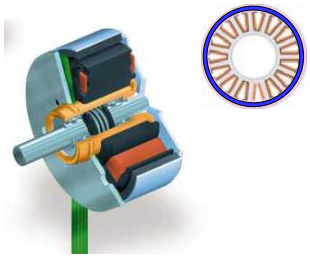
- maxon EC motor
  - many types: e.g. short – long, sterilisable, integr. electronics, …
  - typically for high speeds
- maxon EC-max
  - Philosophy: reliable EC motor at reasonable price
- maxon EC-powermax
  - Philosophy: the strongest possible motor



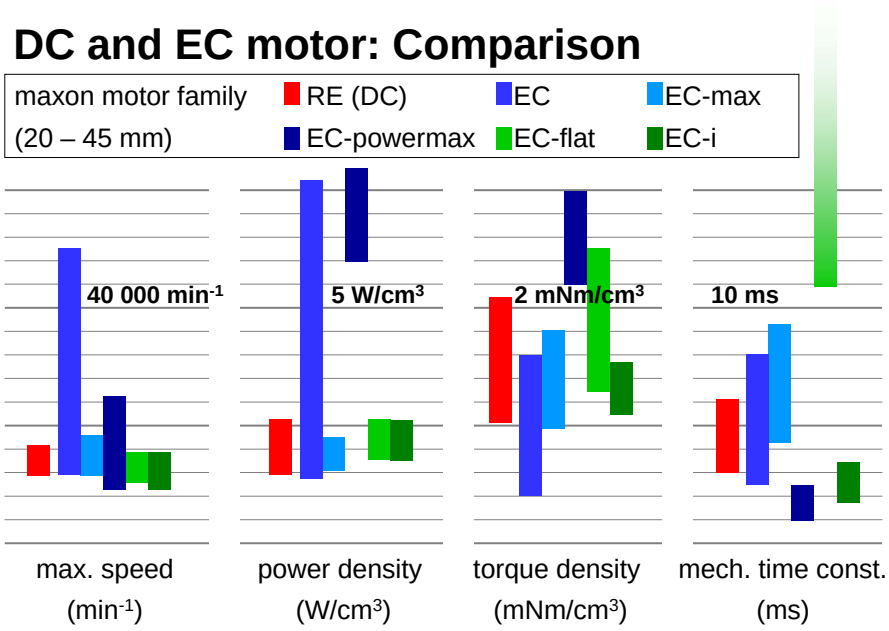
maxon EC motor: Slotted design

- maxon EC-i
  - Philosophy: strong EC Motor at attractive price
  - dynamic motor, high 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



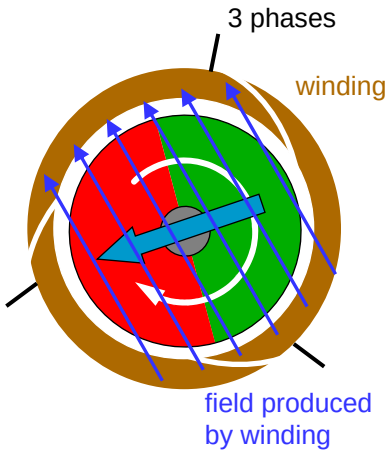


DC and EC motor: Comparison



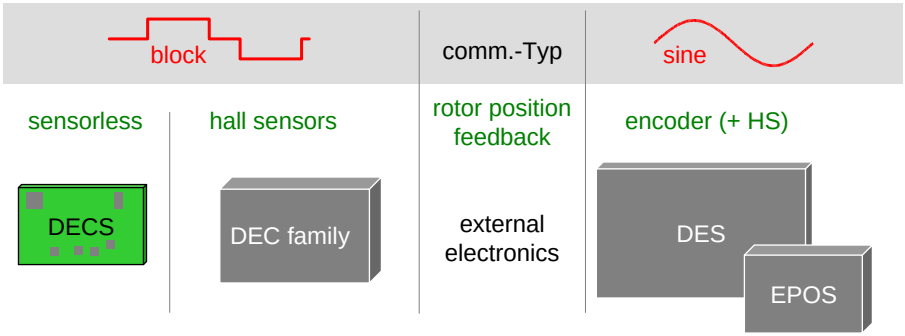
Interaction of rotor and stator

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



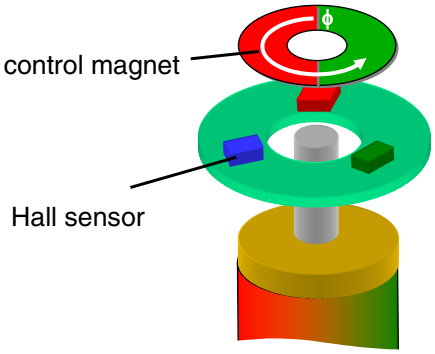
Electronic commutations systems

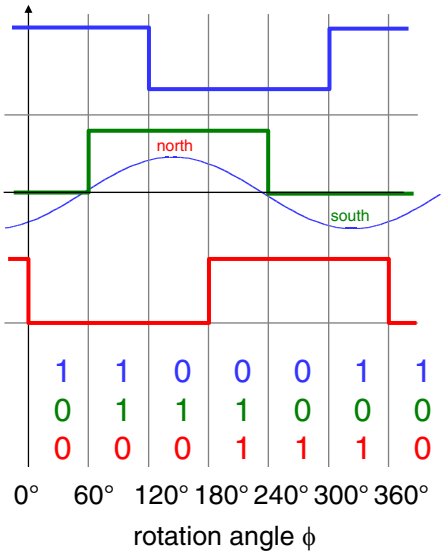
- common goal: Applying the current to get the maximum torque
- perpendicular magnetic field orientation of
  - rotor (permanent magnet)
  - and stator (winding)
- knowledge of rotor position with respect to winding



Block commutation

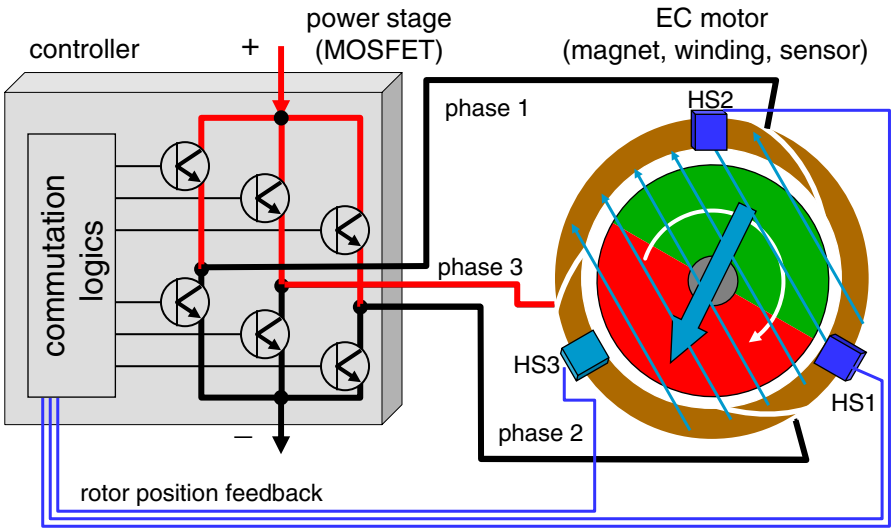
rotor position from Hall sensor signals



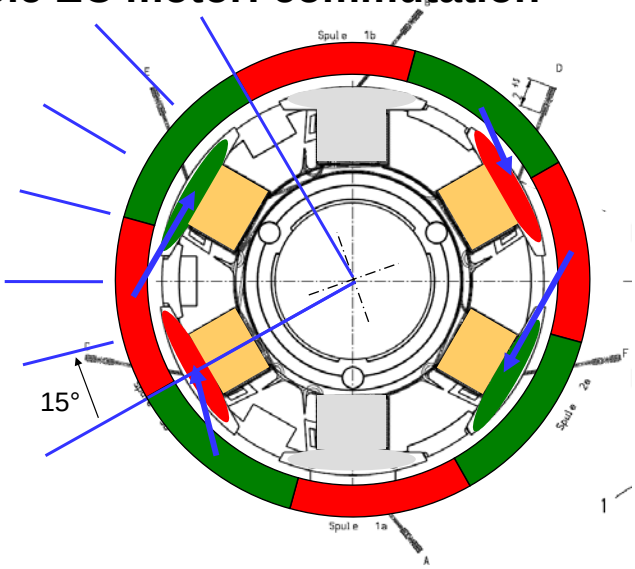


EC-max and EC flat:
Power magnet is probed directly

Block commutation



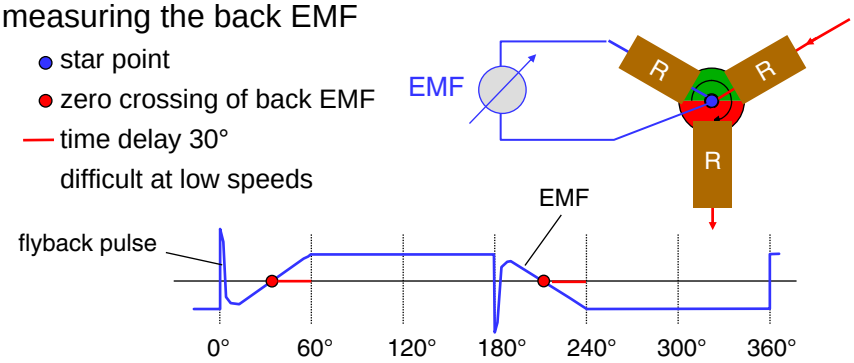
Multipole EC motor: commutation



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

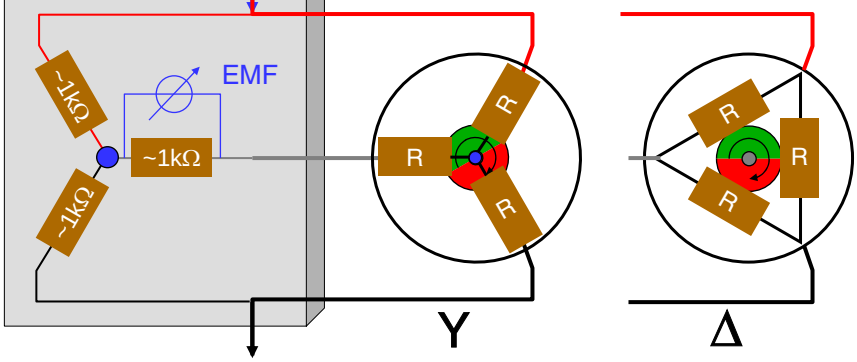


- special starting procedure similar to stepper motor

sensorless commutation only for continuous operation at high speeds

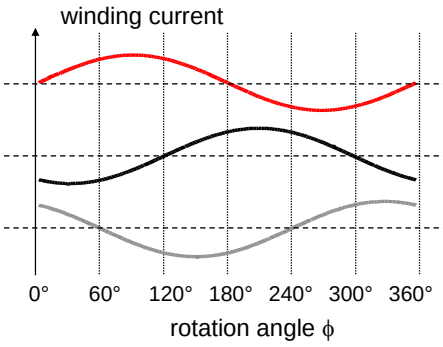
Sensorless block commutation

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



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