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

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Part 1: DC motor designs

conventional, slotted
e.g. Dunkermotor

coreless
e.g. maxon
Conventional DC motor

- el. connections
- winding
- iron core
- flange
- commutator
- permanent magnet (external)
- housing (magn. return)
- brush system

Coreless maxon DC motor (RE 35)

- el. connections
- self supporting winding
- shaft
- ball bearing
- press ring
- commutator plate
- brushes
- ball bearing
- commutator
- permanent magnet (in the centre)
- housing (magnetic return)
- flange
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

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
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

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?
maxon DC motor variants

- RE motor with NdFeB magnet
- A-max motor with AlNiCo magnet
- Ball bearing
- Precious metal brushes
- Graphite brushes
- Sintered sleeve bearing

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

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maxon DC motor families comparison

<table>
<thead>
<tr>
<th>permanent magnet motor range</th>
<th>AlNiCo A-max, S, A</th>
<th>NdFeB RE, RE-max</th>
</tr>
</thead>
<tbody>
<tr>
<td>example</td>
<td>A-max 19 GB</td>
<td>RE 13 GB</td>
</tr>
<tr>
<td>speed / torque gradient</td>
<td>1150 min⁻¹/mNm</td>
<td>1250 min⁻¹/mNm</td>
</tr>
<tr>
<td>rated power</td>
<td>2.5 W</td>
<td>3 W</td>
</tr>
<tr>
<td>diameter</td>
<td>19 mm</td>
<td>13 mm</td>
</tr>
<tr>
<td>length</td>
<td>31.5 mm</td>
<td>34.5 mm</td>
</tr>
<tr>
<td>motor dimension</td>
<td>8.9 cm³</td>
<td>4.6 cm³</td>
</tr>
<tr>
<td>cont. torque</td>
<td>3.8 mNm</td>
<td>2.4 mNm</td>
</tr>
<tr>
<td>approximate price</td>
<td>≈ 50.- CHF</td>
<td>≈ 100.- CHF</td>
</tr>
</tbody>
</table>

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/

Permanent magnets

<table>
<thead>
<tr>
<th>magnet</th>
<th>Curie-temperature</th>
<th>operation range°C</th>
<th>motor design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nd$<em>2$Fe$</em>{14}$B</td>
<td>310°C</td>
<td>110-170°C</td>
<td>all possible, EC</td>
</tr>
<tr>
<td>Sm$<em>2$Co$</em>{17}$</td>
<td>825°C</td>
<td>350°C</td>
<td></td>
</tr>
<tr>
<td>SmCo$_5$</td>
<td>720°C</td>
<td>250°C</td>
<td></td>
</tr>
<tr>
<td>AlNiCo</td>
<td>~850°C</td>
<td>550°C</td>
<td>coreless only</td>
</tr>
<tr>
<td>ferrites</td>
<td>450°C</td>
<td>250-350°C</td>
<td>conventional</td>
</tr>
</tbody>
</table>
Part 3: Rotor and winding

DC motors – stator / rotor interaction

Coreless winding systems
coreless (DC) - slotless (EC)

maxon and others | maxon | Faulhaber Portescap

Source: Portescap
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
    - outgassing 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

\[ M = k_M \cdot I \]

$I$ = current

---

Speed and voltage: speed constant

- Rotating winding in the air gap
  - In an inhomogeneous magnetic field
  - Induced voltage $U_{\text{ind}}$ (EMF) depends on
    - Geometry
    - Magnetic flux density
    - Number of winding turns
    - Speed $n$

\[ n = k_n \cdot U_{\text{ind}} \]

- Speed constant $k_n$
  - Inversely proportional to $k_M$
  - Inversely proportional to generator constant ($V/1000$ rpm)
Part 5: Commutation with brushes

DC commutation: torque ripple

<table>
<thead>
<tr>
<th>commutator segments</th>
<th>commut. points</th>
<th>torque ripple</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>10</td>
<td>5 %</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>14 %</td>
</tr>
<tr>
<td>7</td>
<td>14</td>
<td>2.5 %</td>
</tr>
<tr>
<td>9</td>
<td>18</td>
<td>1.5 %</td>
</tr>
<tr>
<td>11</td>
<td>22</td>
<td>1 %</td>
</tr>
<tr>
<td>13</td>
<td>26</td>
<td>0.75 %</td>
</tr>
</tbody>
</table>
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

DC commutation: rotors

Graphite
- glass fibre bondage
- copper commutator

Precious metal
- 2 shaft ends
- CLL disk
- silver commutator
- tape bondage
DC commutation: terminal resistance

Precious metal

Terminal resistance

![Graph showing terminal resistance](image)

Problem
- Brush fire => Reduced life

Solution
- Capacitors and resistors between neighbouring commutator segments
- Energy is deviated into capacitor: no arcs produced

Precious metal commutation: CLL

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Solution
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Service life and CLL (examples)

Motor 1
- $I = 50 \text{ mA}$
- $n = 13'000 \text{ rpm}$
- $U = 24 \text{ V}$

Motor 2
- $I = 250 \text{ mA}$
- $n = 1'500 \text{ rpm}$
- $U = 10 \text{ V}$

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
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 electroerosion (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.

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