Mechanics and Motors

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maxon motor

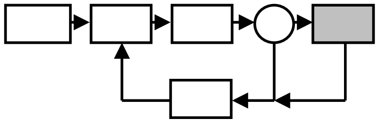
Agenda

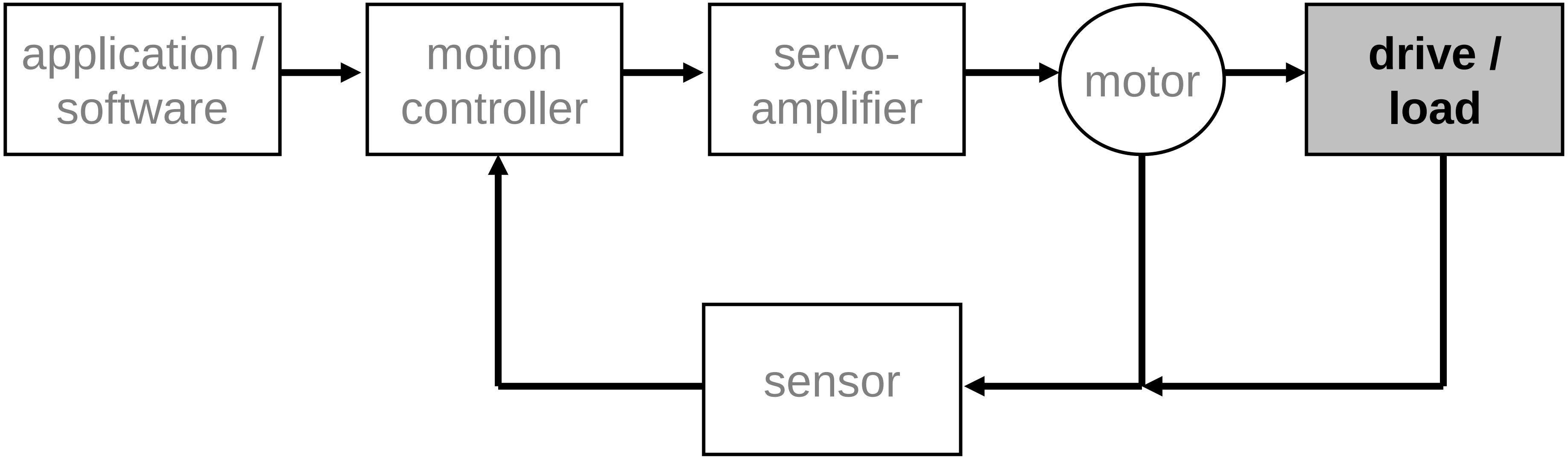
- Part 1: load requirements
  - Operating points and profile
  - Forces and Torques
  - Precision

- Part 2: mechanical drives
  - Power transformation
  - Example spindle and gear at centralized motion controllers

- Part 3: DC / EC / Stepper motors

Load / mechanical drives

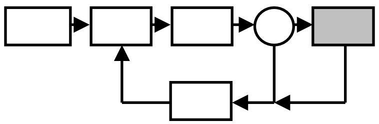




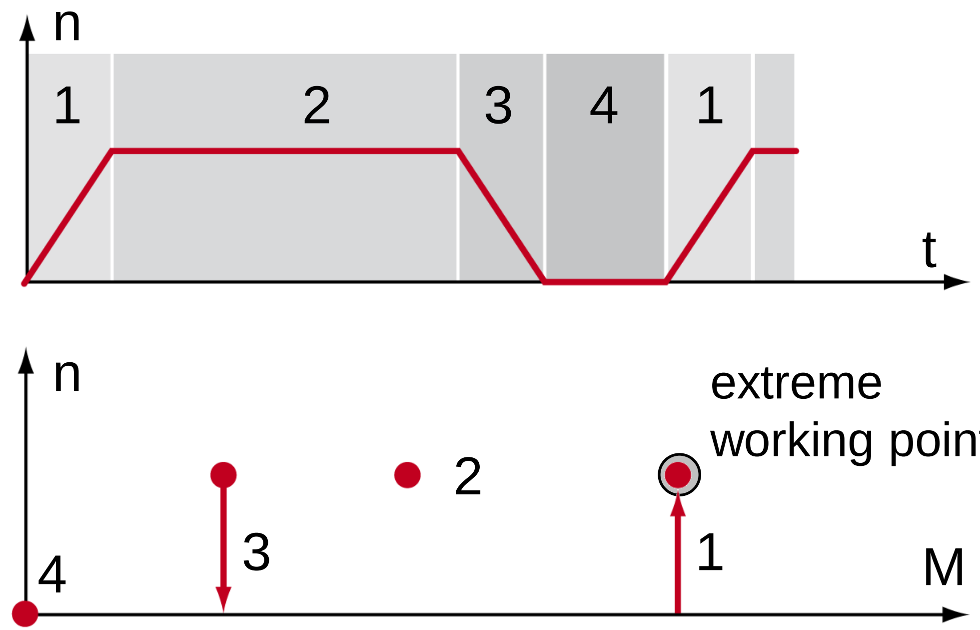
Part 1: load requirements: goal and purpose

- How do the motion profiles look like?
  - Acceleration times
  - Velocity and speed
  - forces and torques
- How is the requested precision?
- How the mechanical power can be transformed?
- Which are the most important key data of gears?

- Goal: Finding the key parameter for drive selection and of gears.

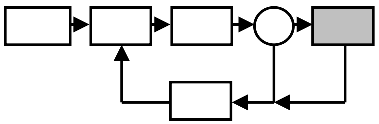


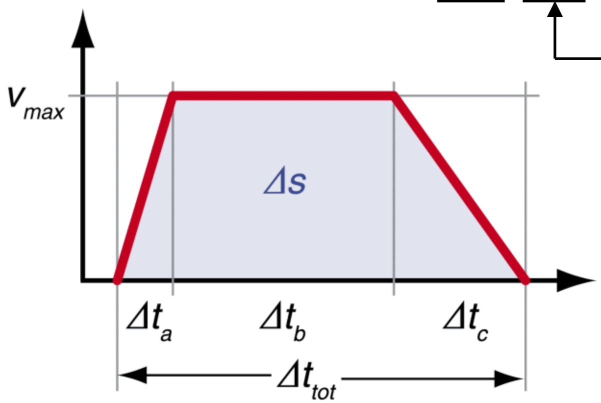
Working point and motion profile



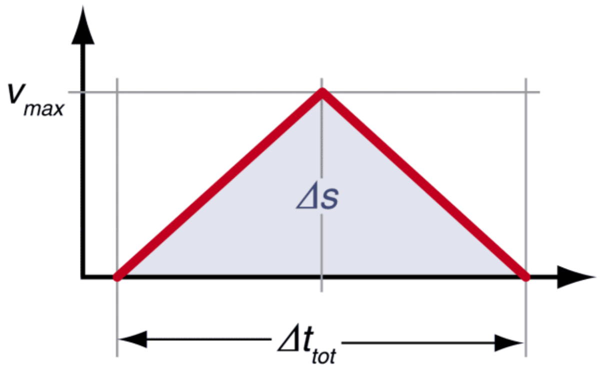
- (M_1,n_1) acceleration — friction and acceleration
- (M_2,n_2) const. speed — friction only
- (M_3,n_3) deceleration — friction helps during deceleration
- (M_4,n_4) dwell — depending on friction

Motion profiles

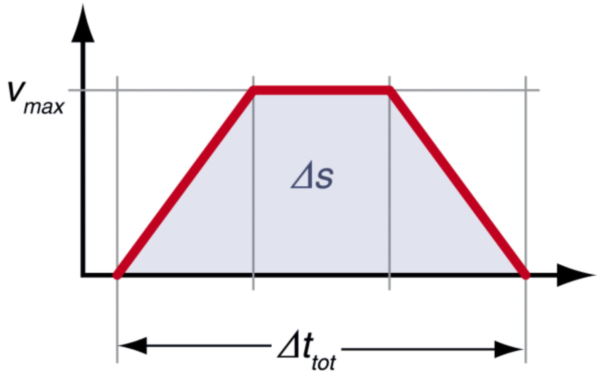




- general parameter
  - duration
  - max. velocity
  - distance

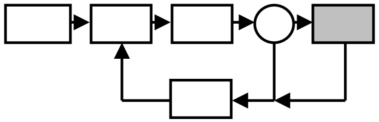


- symmetrical triangular profile
  - for fast motions
  - minimum acceleration



- 3/3 profile
  - minimum power
  - thermally advantageous

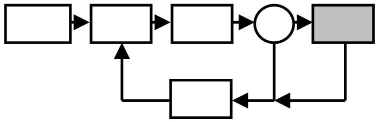
Force and torque



- The **total force** is the important number!

- feeding forces
  - for execution of the real task
  - e.g. penetration of a membrane, drill feeding force
- constant force / torque
  - act always in the same direction
  - e.g. gravity
- friction
  - act against the direction of motion
  - estimation with the help of the friction coefficient

Determination of forces / torques



- Simple measurement
  - required precision: 5-10%
  - e.g. by means of reel and spring balance
- Estimation of friction torques with coefficient of friction
  - Coefficient of friction μ_R
  - e.g. ball bearing

$$M_R = 0.5 \cdot d \cdot \mu_R \cdot F$$

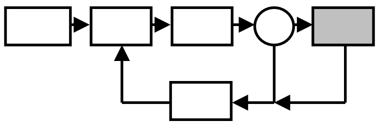
- Acceleration torques
  - Mass inertias

$$M_\alpha = J \cdot \alpha = J \cdot \frac{\Delta\omega}{\Delta t} = J \cdot \frac{\pi}{30} \frac{\Delta n}{\Delta t}$$

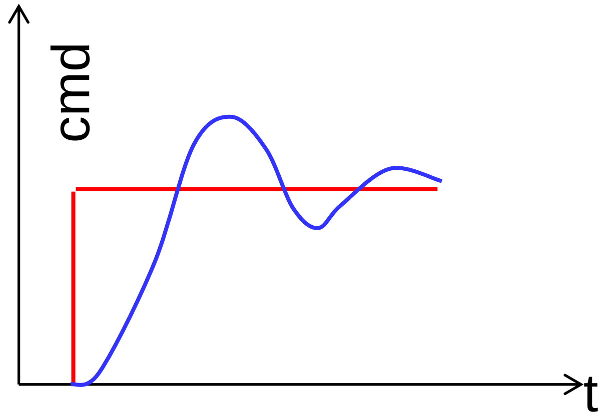
- motor for determination of torques
  - By means of measuring the current
  - Torque constant k_M
  - under original conditions

$$M = k_M \cdot I$$

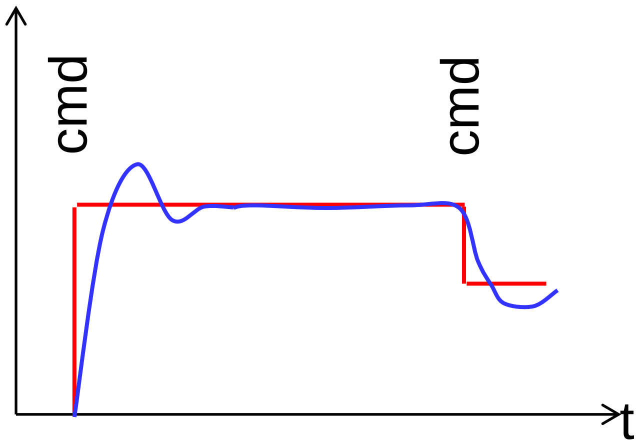
Additional load requirements



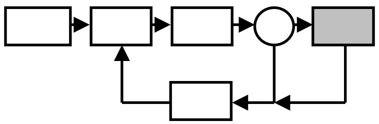
- Position accuracy
  - absolute, relative
  - repeatability
  - overshoot permitted?



- Speed accuracy
  - speed ripple within one revolution
  - corrected in which time?

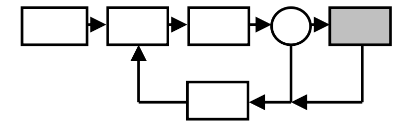


Part 2: Mechanical drives



- **rotation**
  - **gearhead**
    - spur gearhed
    - planetary gearhead
    - bevel gear
    - worm gear
    - Wolfrom gear
  - **belt**
    - toothed belt
    - chain drive
  - **special design**
    - cyclo gear
    - Harmonic Drive®
- **translation**
  - **spindle**
    - ball screw
    - trapezoidal screw
  - **rack and pinion**
  - **conveyor belt**
    - crane
  - **eccentric drive**
    - crankshaft

Mechanical power transformation

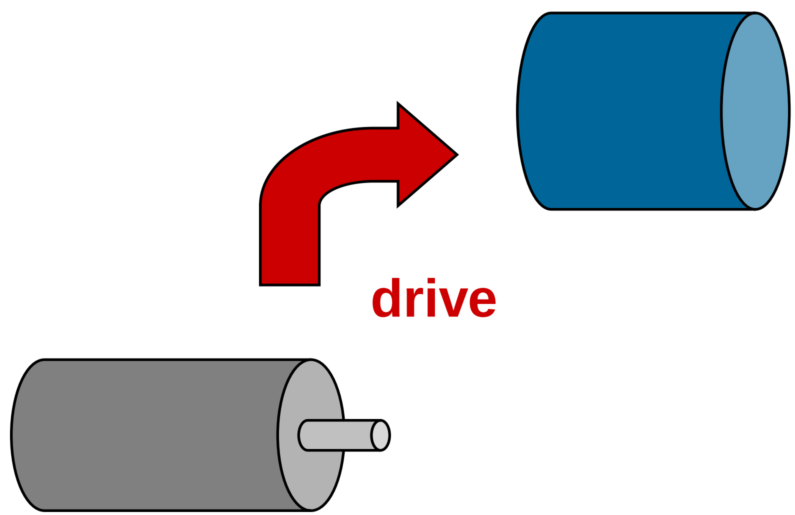


- by means of drive element
- characteristic parameters
  - reduction i
  - efficiency η
  - inertias
  - Play

output: load

M_{out}, n_{out}

F_{out}, v_{out}



input: motor

M_{in}, n_{in}

- Transformation formula

$$M_{in} = \frac{M_{out}}{i \cdot \eta} \qquad M_{in} = \frac{F_{out}}{i \cdot \eta}$$

$$n_{in} = n_{out} \cdot i \qquad n_{in} = v_{out} \cdot i$$

Screw drives

- speed

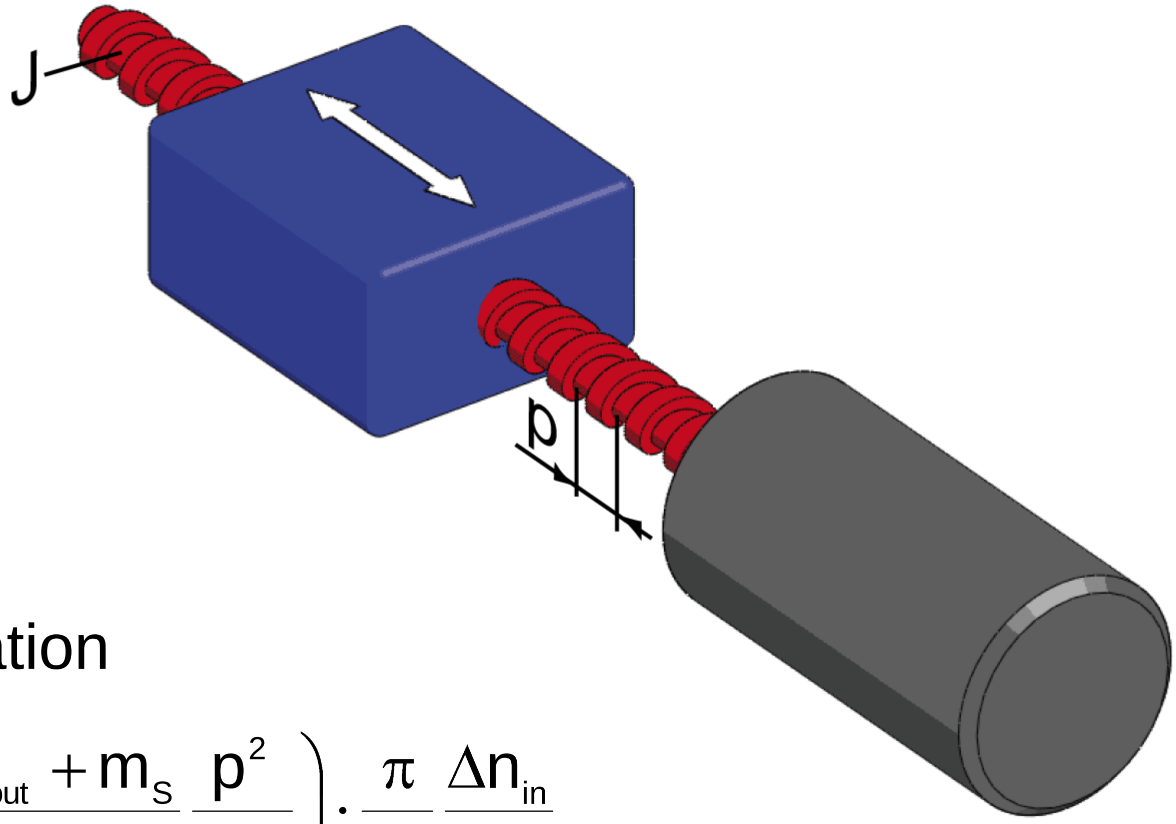
$$n_{in} = \frac{60}{p} \cdot v_{out}$$

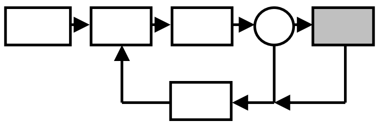
- torque

$$M_{in} = \frac{p}{2\pi} \cdot \frac{F_{out}}{\eta}$$

- torque for acceleration

$$M_{in,\alpha} = \left(J_{in} + J_S + \frac{m_{out} + m_S}{\eta} \frac{p^2}{4\pi^2} \right) \cdot \frac{\pi}{30} \frac{\Delta n_{in}}{\Delta t_\alpha}$$





Gearhead stage

- speed

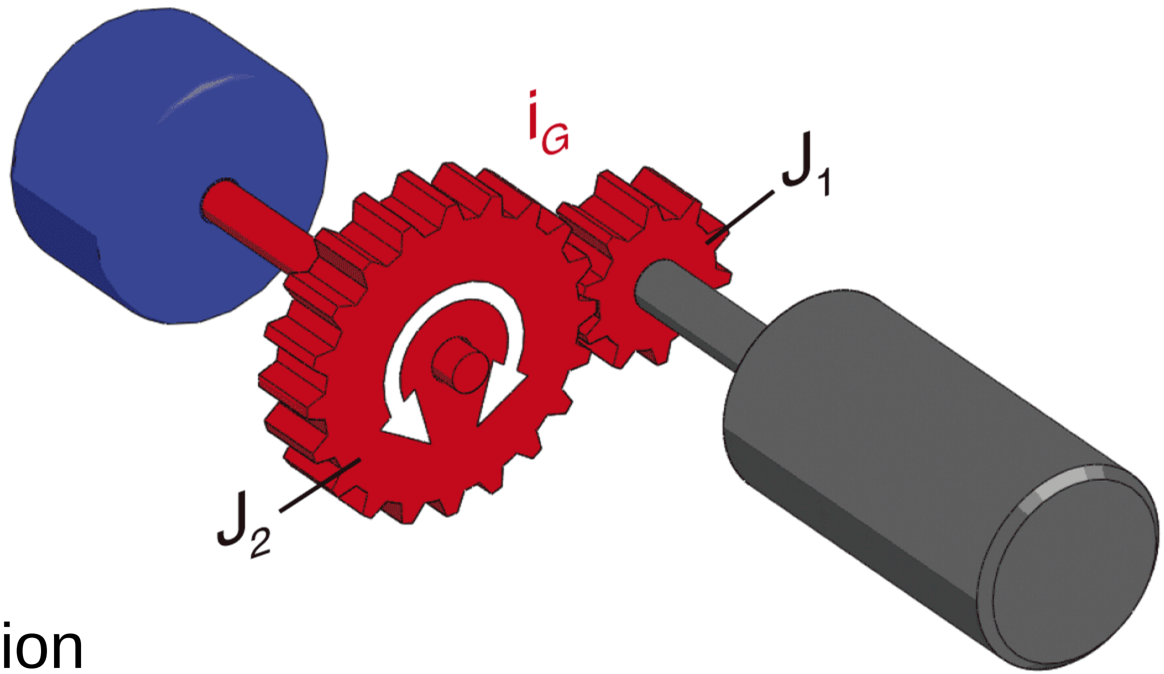
$$n_{in} = n_{out} \cdot i_G$$

- torque

$$M_{in} = \frac{M_{out}}{i_G \cdot \eta_G}$$

- torque for acceleration

$$M_{in,\alpha} = \left(J_{in} + J_1 + \frac{J_{out} + J_2}{i_G^2 \cdot \eta_G} \right) \cdot \frac{\pi}{30} \frac{\Delta n_{in}}{\Delta t_\alpha}$$

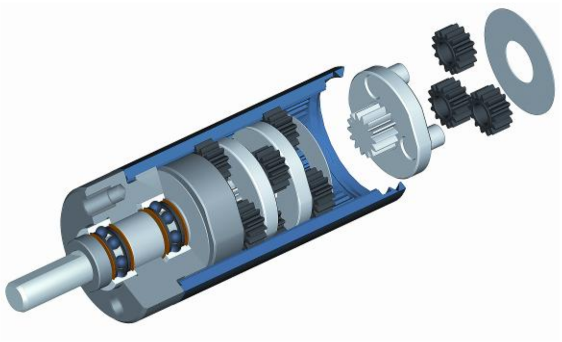


maxon gears

- for operation at high torques and low speeds
- 2 standard versions:

GS: spur gearheads

lower power transfer



GP: planetary gearheads

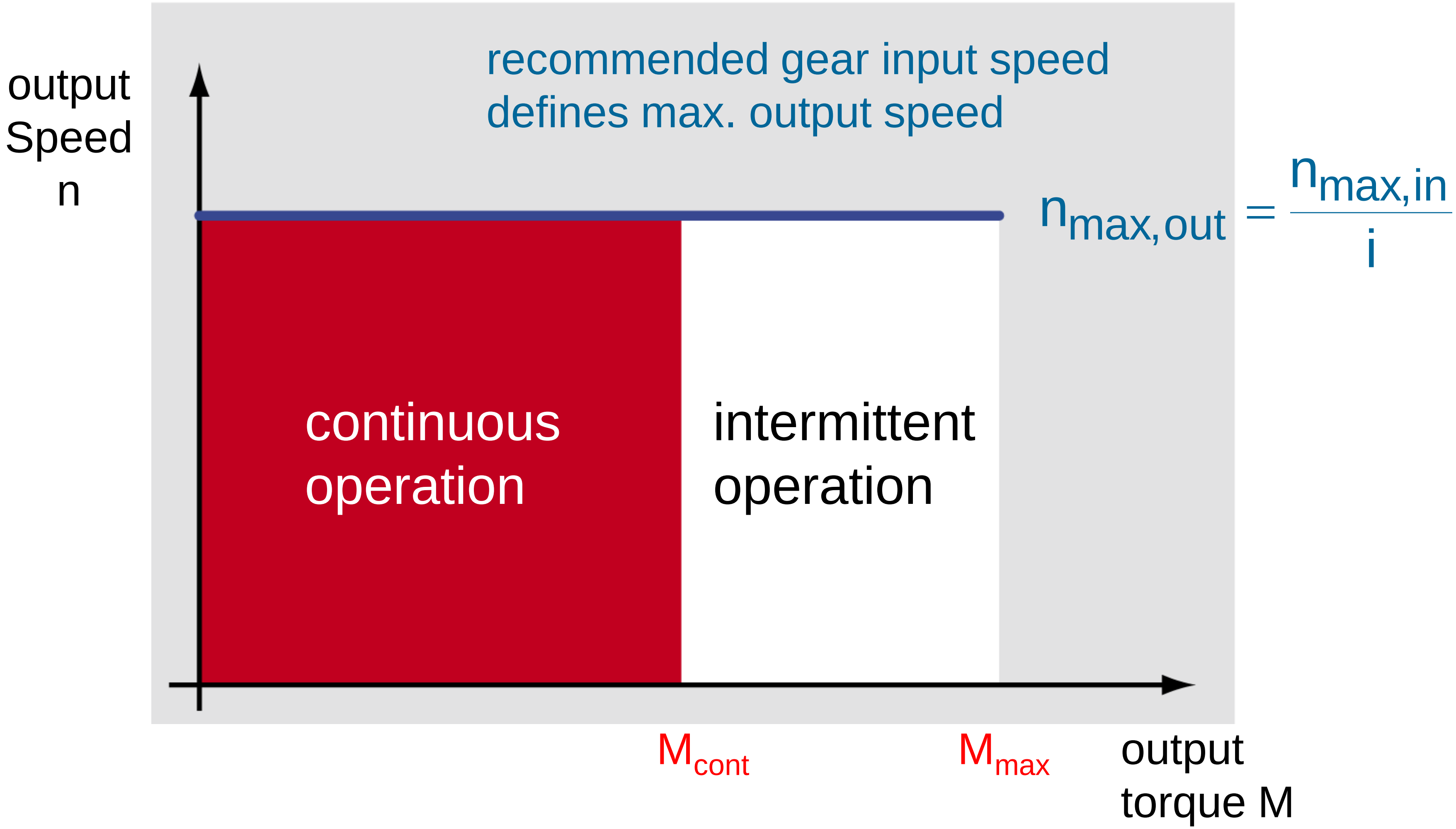
higher power transfer

- material options
  - plastic: lower power, lower cost
  - ceramic: higher power, higher service life
- Bearing options
  - Ball bearing: for bigger planetary gearheads
  - Sleeve bearing: for GS and smaller GP

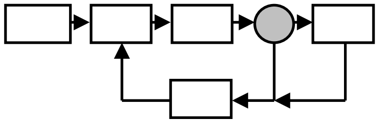
Most important gearhead data

- reduction, absolute reduction
- efficiency
  - as a function of torque
- gearhead limits
  - max. continuous torque (output)
  - intermittent torque (short-term = 1s)
  - max. input speed
  - temperature (lubrication)
- backlash
- load on bearings

Operating range diagram

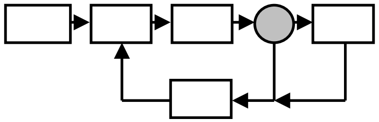


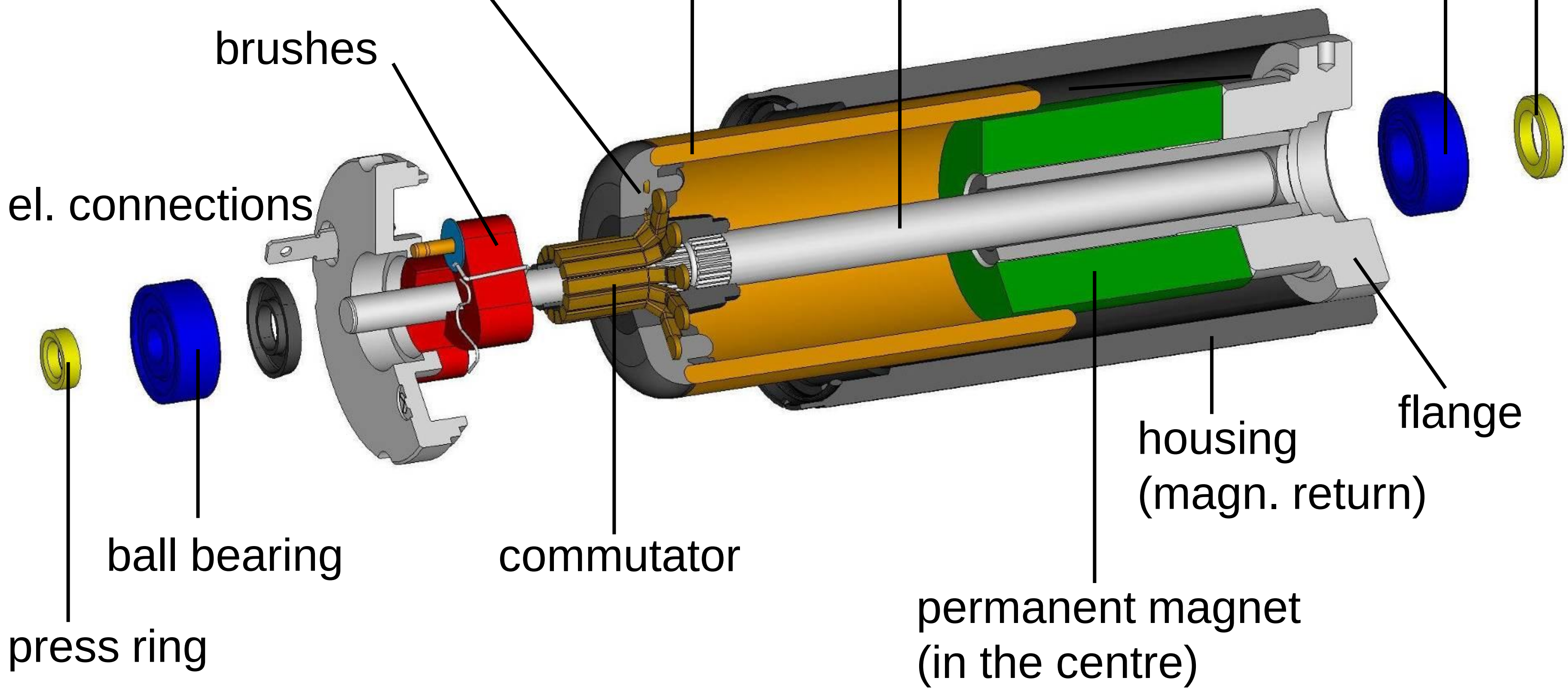
Part 3: Motors: goal and purpose



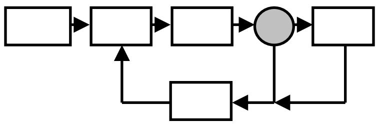
- What is the difference between coreless and conventional DC motors?
- Where can the basic differences between DC, EC and stepper motors be found?
- When are Graphite or precious metal brushes used?
- What means electronic commutation? And what kind are existing?
- What do the different motor data mean? How big are their tolerances?

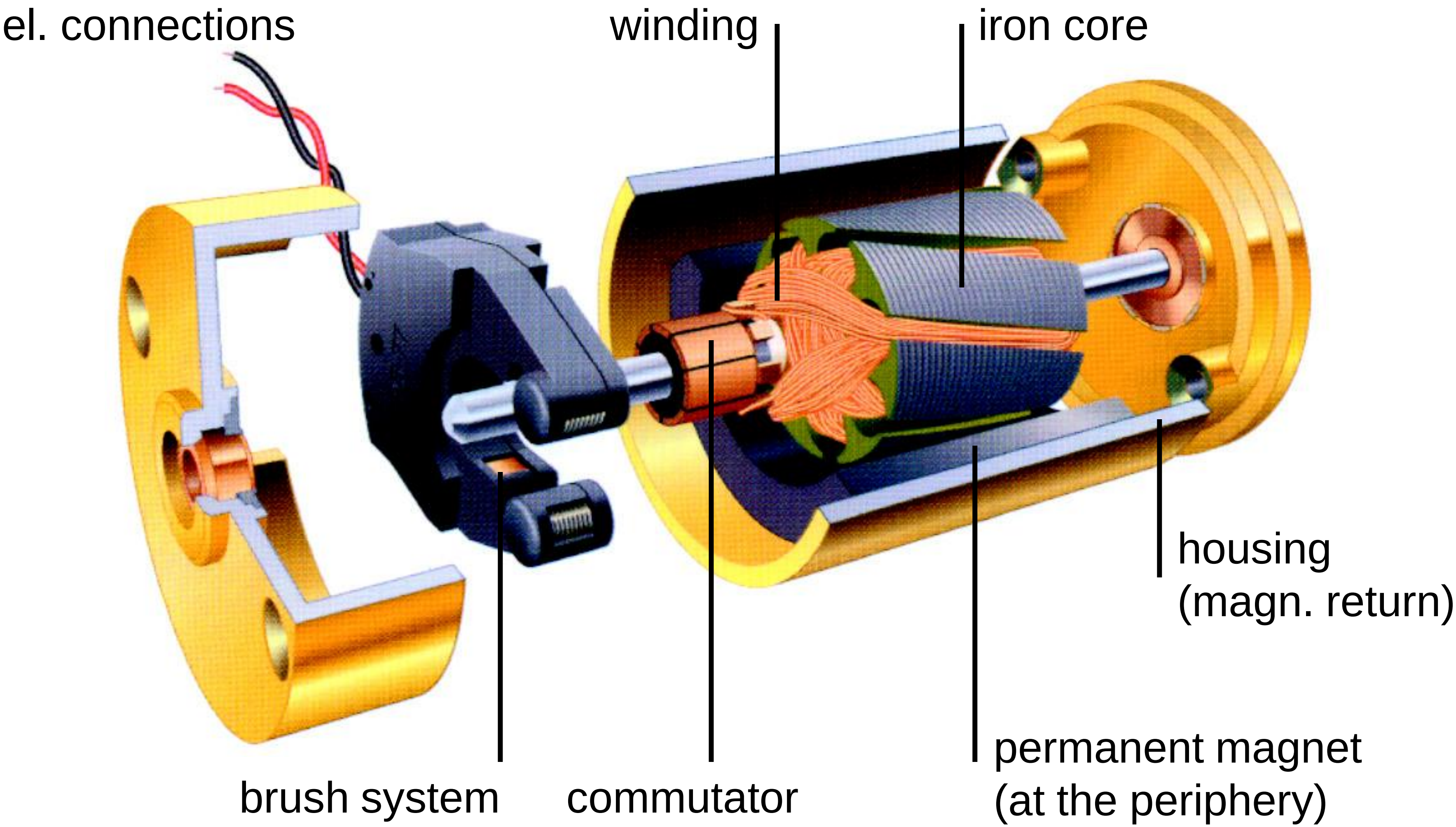
Coreless maxon DC motor (RE 35)





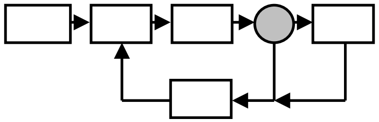
Conventional DC motor



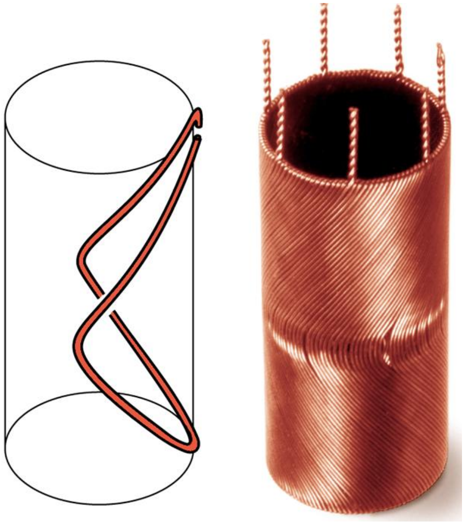


19, © by maxon motor ag 2008, BRJ

DC: advantage coreless 1/2

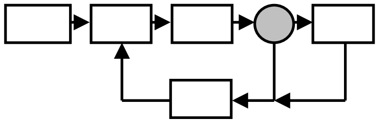


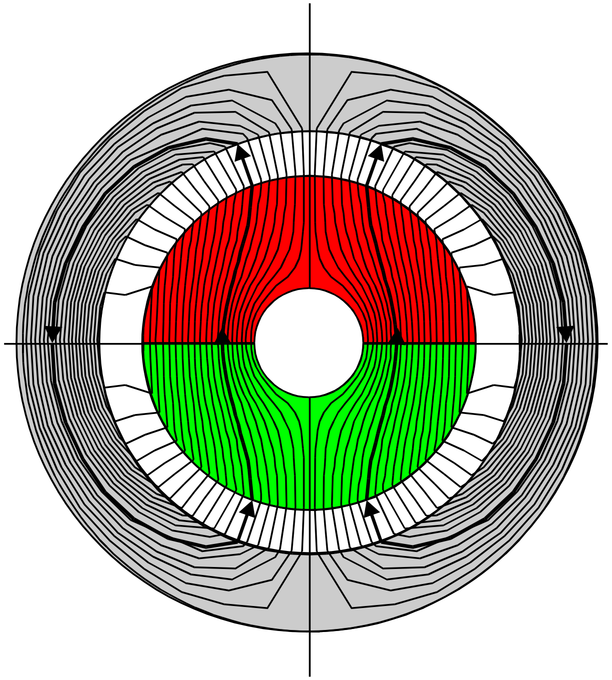
- no cogging:
  - smooth running even at small speeds
  - less vibration and noise
  - any rotor position can be controlled in a simple way
  - no nonlinear control behaviour



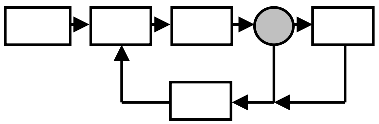
- small inductance
  - less brush fire
    - higher life expectancy
    - less electromagnetic emissions
  - but fast reaction of the current
    - problems in combination with pulsed supply (choke needed)

DC: advantage coreless 2/2





- no iron – no iron losses
  - constant magnetization
  - high efficiency, up to above 90%
  - low no load current, typical < 50 mA
- compact design
  - higher ratio of power to volume
- small rotor mass inertia
  - high dynamics; typical acceleration times: 5 – 50 ms



maxon DC motor families

- RE Program
  - Optimised in terms of power
  - High-quality DC motor with NdFeB magnet
  - High speeds and torques

Ø 6 - 75mm

- A-max Program
  - good price performance ratio
  - DC motor with AlNiCo magnet

Ø 12 - 32mm

- RE-max Program
  - Performance between RE and A-max

Ø 13 - 29mm

- F, A Program
  - motors of older design

DC commutation systems

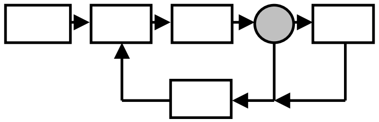
Graphite

- Ideal for higher currents
- copper reduces contact and brush resistance
- graphite acts as lubricant
- Spring preloaded

precious metal

- Ideal for smallest currents and voltages
- small contact and brush resistance (50mΩ)
- Special lubrication
- CLL for extended service life

DC commutation: pros and cons



graphite

- well suited for high currents and current peaks
- well suited for start-stop and reversed operation
- bigger motors (from ca. 10W)

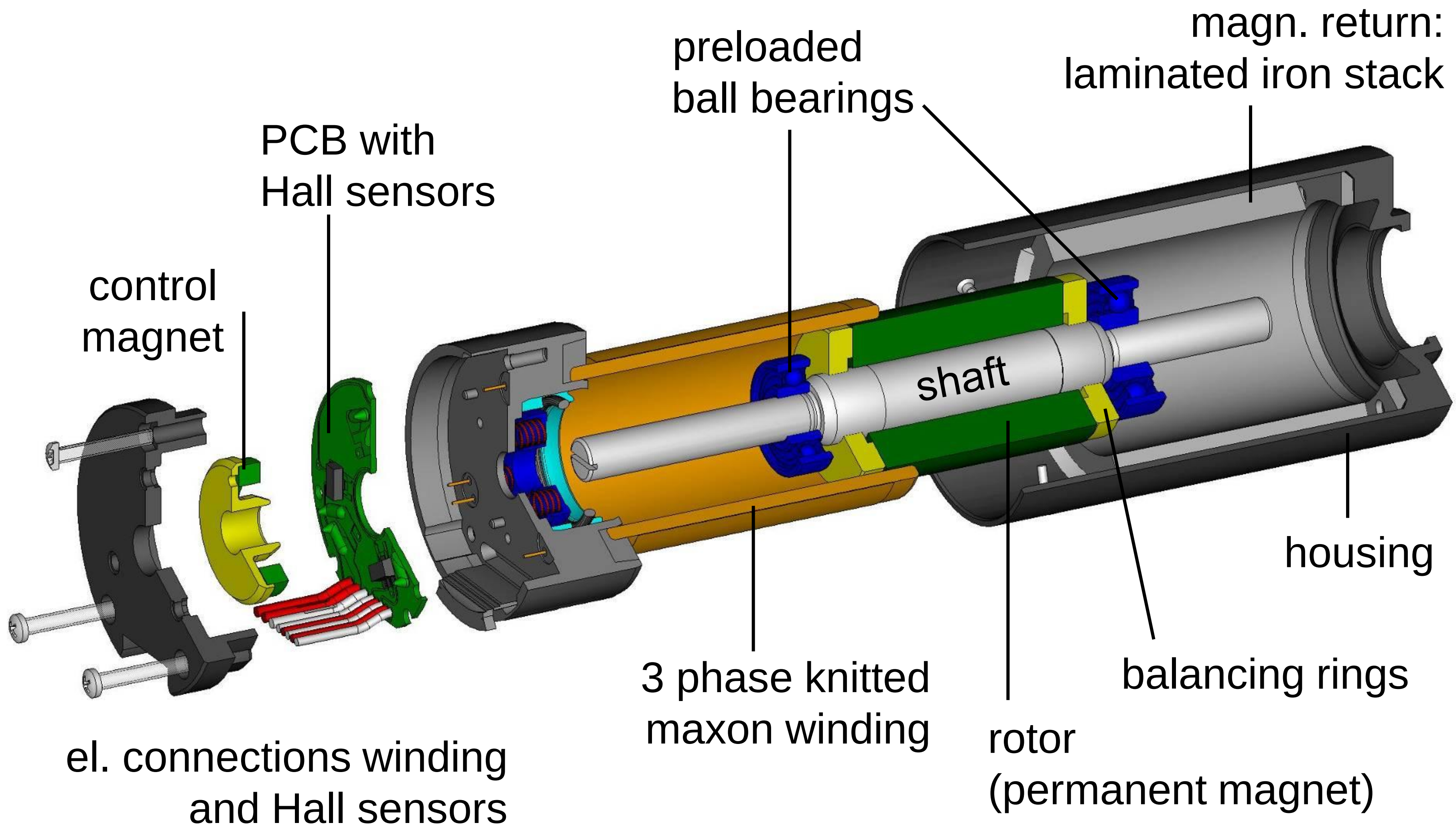
- higher friction, higher no-load currents
- not well suited for small currents
- more audible noise and electromagnetic emission
- Higher cost price

precious metal

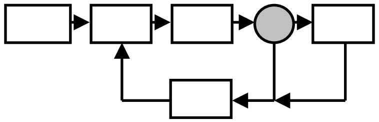
- well suited for smallest currents and voltages
- well suited for continuous operation
- smaller motors
- very low friction and noise
- low electromagnetic emission
- favourable price

- not well suited for high currents and current peaks
- not well suited for start-stop operation

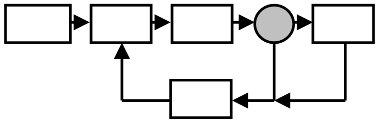
EC motor / brushless DC motor



Properties of EC motors



- 3 phases winding in the stator
  - slotless maxon winding: no magnetic detent, low vibrations
  - Flat motors with slotted winding
- Rotating permanent magnet of NdFeB (sometimes SmCo)
- Preloaded ball bearings
- motor behavior similar to DC motor thanks to electronic commutation
- names: EC motor, BLDC motor



maxon EC motor families

- maxon EC motor
  - High speeds and torques

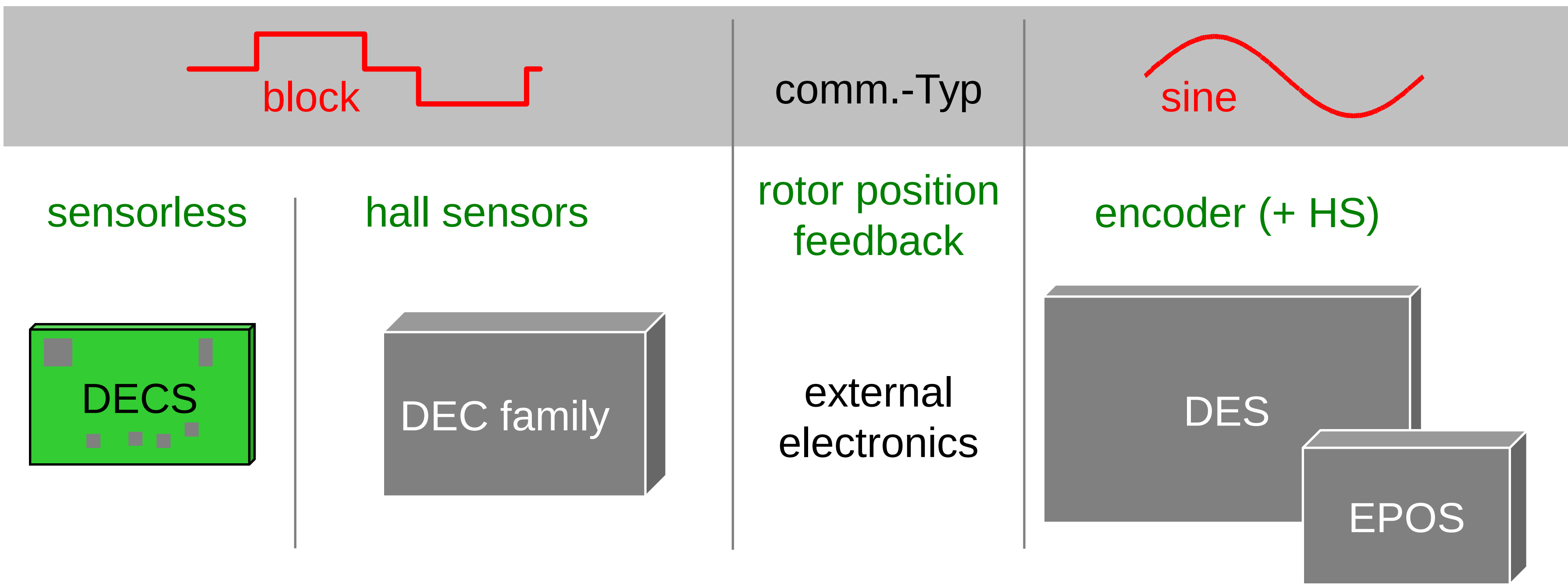
- EC-max
  - good price performance ratio
  - not power optimised: relatively high torque
  - Speeds up to ca. 12‘000 min^{-1}

- EC-powermax
  - power optimised: high torque
  - Speeds up to ca. 25‘000 min^{-1}

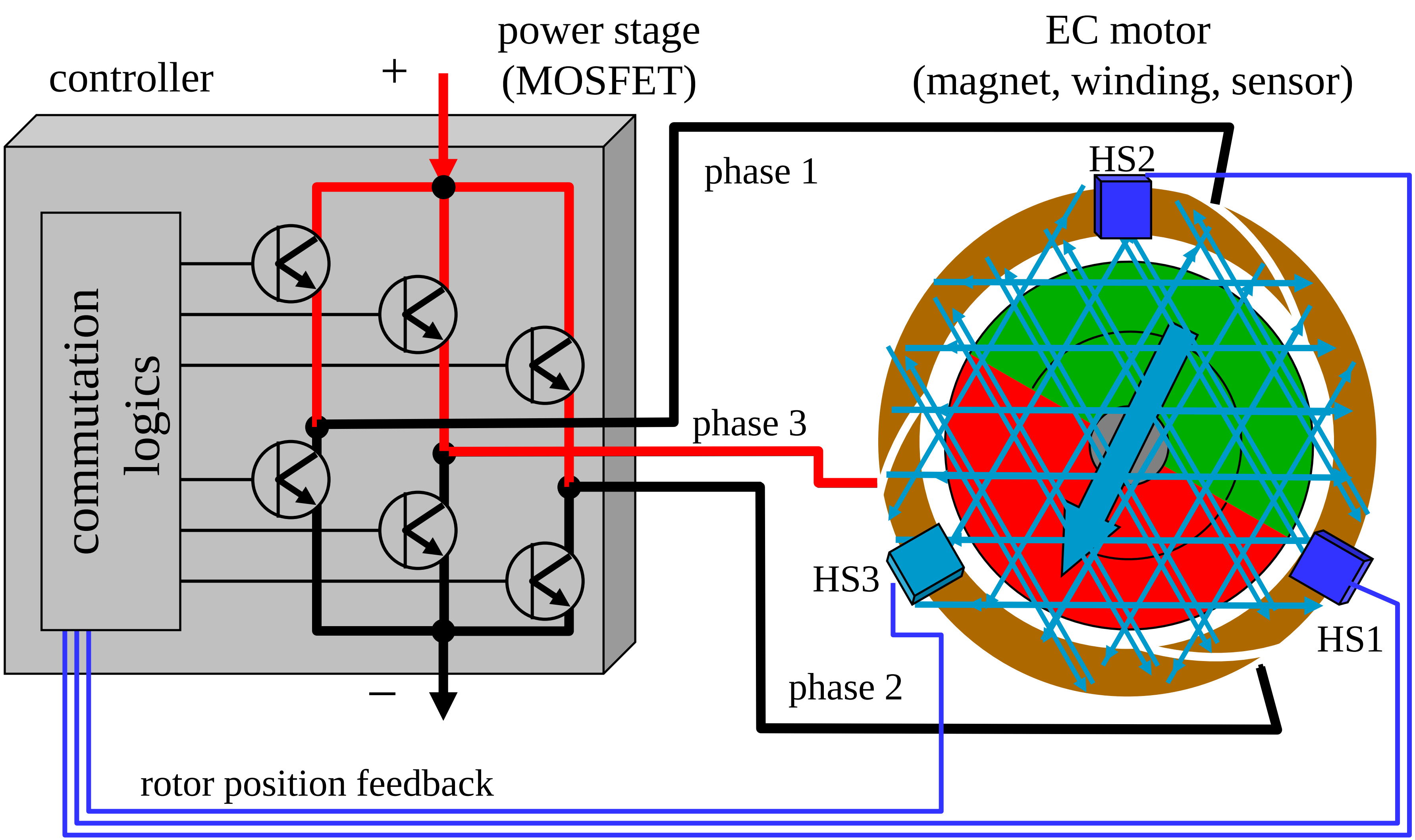
- EC flat motor
  - good price performance ratio
  - Speeds up to ca. 12‘000 min^{-1}
  - relatively high torque

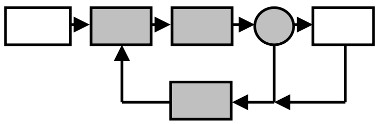
Electronic commutations systems

- 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



EC: Example Block commutation





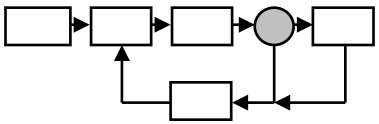
DC and EC motor: comparison

DC motor

- simple operation and control, also possible without electronics
- No electronic parts in the motor
- life expectancy limited due to the commutation
- Speeds restricted due to the commutation

EC motor

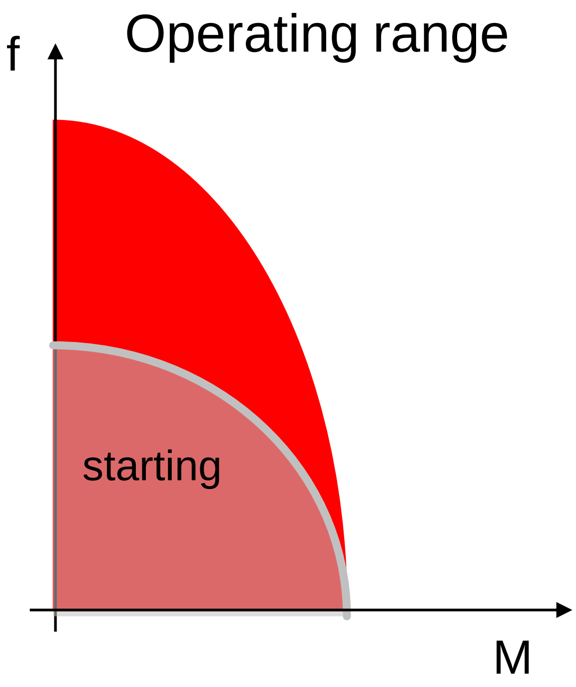
- Highlife expectancy, high speeds
  - Preloaded ball bearings
- No arc production
- Iron losses in the magnetic return
- Need of electronics for operation
  - more cables
  - higher price
- Electronic parts in the motor (hall sensors)



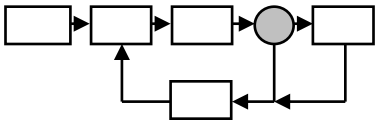
Stepper motors

3 main types:

- Permanent magnet (P.M.) motors
  - cheap
  - rather big steps
- Variable reluctance (V.R.) motors
  - limited torque
- Hybrid motors

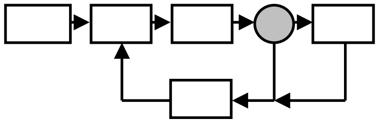


Stepper motor: properties



- Robust, simple design
- a "digital" motor for positioning
  - Rotation angle proportional to input pulses
  - Step failures: 3-5% of one step, not cumulated
  - high stall torques
- Open loop control
  - no sensor needed for feedback, low price
- Rough operation (radial run-out) at low speeds
  - noise, especially at high speeds; vibrations
  - Resonance effects and transient oscillation
- Current consumption independent of the load
  - Torque dimensioned in reference to the peak load (load inertia)
  - Danger of overheating, high losses at high speeds

Stepper motor possible, if…



- fulfils speed and torque requirement
- no continuous speed higher than 2000 rpm required
- no constant speed at small speed requested
- no torque control required
- no fast change in torque required
- not necessary to reach the final position very fast
- no positioning control required
- the application is not noise sensitive

Motor Data

			214895	214896	214897	214898	214899	215982	215983	215985	215986	215987
	Values at nominal voltage											
1	Nominal voltage	V	3.0	4.5	12.0	15.0	21.0	24.0	24.0	30.0	36.0	48.0
2	No load speed	rpm	12200	10500	11500	11600	12200	12000	10600	11100	11800	10400
3	No load current	mA	32.6	16.9	7.38	6.02	4.66	3.94	3.26	2.79	2.57	1.56
4	Nominal speed	rpm	11300	8380	8760	8870	9440	9210	7870	8300	8960	7450
5	Nominal torque (max. continuous torque)	mNm	1.33	2.39	3.41	3.38	3.36	3.38	3.37	3.34	3.28	3.22
6	Nominal current (max. continuous current)	A	0.600	0.600	0.350	0.281	0.209	0.180	0.160	0.132	0.115	0.0745
7	Stall torque	mNm	17.1	12.1	14.4	14.3	14.9	14.7	12.9	13.3	13.7	11.5
8	Starting current	A	7.32	2.95	1.45	1.17	0.910	0.772	0.604	0.518	0.473	0.262
9	Max. efficiency	%	87	86	86	86	86	86	86	86	86	85
	Characteristics											
10	Terminal resistance	Ω	0.410	1.52	8.30	12.8	23.1	31.1	39.7	57.9	76.2	183
11	Terminal inductance	mH	0.0114	0.0349	0.206	0.314	0.558	0.759	0.956	1.38	1.75	4.04
12	Torque constant	mNm / A	2.34	4.09	9.92	12.3	16.3	19.1	21.4	25.7	29.0	44.0
13	Speed constant	rpm / V	4090	2340	962	779	584	501	446	372	329	217
14	Speed / torque gradient	rpm / mNm	718	871	804	815	825	817	828	839	865	906
15	Mechanical time constant	ms	7.93	7.44	7.27	7.29	7.30	7.31	7.35	7.32	7.35	7.47
16	Rotor inertia	gcm^2	1.05	0.816	0.864	0.854	0.844	0.854	0.848	0.834	0.811	0.788

Specifications

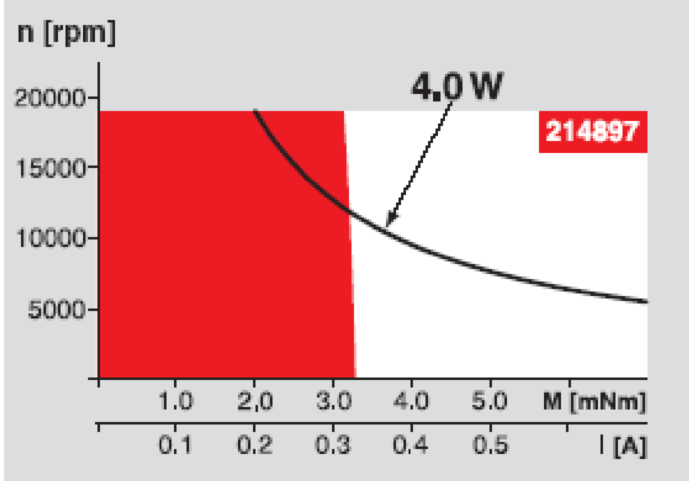
Thermal data

17	Thermal resistance housing-ambient	35 K / W
18	Thermal resistance winding-housing	12 K / W
19	Thermal time constant winding	7.7 s
20	Thermal time constant motor	455 s
21	Ambient temperature	-30 ... +65°C
22	Max. permissible winding temperature	+85°C

Mechanical data (sleeve bearings)

23	Max. permissible speed	19000 rpm
24	Axial play	0.05 - 0.15 mm
25	Radial play	0.012 mm
26	Max. axial load (dynamic)	0.8 N
27	Max. force for press fits (static)	35 N
28	Max. radial loading, 5 mm from flange	1.4 N

Operating Range



Comments

Continuous operation
In observation of above liste
(lines 17 and 18) the maximu
temperature will be reache
operation at 25°C ambient.
= Thermal limit.

Short term operation
The motor may be briefly overl

Assigned power rating