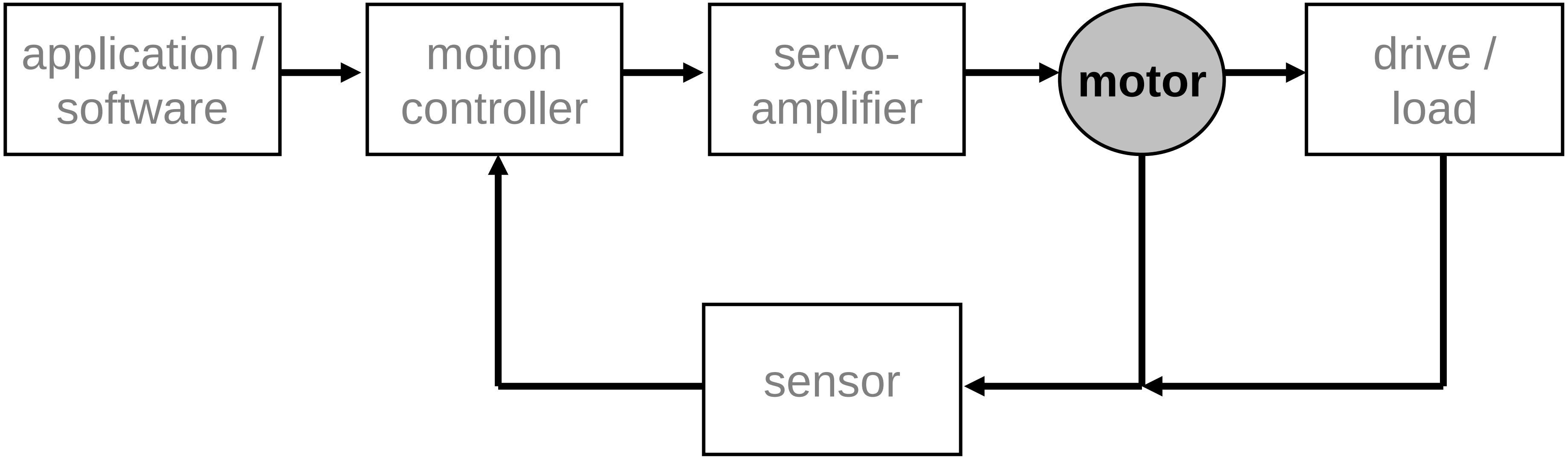
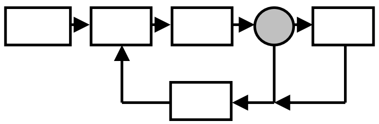
Motor data of DC motors

Jan Braun/ Gerard Scholten /
Gerrit Stoels

maxon motor

Motor data


application / software
motion controller
servo-amplifier
motor
drive / load
sensor

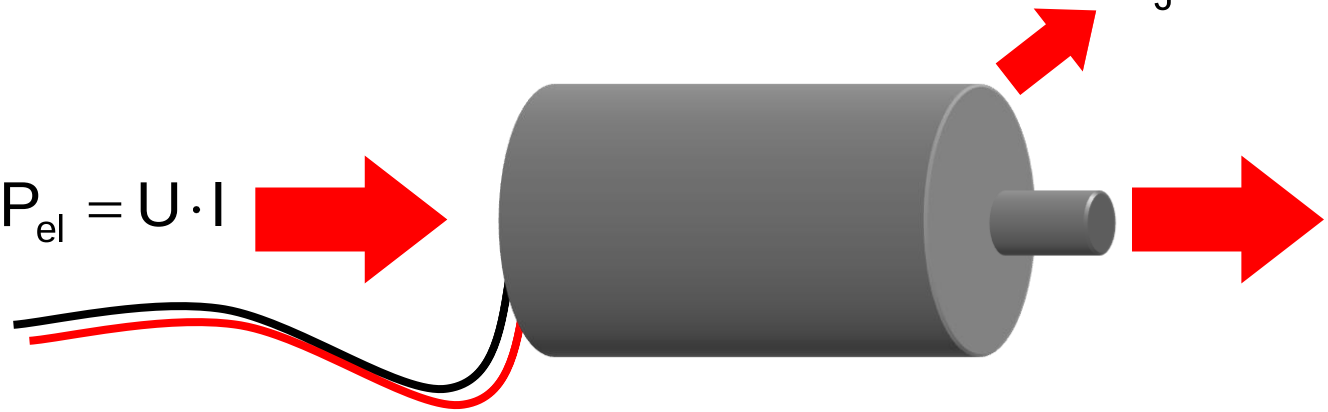


Agenda

- Motor behaviour / characteristics
- Operating ranges
- Motor data in the catalogue
- Applies to DC and EC motors
  - "EC" = "brushless DC" (BLDC)

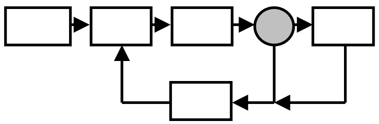
$$P_J = R \cdot I^2$$

$$P_{el} = U \cdot I$$



$$P_{mech} = \frac{\pi}{30} n \cdot M$$

Electromechanical constants



- Torque constant k_M
  – produced torque is proportional to motor current
  – unit: mNm / A

$$M = k_M \cdot I$$

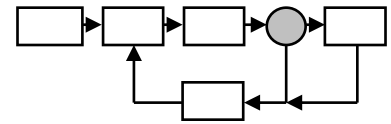
- Speed constant k_n
  – law of induction: changing flux in a conductor loop
  – induced voltage proportional to speed
  – mostly used for calculating no-load speeds n_0
  – unit: min^{-1} / V

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

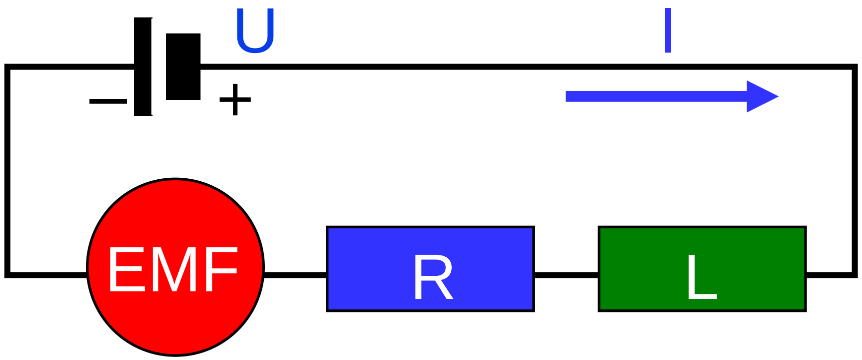
$$n_0 = k_n \cdot U$$

- Relationship
  – k_M and k_n are reciprocal values
  – in catalogue units:

$$k_M \cdot k_n = \frac{30'000}{\pi} \frac{mNm}{A} \frac{min^{-1}}{V}$$



Motor as an electrical circuit



applied motor voltage U:

$$U = L \cdot \frac{\partial I}{\partial t} + R \cdot I + EMF \cong R \cdot I + U_{ind}$$

$$U_{ind} = U - R \cdot I$$

$$\frac{n}{k_n} = U - R \cdot \frac{M}{k_M}$$

$$n = k_n \cdot U - \left(\frac{30'000}{\pi} \cdot \frac{R}{k_M^2} \right) \cdot M$$

$$n = k_n \cdot U - \frac{\Delta n}{\Delta M} \cdot M$$

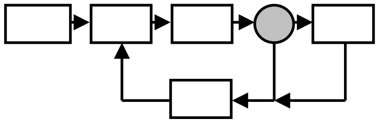
EMF: induced voltage U_{ind}

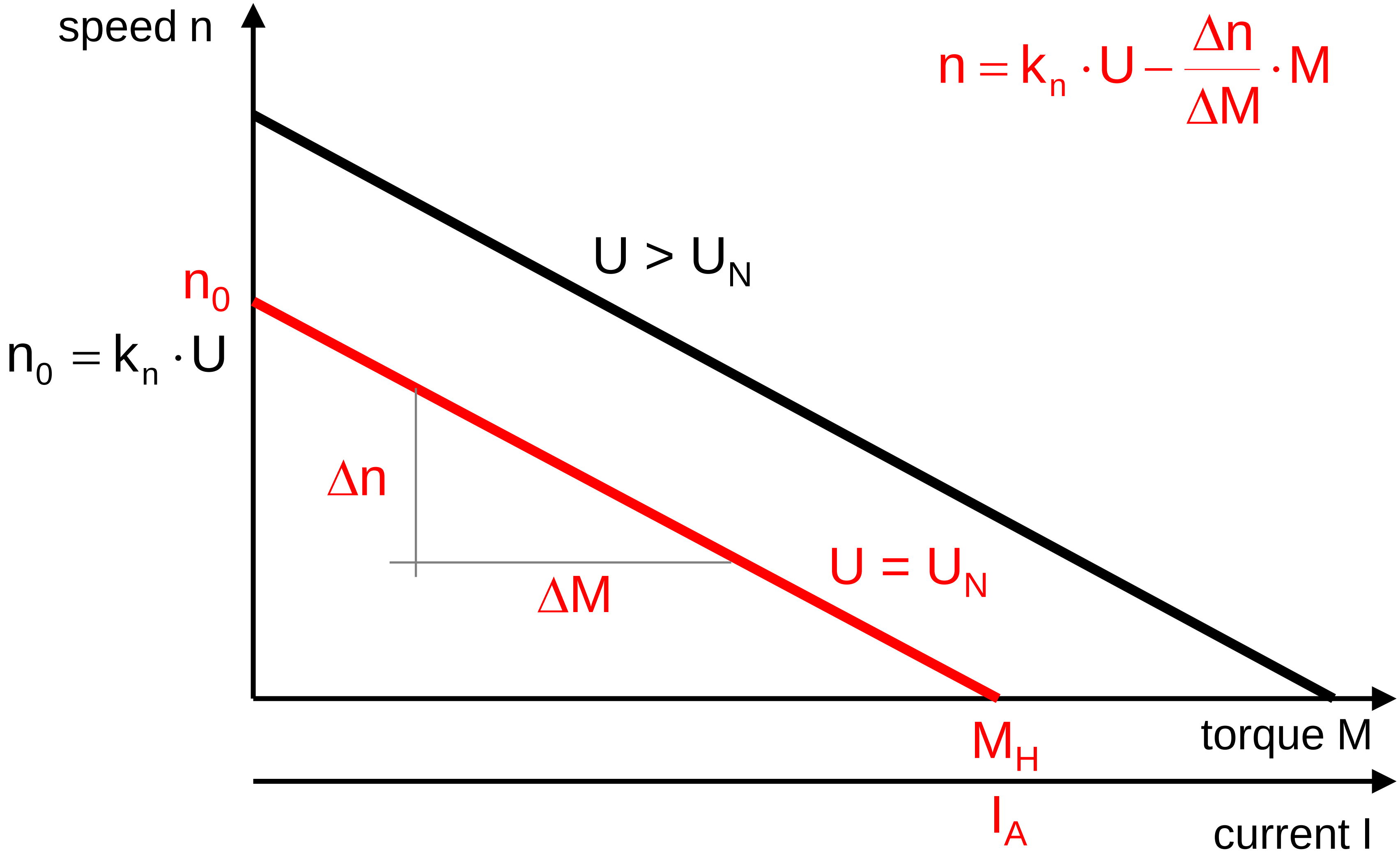
(winding) resistance R

winding inductance L

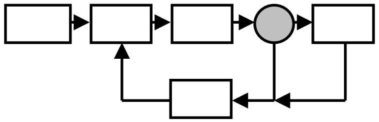
- voltage losses over L can be neglected in DC motors

Speed-torque line





maxon motor data sheet



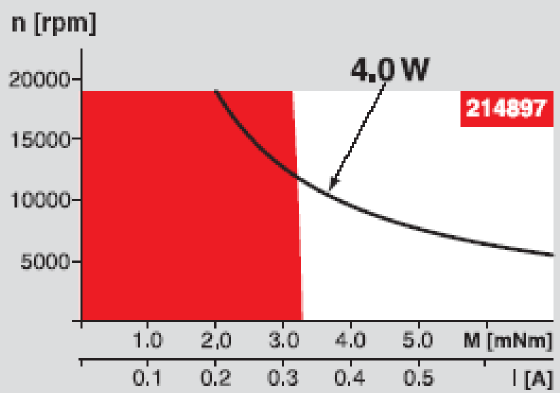
			214895	214896	214897	214898	214899	215982	215983	215985	215986	215987
Motor Data												
	Values at nominal voltage											
1	Nominal voltage	V	3.0	4.5	12.0	15.0	21.0	24.0	24.0	30.0	36.0	48.0
2	No load speed	rpm	12200	10500	11500	11600	12200	12000	10600	11100	11800	10400
3	No load current	mA	32.6	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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25.7	29.0	44.0
13	Speed constant	rpm /	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	372	329	217
14	Speed / torque gradient	rpm / mNm	718	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	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

Characteristics

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



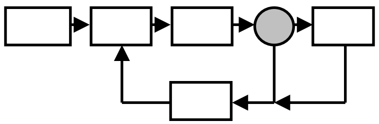
Comments

Continuous operation
In observation of above listed thermal resistance (lines 17 and 18) the maximum permissible winding temperature will be reached during continuous operation at 25°C ambient.
= Thermal limit.

Short term operation
The motor may be briefly overloaded (recurring).

Assigned power rating

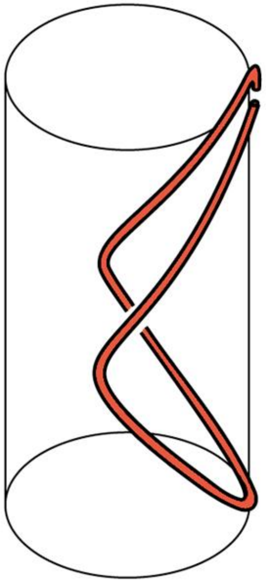
Winding resistance



resistance increases from left to right

low resistance winding ⟷ high resistance winding

- thick wire, few turns
- low rated voltage
- high rated and starting currents
- high specific speed (min^{-1}/ V)
- low specific torque (mNm/A)



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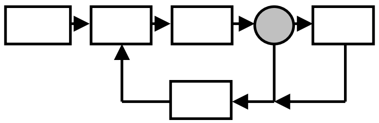
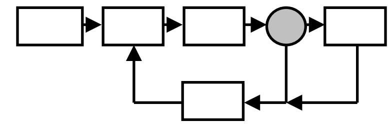
Characteristic motor data



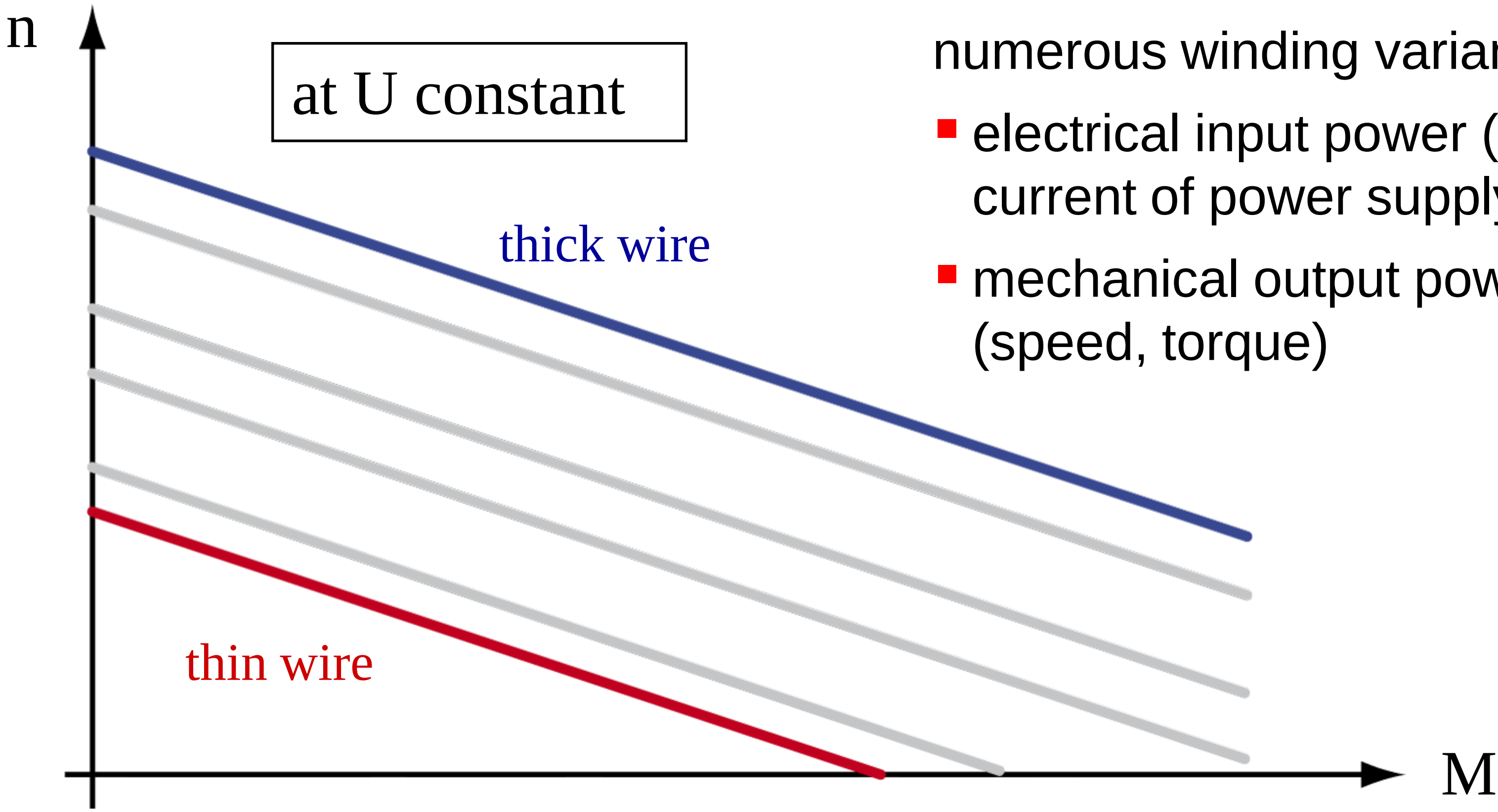
describe the motor design and general behaviour

- independent of actual voltage or current

- strongly winding dependent values (electromechanical)
  - terminal resistance (phase to phase) R
  - terminal inductance (phase to phase) L
  - torque constant k_M
  - speed constant k_n
- almost independent of winding (mechanical)
  - speed-torque gradient $\Delta n/\Delta M$
  - mechanical time constant τ_m
  - rotor mass inertia J_{Mot}



Winding series



numerous winding variants adjust

- electrical input power (voltage, current of power supply)
- mechanical output power (speed, torque)

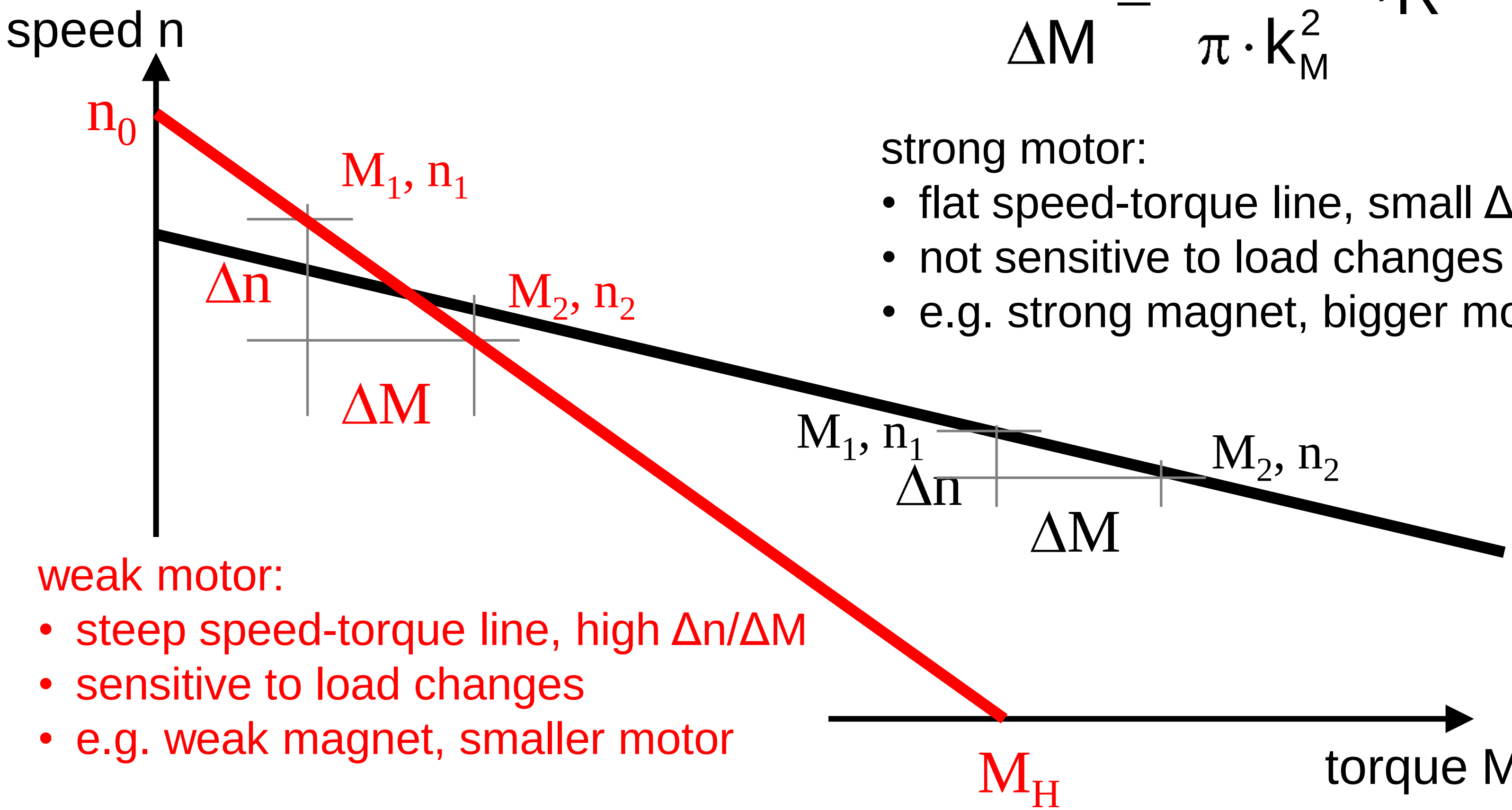
speed-torque gradient

- basically constant for the winding series
- constant filling factor: a constant amount of copper fills the air gap

Speed-torque gradient

by how much is the speed reduced Δn, if the output motor torque is enhanced by ΔM?

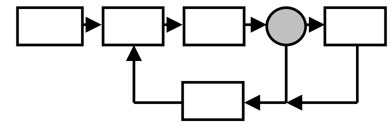
$$\frac{\Delta n}{\Delta M} = \frac{30'000}{\pi \cdot k_M^2} \cdot R$$



strong motor:
- flat speed-torque line, small $\Delta n/\Delta M$
- not sensitive to load changes
- e.g. strong magnet, bigger motor

weak motor:
- steep speed-torque line, high $\Delta n/\Delta M$
- sensitive to load changes
- e.g. weak magnet, smaller motor

maxon motor data sheet



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5	Nominal torque (max. continuous torque)	mNm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	Nominal current (max. continuous current)	A	0.600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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Values at nominal voltage

Characteristics

Specifications

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Mechanical data (sleeve bearings)

23	Max. permissible speed	19000 rpm
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25	Radial play	0.012 m[illegible]
26	Max. axial load (dynamic)	0.8 N
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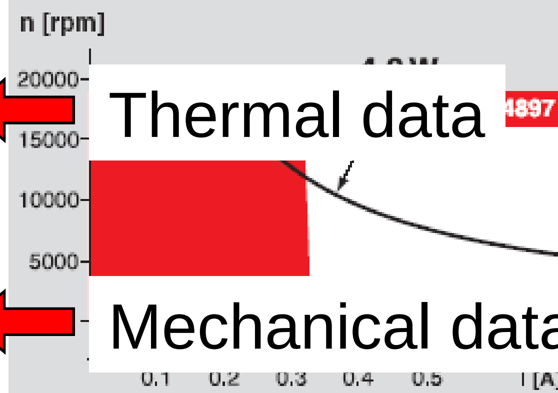
28	Max. radial loading, 5 mm from flange	1.4 N

Thermal data

Mechanical data (bearing)

Operating Range



Comments

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= Thermal limit.

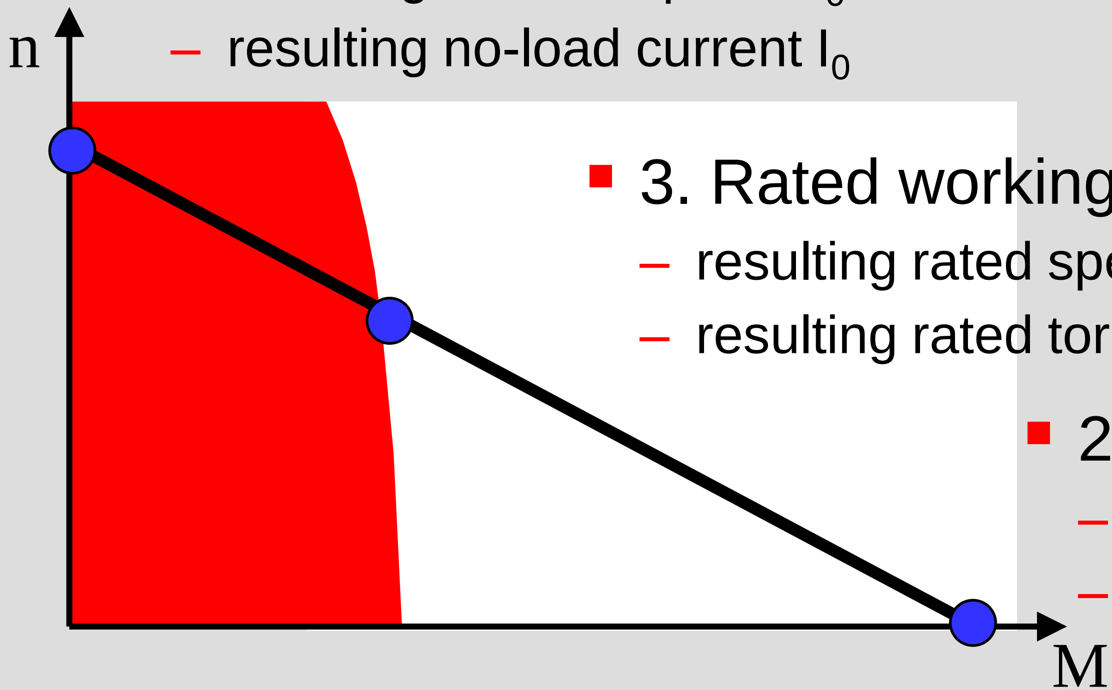
Short term operation
The motor may be briefly overloaded (recurring).

[illegible]ver rating

Values at nominal voltage

describe the special working points:

- at rated voltage U_N
- at rated current I_N

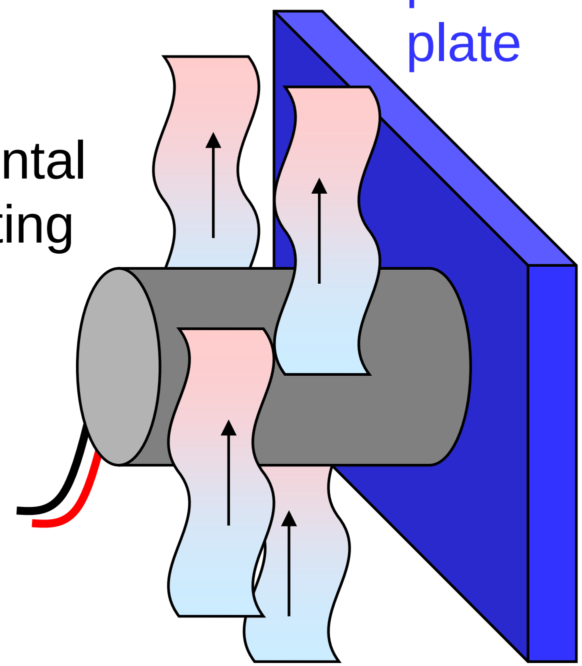


- 1. No-load operating point
  – resulting no-load speed n_0
  – resulting no-load current I_0
- 3. Rated working point
  – resulting rated speed n_N
  – resulting rated torque M_N
- 2. Motor at stall
  – resulting stall torque M_H
  – resulting starting current I_A

Thermal motor data

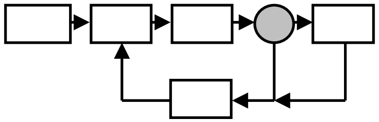
describe the motor heating and thermal limits

- depend strongly on mounting conditions
- standard mounting:

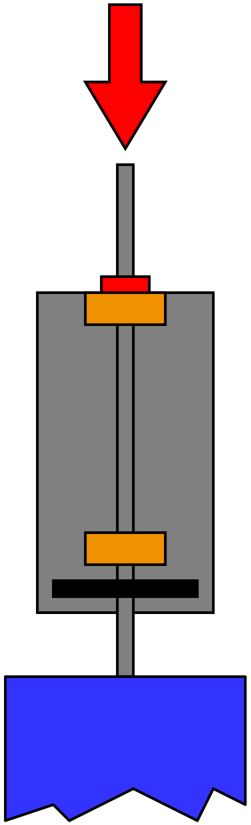


- heating and cooling
  - thermal resistance housing-ambient R_{th2}
  - thermal resistance winding-housing R_{th1}
  - thermal time constant of winding t_{thW}
  - thermal time constant of motor t_{thS}
- temperature limits
  - ambient temperature range
  - max. winding temperature T_{max}

Mechanical motor data



describe maximum speed and the properties of bearings

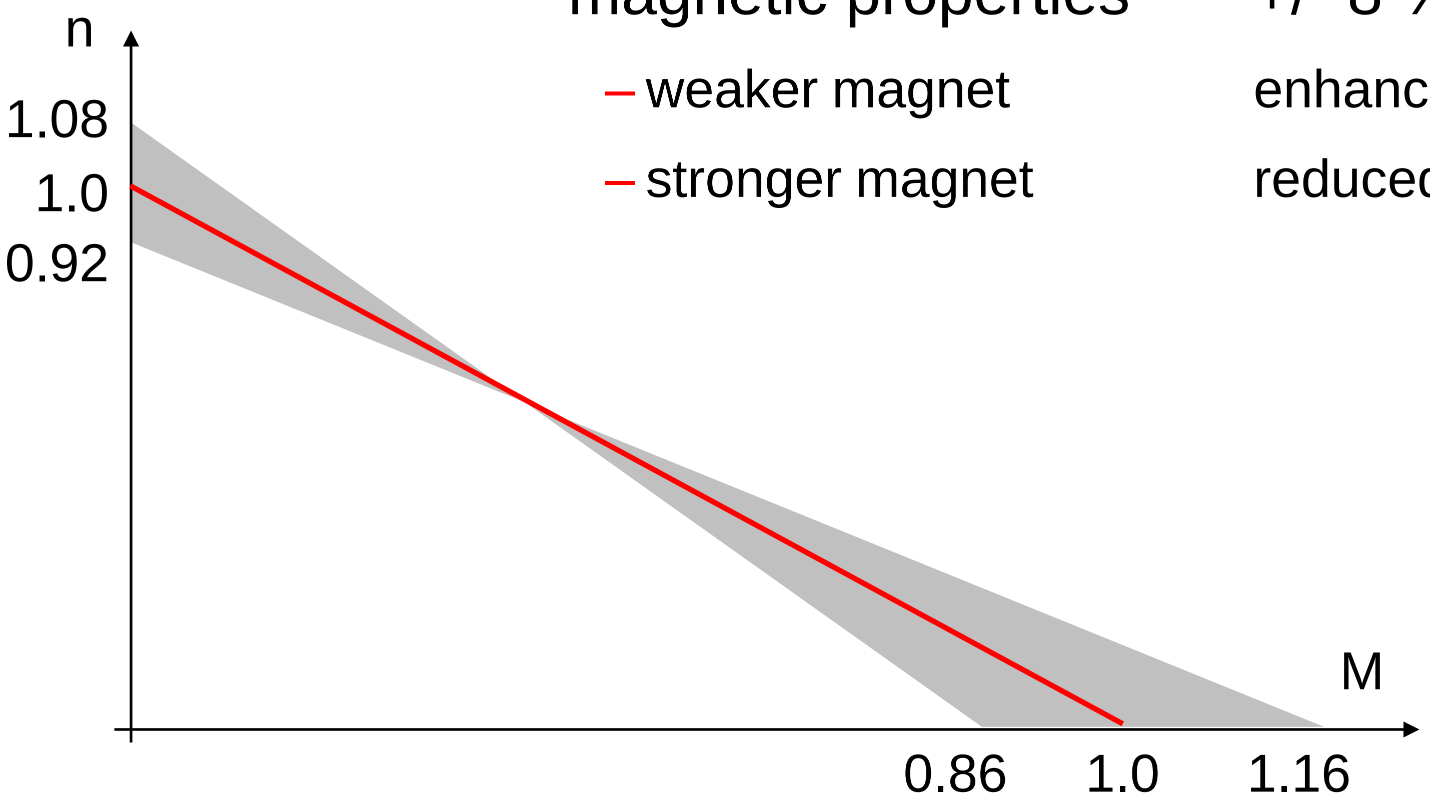


axial press fit force
(shaft supported)

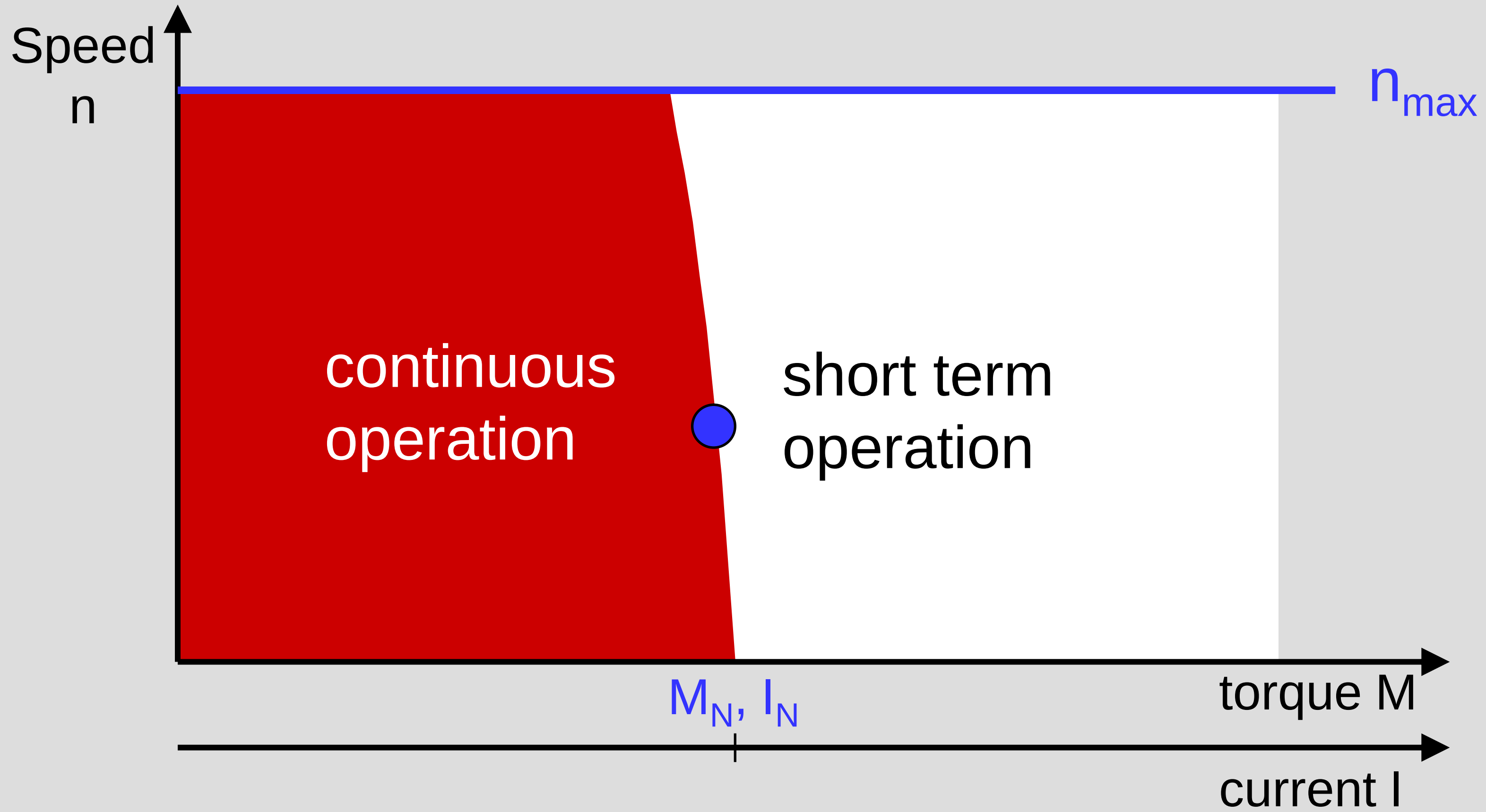
- max. permissible speed
  - limited by bearing (EC)
  - limited by relative speed between collector and brushes (DC)
- axial and radial play
  - suppressed by a preload
- axial and radial bearing load
  - dynamic: in operation
  - static: at stall

maxon standard tolerances

- winding resistance +/- 7 %
- magnetic properties +/- 8 %
  - weaker magnet enhanced n_0
  - stronger magnet reduced n_0



Motor limits: operation ranges



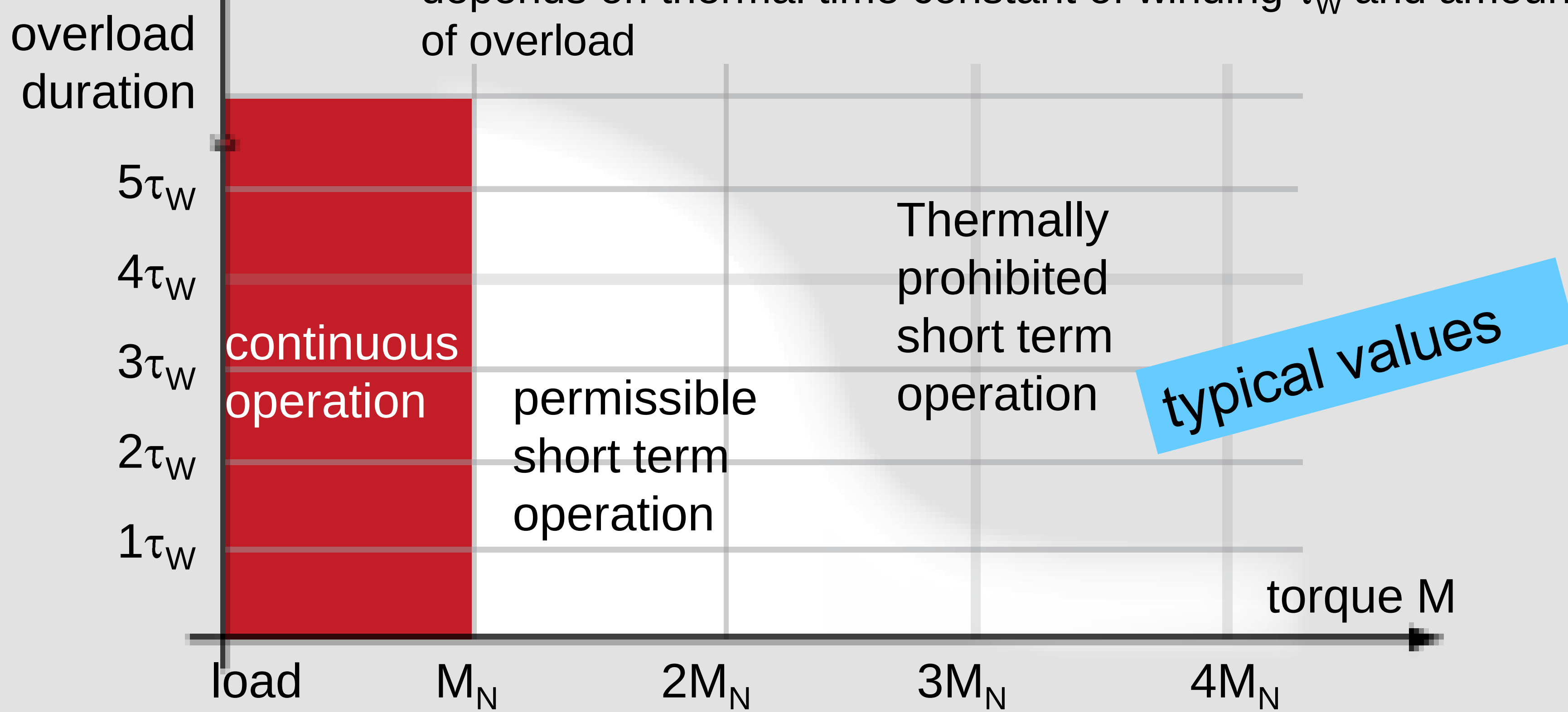
- higher ambient temperature
- heat accumulation

↔

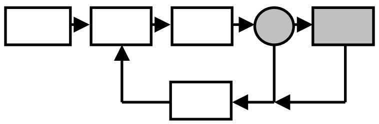
- lower ambient temperature
- good heat dissipation

Short-term operation overload

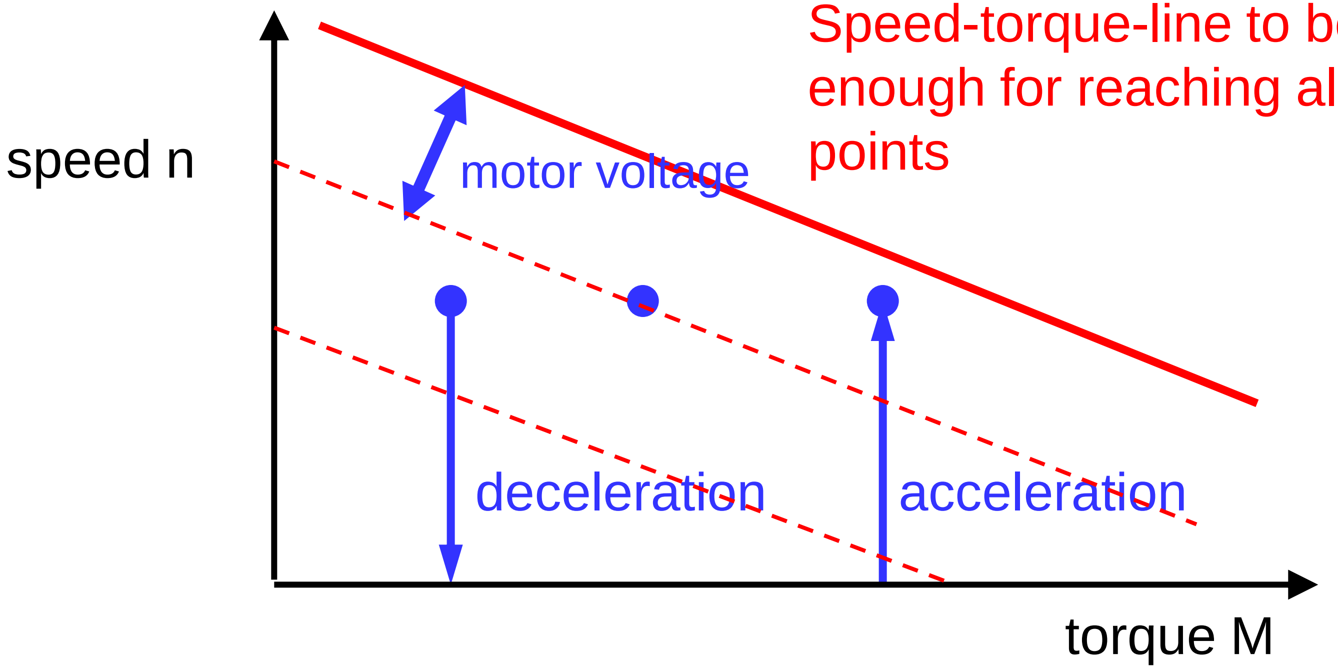
- motor may be overloaded for a short time and repeatedly
  - Limit: max. permissible winding temperature
  - depends on thermal time constant of winding τ_W and amount of overload

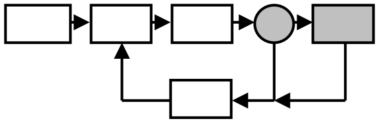


Working points



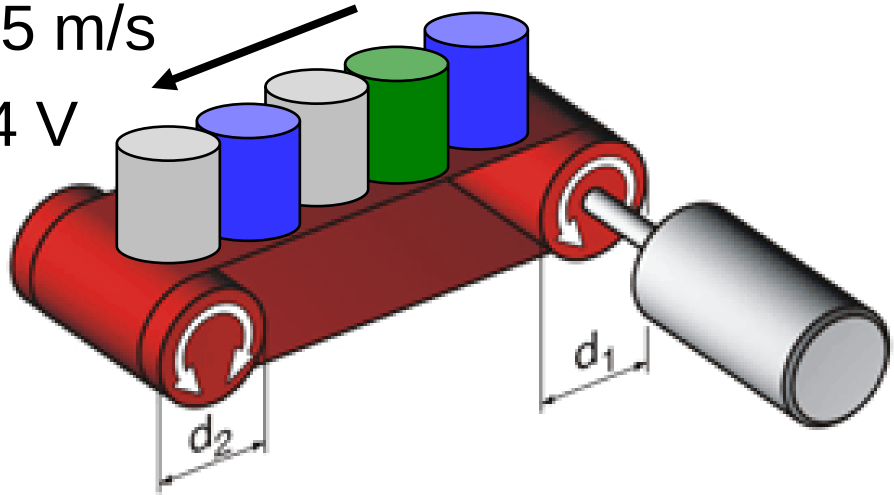
- working points are characterized by a load speed n_L at a given load torque M_L
- working points lie on the speed-torque-line: select the motor voltage accordingly





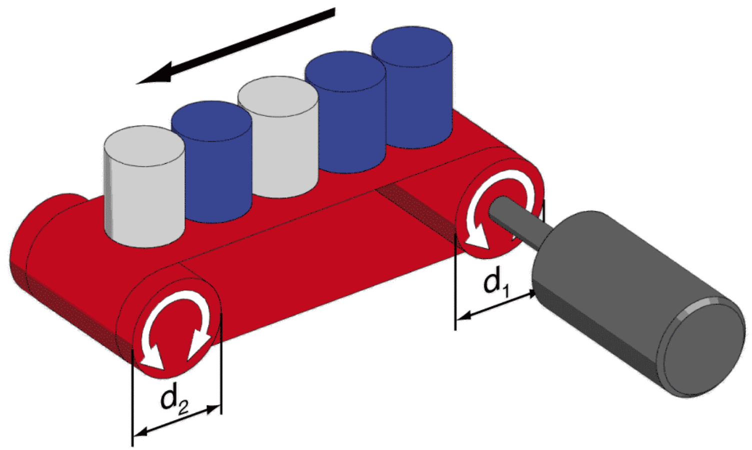
Example: situation analysis for Conveyor belt for samples

▪ pulley diameter	100 mm
▪ maximum mass on belt	3 kg
▪ coefficient of friction on support	ca. 0.3
▪ friction force (empty belt)	ca. 40 N
▪ feed velocity	0.5 m/s
▪ supply voltage	24 V



Example: Conveyor belt for samples

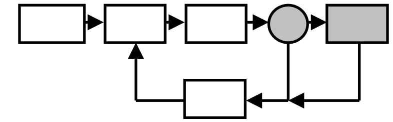
- Which information is missing?



- Acceleration
- Current
- Mass (pulley, belt)
- Maximum length / diameter
- Ambient conditions
- …….

pulley diameter	100 mm
maximum mass on belt	3 kg
coefficient of friction on support	ca. 0.3
friction force (empty belt)	ca. 40 N
feed velocity	0.5 m/s
supply voltage	24 V

Overview



Step 1 | Step 2 | Step 3 | Step 4

Direction of selection →

load + drive
$n_{L,} M_L$

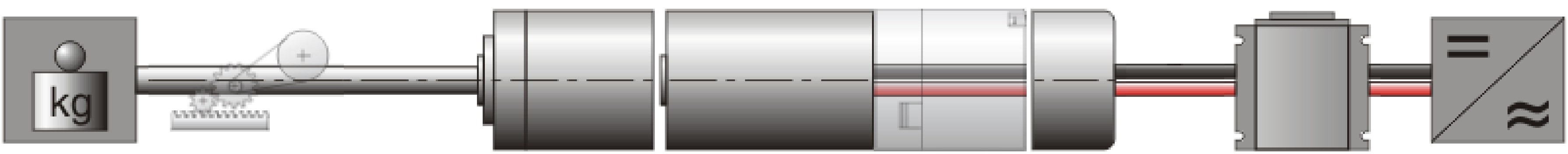
gearhead

motor type
$n_{mot,} M_{mot}$

winding
$k_{n,} k_M$

servo-controller
U_{mot}, I_{mot}

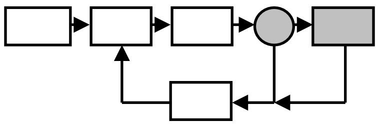
supply
U, I



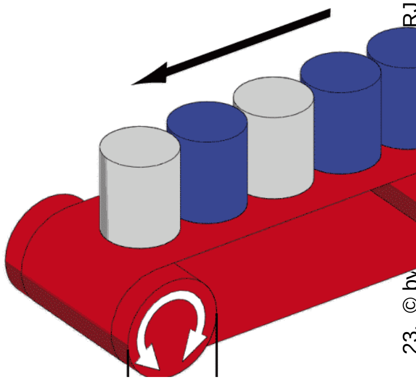
$$P_{mech} = \frac{\pi}{30} \cdot n \cdot M \quad \longleftarrow \quad P_{el} = U \cdot I$$

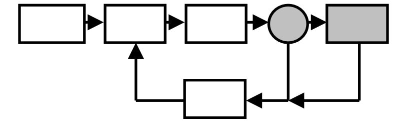
Power flow

Step 1: working points



- speed $$n_L = \frac{30}{\pi}\cdot\omega = \frac{30}{\pi}\cdot\frac{v_L}{\frac{d}{2}} = \frac{30}{\pi}\cdot\frac{0.5}{0.05} \approx 100\,\text{min}^{-1}$$
- feed force $$F_L = \mu\cdot m\cdot g + F_R = 0.3\cdot 3\cdot 10 + 40 = 9 + 40 \cong 50\text{N}$$
- torque $$M_L = \frac{d}{2}\cdot F_L = \frac{0.1}{2}\cdot 49 \cong 2.5\text{Nm}$$
- power $$P_L = v_L\cdot F_L = 0.5\cdot 49 \cong 25\text{W}$$
- acceleration $$F_{La} = m\cdot\frac{\Delta v_L}{\Delta t} = 3^{+}\cdot\frac{0.5}{1} = 1.5\text{N}$$

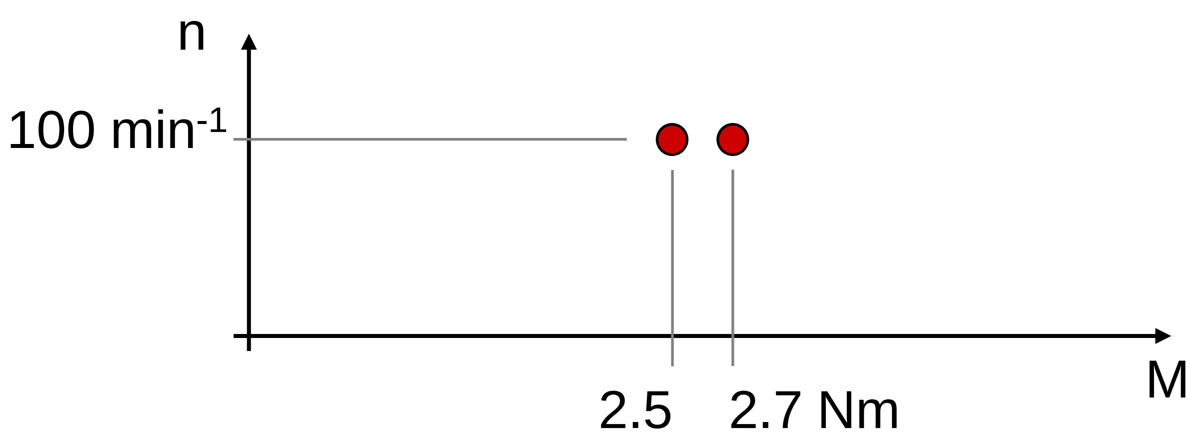


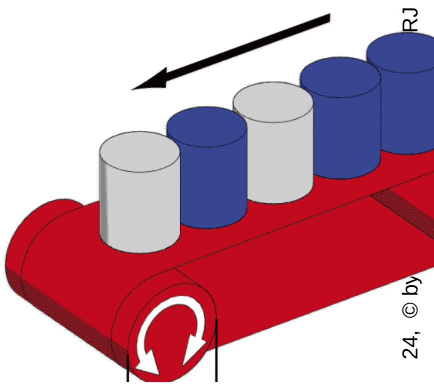


Key values

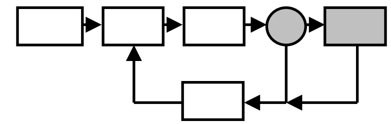
Requested is a drive, which can achieve the following:

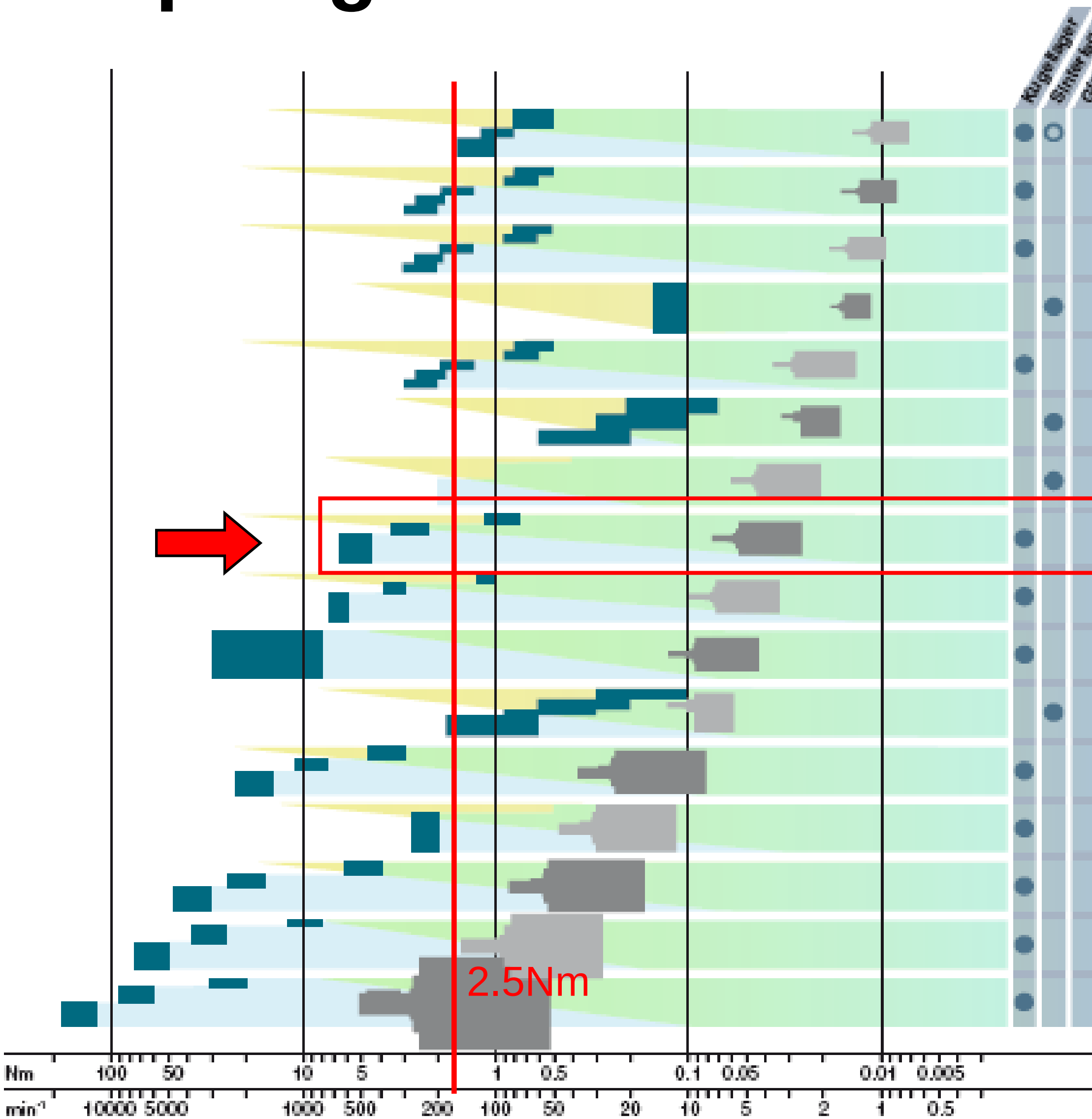
- max. speed n_{max} 100 min^{-1}
- average. torque M_{eff} ca. 2.5 Nm
- max. torque M_{max} ca. 2.7 Nm
- duration of M_{max} 1s





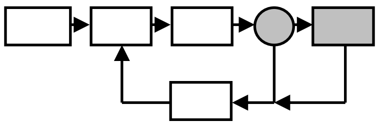
Step 2: gearhead selection



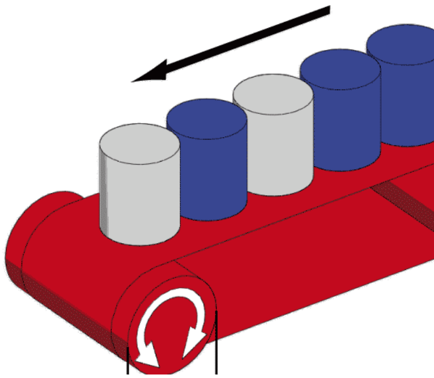


	maxon gear		Seite
GP 22 A	Planetengetriebe Ø22 mm 0.5-1.0 Nm	3.8:1 4592:1	221
GP 22 C	Planetengetriebe Ø22 mm 0.5-2.0 Nm	3.8:1 4592:1	222/223
GP 22 M	Planetengetriebe Ø22 mm, steril. 0.5-2.0 Nm	3.8:1 4592:1	224
GS 24 A	Stirnradgetriebe Ø24 mm 0.1 Nm	7.2:1 325:1	225
GP 26 B	Planetengetriebe Ø26 mm 0.5-2.0 Nm	3.8:1 4592:1	226
GS 30 A	Stirnradgetriebe □30 mm 0.07-0.2 Nm	15:1 500:1	227
GP 32 K	Planetengetriebe Ø32 mm 0.4-2.0 Nm	5.2:1 236:1	228
GP 32 A	Planetengetriebe Ø32 mm 0.75-4.5 Nm	3.7:1 6285:1	229/230
GP 32 C	Planetengetriebe Ø32 mm 1.0-6.0 Nm	3.7:1 6285:1	231/232
GP 32 HP	Planetengetriebe Ø32 mm 8.0 Nm	14:1 1093:1	233
GS 38 A	Stirnradgetriebe □38 mm 0.1-0.6 Nm	6:1 900:1	234
GP 42 C	Planetengetriebe Ø42 mm 3-15 Nm	3.5:1 936:1	235/236
GS 45 A	Stirnradgetriebe Ø45 mm 0.5-2.0 Nm	5:1 1952:1	237
GP 52 C	Planetengetriebe Ø52 mm 4-30 Nm	3.5:1 936:1	238/239
GP 62 A	Planetengetriebe Ø62 mm 8-50 Nm	5.2:1 236:1	240
GP 81 A	Planetengetriebe Ø81 mm 20-120 Nm	3.7:1 308:1	241

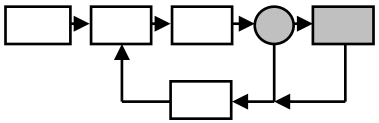
Step 2: gearhead selection



- planetary gearhead GP 32 A
- continuous torque 4.5 Nm
  - at least 3 stages
- input speed 6000 min^{-1}
  - Reduction 51:1
  - efficiency 70 %
- requirements motor (key values)
  - speed $n_{mot} = n_L \cdot i = 100 \cdot 51 = 5100\, min^{-1}$
  - torque $M_{mot} = \frac{M_L}{i \cdot \eta_G} = \frac{2.5}{51 \cdot 0.7} \cong 70 mNm$
  - max. torque ca. 75 mNm, 1s



Step 3: selection of the motor type

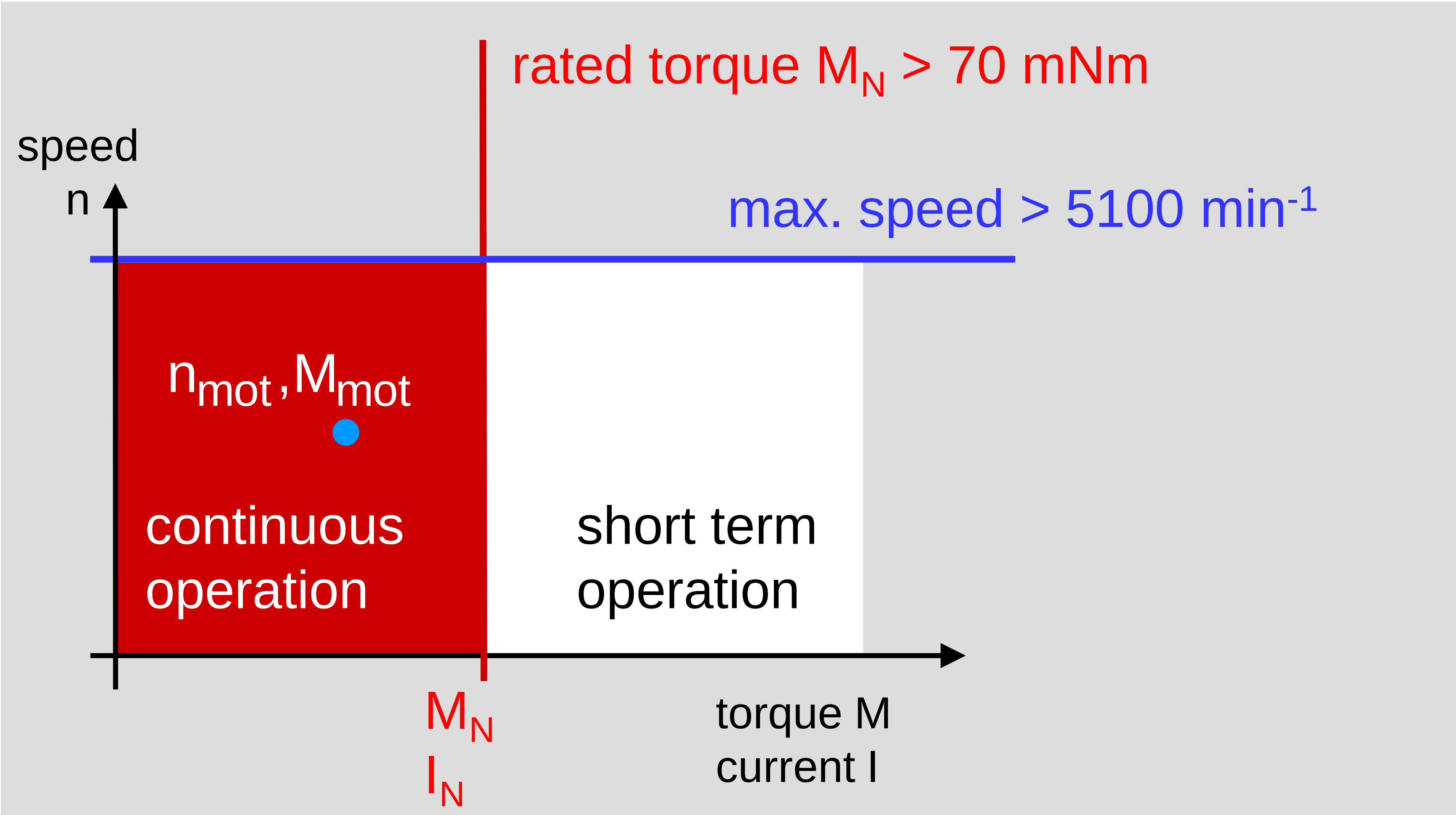


- Combinations with the chosen gearhead
- Torques
  - Continuous torque
  - Intermittent torque
- Speed
  - Max. permissible speed
- Combinations with needed sensor
  - Encoder, DC-Tacho, Resolver, …

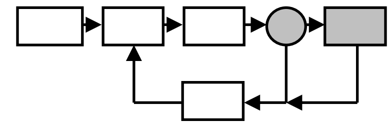
Additional criteria:

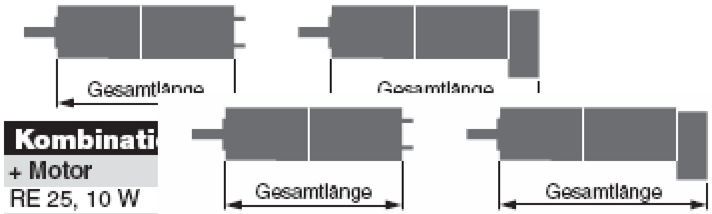
- Commutation: Graphite, Metal, brushless
  - Life expectancy
- Shaft, bearing
  - Diameter, length
  - Drive element
  - Bearing load radial, axial
- Electrical connections
  - Pig tail, cable, connector
- Temperatures

Selection of the motor type



Selection of the motor type

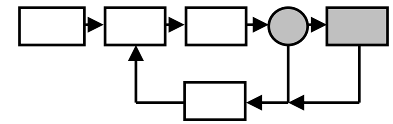




Kombinati
+ Motor
RE 25, 10 W
RE 25, 10 W
RE 25, 10 W
RE 25, 10 W
RE 25, 10 W
RE 25, 20 W
RE 25, 20 W
RE 25, 20 W
RE 25, 20 W
RE 25, 20 W
RE 25, 20 W
RE 25, 20 W
RE 25, 20 W
RE 26, 18 W
RE 26, 18 W
RE 26, 18 W
RE 26, 18 W
RE 26, 18 W
A-max 26
A-max 26
A-max 26
A-max 26
A-max 26
RE-max 29
RE-max 29

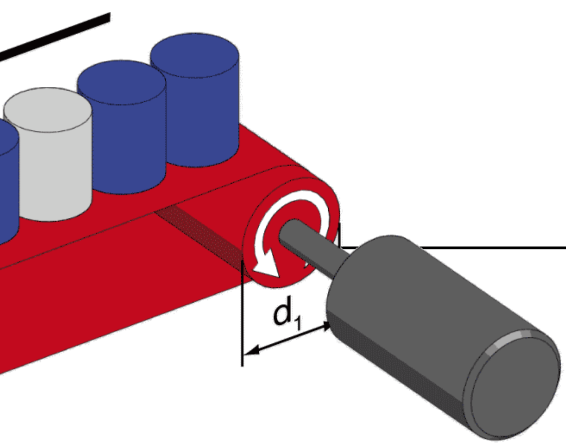
Ausgabe April 20

Kombination														
+ Motor	Seite	+ Tacho / Bremse	Seite	Gesamtlänge [mm] = Motorlänge + Getriebelänge + (Tacho / Bremse) + Montageteile										
RE 30, 60 W	80			94.5	104.4	104.4	111.1	111.1	117.8	117.8	117.8	124.5	124.5	124.5
RE 30, 60 W	80	MR	251	105.9	115.8	115.8	122.5	122.5	129.2	129.2	129.2	135.9	135.9	135.9
RE 35, 90 W	81			97.4	107.3	107.3	114.0	114.0	120.7	120.7	120.7	127.4	127.4	127.4
RE 35, 90 W	81	MR	251	108.8	118.7	118.7	125.4	125.4	132.1	132.1	132.1	138.8	138.8	138.8
RE 35, 90 W	81	HED_ 5540	254/256	118.4	128.3	128.3	135.0	135.0	141.7	141.7	141.7	148.4	148.4	148.4
RE 35, 90 W	81	DCT 22	263	115.5	125.4	125.4	132.1	132.1	138.8	138.8	138.8	145.5	145.5	145.5
RE 35, 90 W	81	AB 28	300	133.5	143.4	143.4	150.1	150.1	156.8	156.8	156.8	163.5	163.5	163.5
RE 35, 90 W	81	HEDS 5540 / AB 28	254/300	150.6	160.5	160.5	167.2	167.2	173.9	173.9	173.9	180.6	180.6	180.6
RE 36, 70 W	82			97.7	107.6	107.6	114.3	114.3	121.0	121.0	121.0	127.7	127.7	127.7
RE 36, 70 W	82	MR	251	109.1	119.0	119.0	125.7	125.7	132.4	132.4	132.4	139.1	139.1	139.1
RE 36, 70 W	82	HED_ 5540	254/256	118.7	128.6	128.6	135.3	135.3	142.0	142.0	142.0	148.7	148.7	148.7
RE 36, 70 W	82	DCT 22	263	115.8	125.7	125.7	132.4	132.4	139.1	139.1	139.1	145.8	145.8	145.8
A-max 32	121/123			89.4	99.3	99.3	106.0	106.0	112.7	112.7	112.7	119.4	119.4	119.4
A-max 32	122/124			88.0	97.9	97.9	104.6	104.6	111.3	111.3	111.3	118.0	118.0	118.0
A-max 32	122/124	MR	251	99.2	109.1	109.1	115.8	115.8	122.5	122.5	122.5	129.2	129.2	129.2
A-max 32	122/124	HED_ 5540	254/256	108.8	118.7	118.7	125.4	125.4	132.1	132.1	132.1	138.8	138.8	138.8
EC 32, 80 W	162			86.5	96.4	96.4	103.1	103.1	109.8	109.8	109.8	116.5	116.5	116.5
EC 32, 80 W	162	HED_ 5540	255/257	104.9	114.8	114.8	121.5	121.5	128.2	128.2	128.2	134.9	134.9	134.9
EC 32, 80 W	162	Res 26	264	106.6	116.5	116.5	123.2	123.2	129.9	129.9	129.9	136.6	136.6	136.6

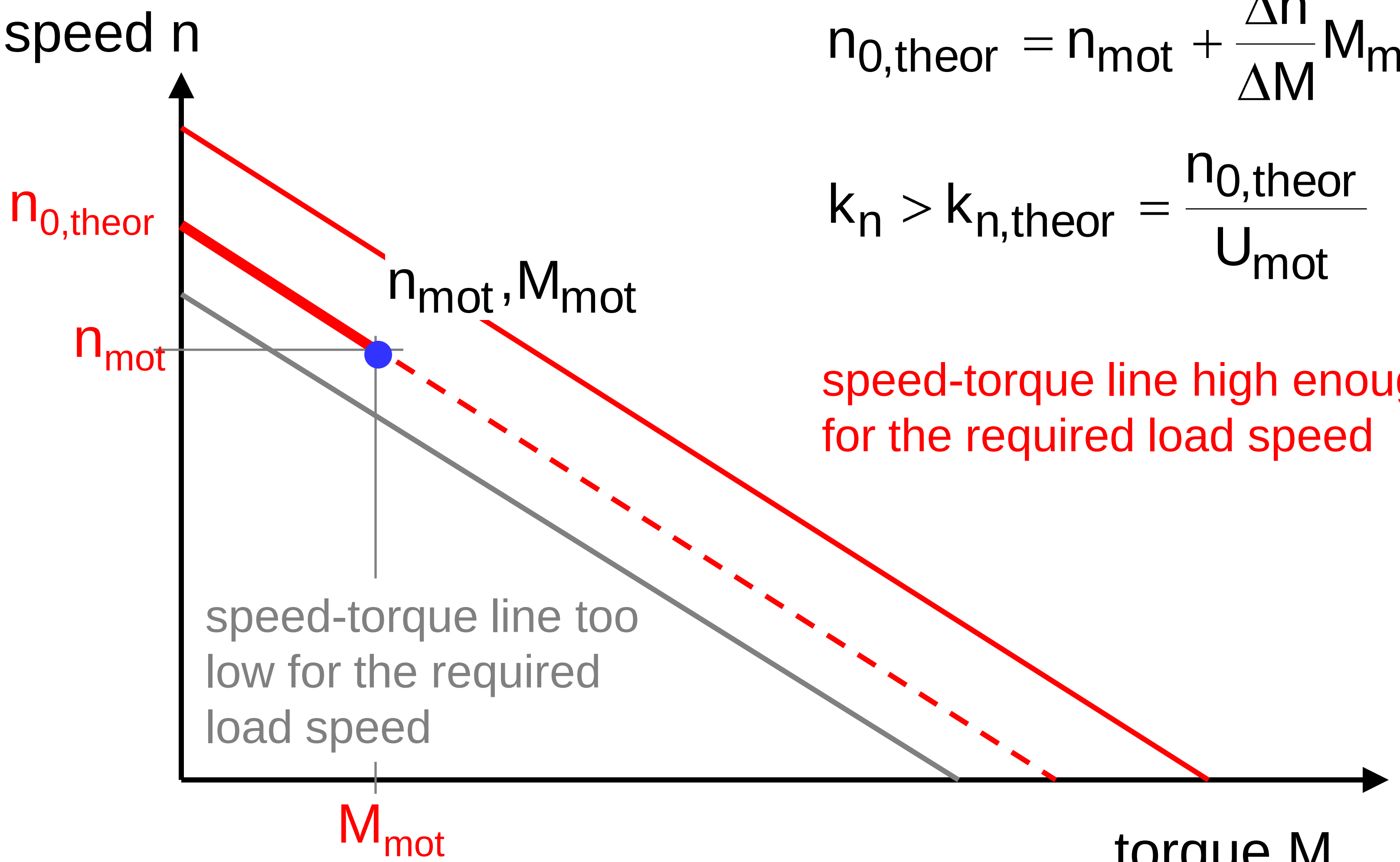


Selection of the motor type

according	motor type	M_N	suited?
maxon modular system	RE 25, RE 26	< 32 mNm	too weak
	A-max 26	< 18 mNm	too weak
	RE-max 29	< 30 mNm	too weak
	RE 30	ca. 80 mNm	good
	RE 35	100 mNm	strong
	RE 36	80 mNm	good
	A-max 32	< 45 mNm	too weak
	EC 32	ca. 45 mNm	too weak



Step 4: Winding selection

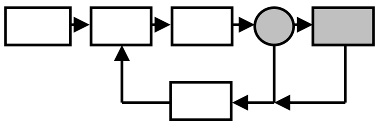


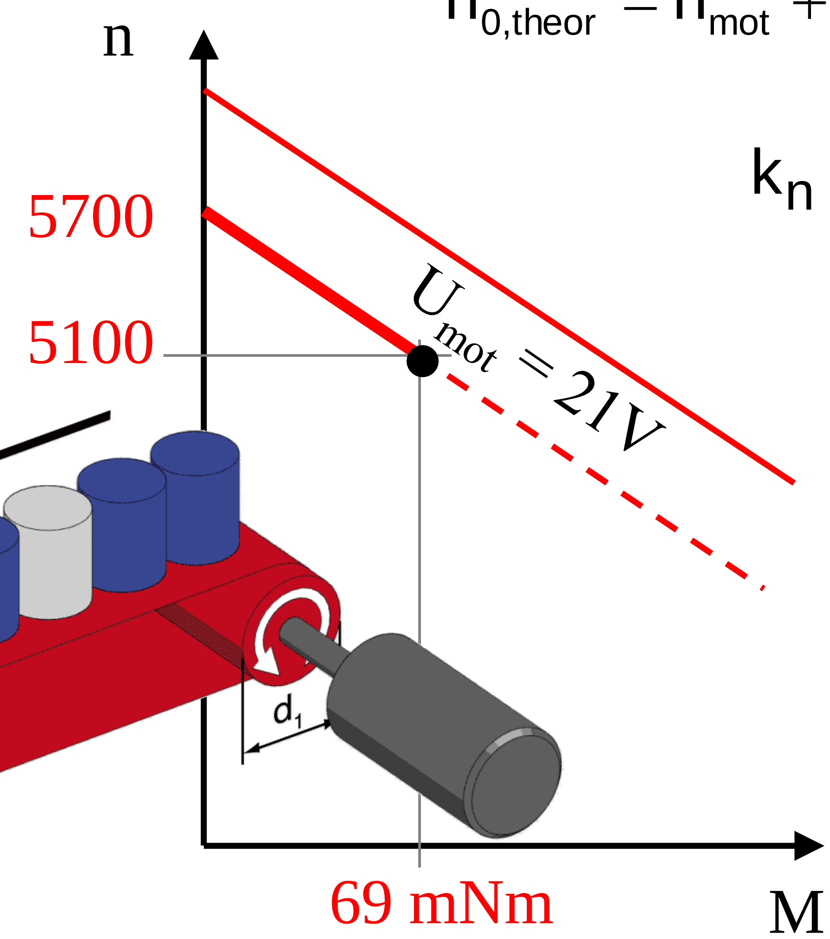
$$n_{0,theor} = n_{mot} + \frac{\Delta n}{\Delta M} M_{mot}$$

$$k_n > k_{n,theor} = \frac{n_{0,theor}}{U_{mot}}$$

speed-torque line high enough for the required load speed

Winding selection





$$n_{0,theor} = n_{mot} + \frac{\Delta n}{\Delta M} M_{mot} = 5100 + 9 \cdot 70 \approx 5700\,\text{min}^{-1}$$

$$k_n > k_{n,theor} = \frac{n_{0,theor}}{U_{mot}} = \frac{5700}{21} = 270\,\frac{\text{rpm}}{\text{V}}$$

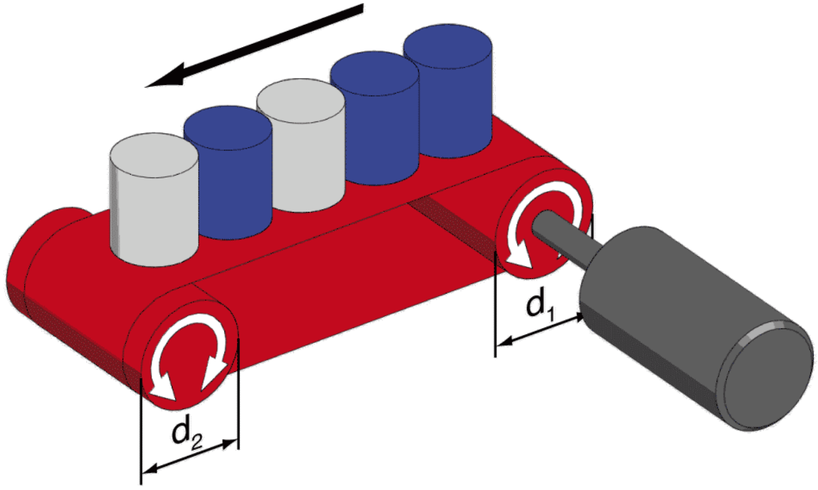
- select motor 310007:
  - speed constant k_n = 369 min^{-1}/V
- needed current
  - with torque constant k_M

$$I_{max} = \frac{M_{max}}{k_M} + I_0$$

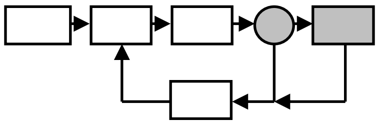
$$= \frac{70}{25.9} + 0.15 = 2.8\text{A}$$

Example Conveyor belt for samples : Solutions with MSP

- List with possible solutions
- Filter
- graphic illustration
- Output documentation



maxon selection program (MSP)



- Selection of maxon products for applications
  - Demonstration of alternative solutions
- For optimising the drive selection
  - Playing with parameter
- for Visualisation of the drive possibilities
- For documentation

- Target group
  - maxon sales engineers
  - Customer with experience of the maxon product segment
  - Students of Technical Universities

maxon selection program 2005

maxon motor

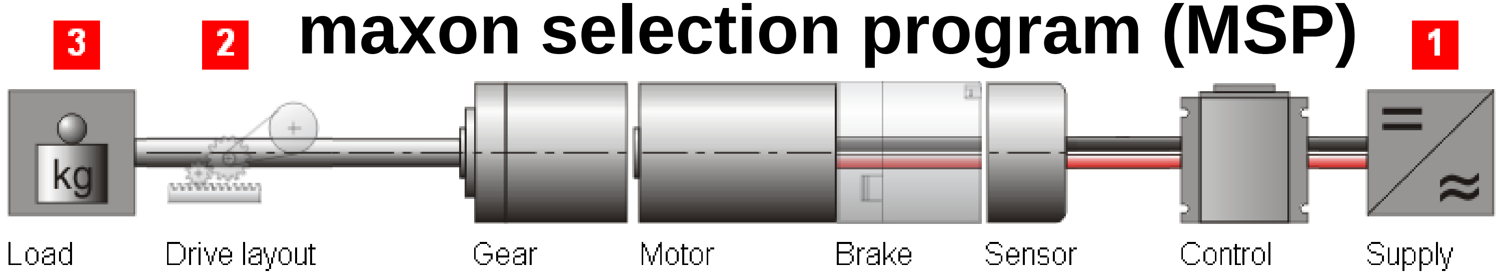
driven by precision

Selection

Load calculator

Comparison

maxon selection program (MSP)



Basic functions of the MSP

- Selection of maxon products
  1. for a given power supply
  2. for a given drive layout: screws, belts, …
  3. at a given load
- Calculation of achievable load characteristics
- Gearmotor comparison
  – finding a maxon replacement product
- Mass inertia calculator

English

V1.0 - 4/2005

Corner marks of the MSP

- Data base: maxon catalogue products
  - Motors (1232), gearheads (685):
  - Sensors (57), Controller
  - Considering of the "maxon Modular System"
    - ca. 80'000 possible Motor gearhead combinations
- No installation needed
  - can be started directly from the maxon CD ROM
  - or copy and start it
- Easy to use, self-explaining user interface
  - minimum "help"

Where to find the MSP

Free of charge:

- on the CD with the catalogue

- on www.maxonmotor.nl => service & downloads
  or
- on www.maxonmotor.be => service & downloads