# ROCO222: Intro to sensors and actuators

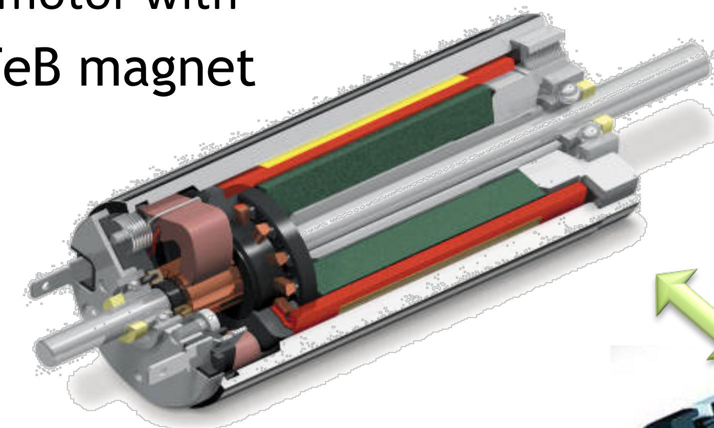
Lecture 7

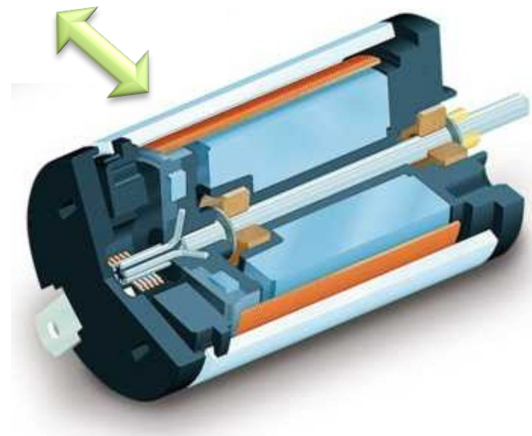
DC motor datasheets

# Maxon DC motor variants

## Lots of choice in choosing a motor

RE motor with
NdFeB magnet





A-max motor with
AlNiCo magnet

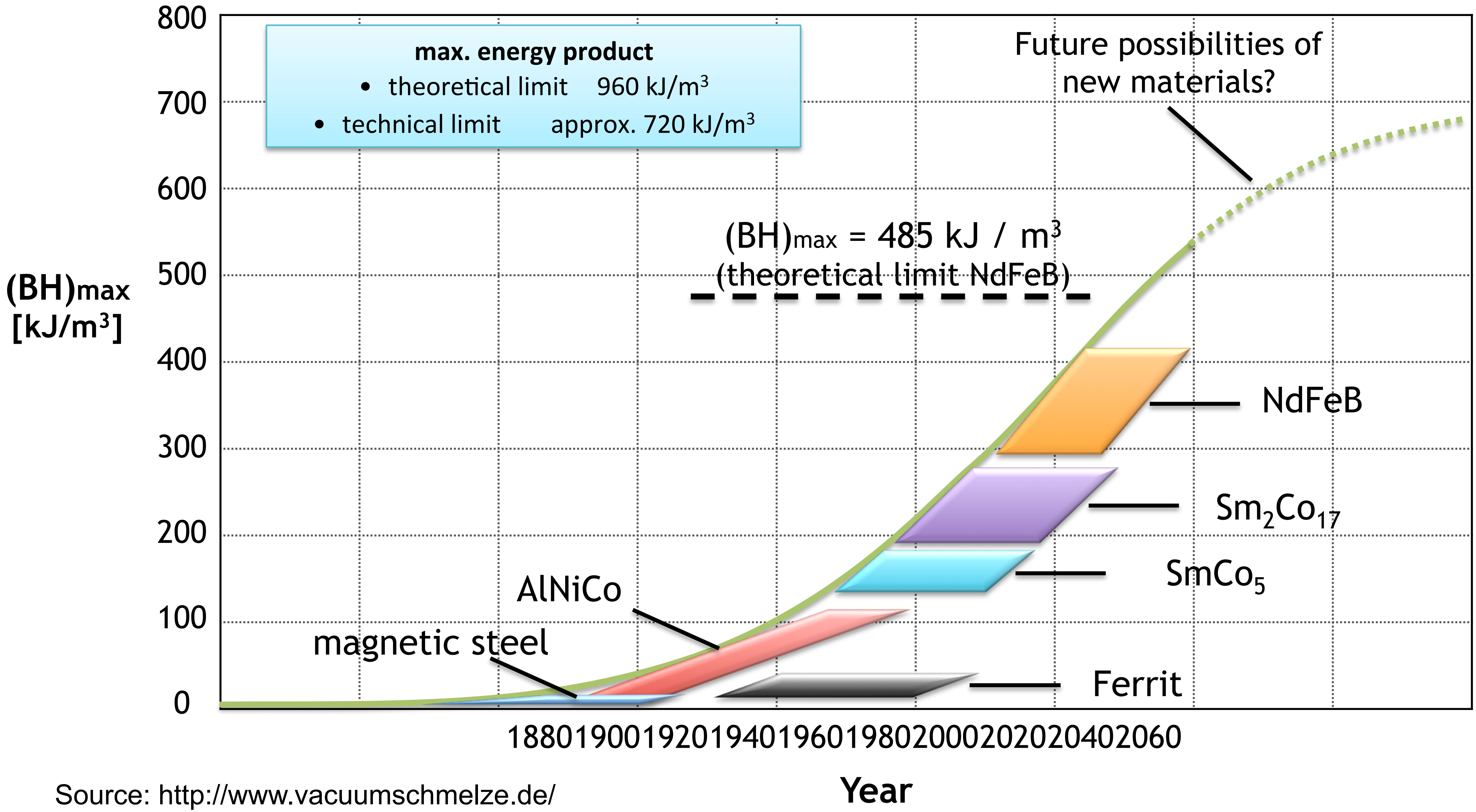
ball
bearing

sintered
sleeve bearing

precious
metal
brushes

graphite
brushes

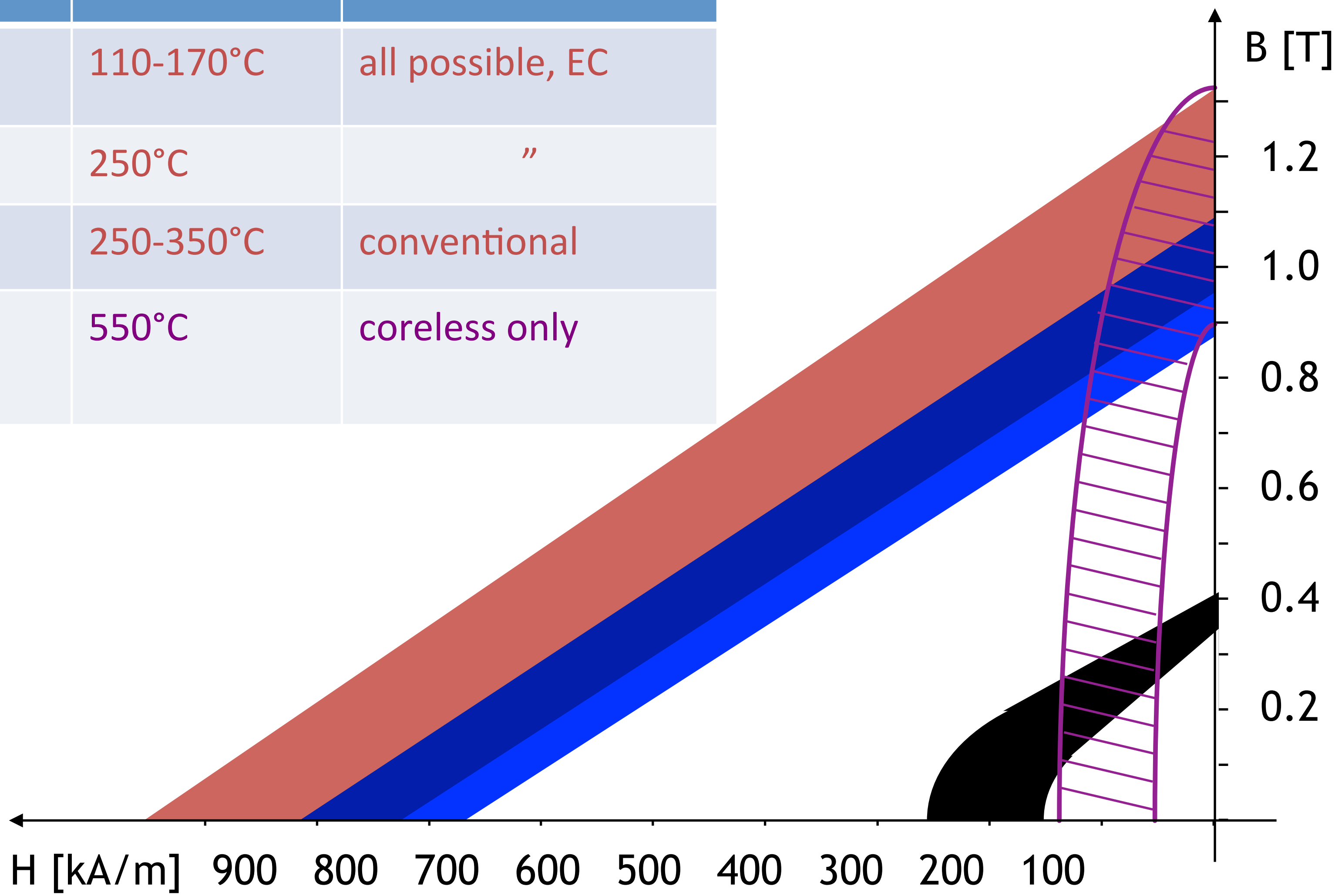
# Development of permanent magnets




Source: http://www.vacuumschmelze.de/

# Permanent magnets

| Magnetic material | Curie temperature | Operation temperature | Motor design |
|---|---|---|---|
| $Nd_2Fe_{14}B$ | 310°C | 110-170°C | all possible, EC |
| $SmCo_5$ | 720°C | 250°C | ” |
| ferrites | 450°C | 250-350°C | conventional |
| AlNiCo | ~850°C | 550°C | coreless only |



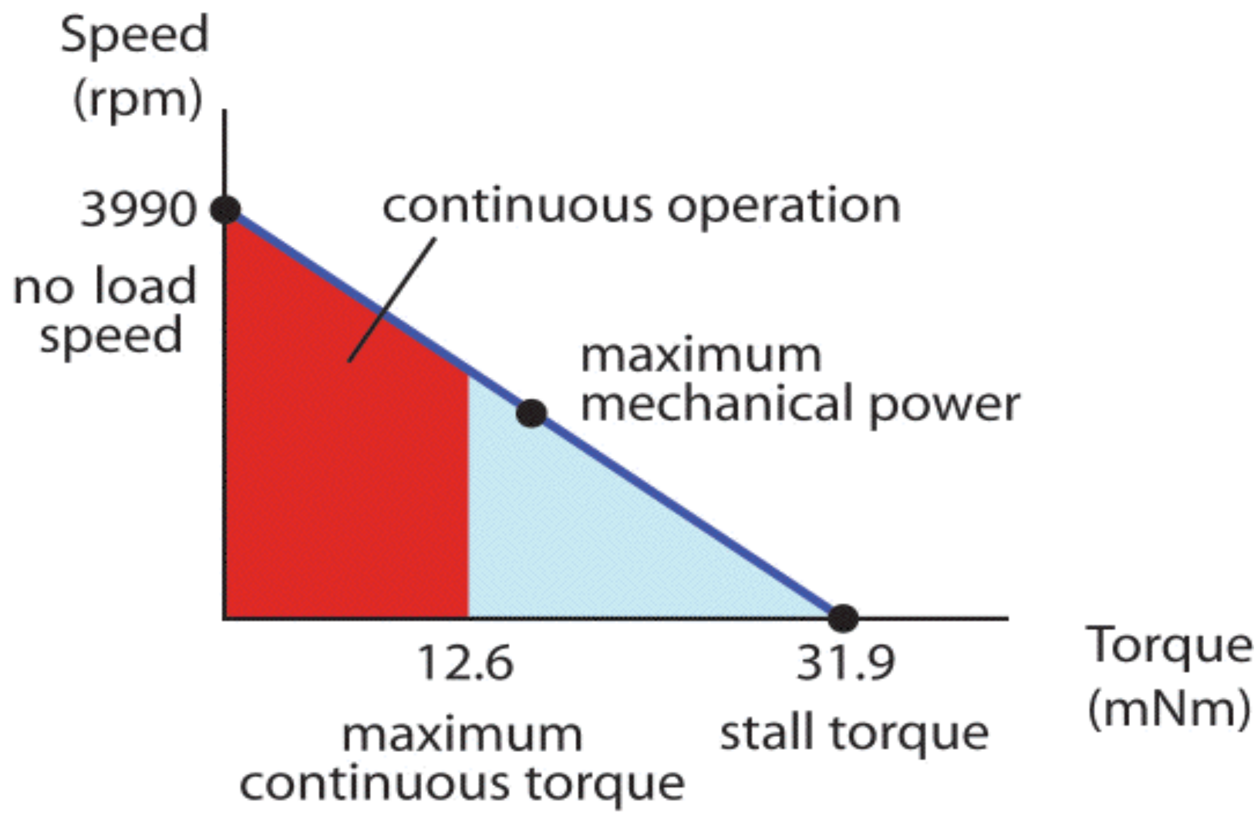
# Understanding motor datasheets

- Examine DC motor datasheets
- Selecting a motor to suit the job

| **Motor Data** (provisional) | | | |
|---|---|---|---|
| | **Values at nominal voltage** | | |
| 1 | Nominal voltage | V | 9 |
| 2 | No load speed | rpm | 2850 |
| 3 | No load current | mA | 49.7 |
| 4 | Nominal speed | rpm | 2610 |
| 5 | Nominal torque (max. continuous torque) | mNm | 87.8 |
| 6 | Nominal current (max. continuous current) | A | 2.96 |
| 7 | Stall torque | mNm | 873 |
| 8 | Starting current | A | 29 |
| 9 | Max. efficiency | % | 92 |
| | **Characteristics** | | |
| 10 | Terminal resistance | Ω | 0.311 |
| 11 | Terminal inductance | mH | 0.0824 |
| 12 | Torque constant | mNm/A | 30.2 |
| 13 | Speed constant | rpm/V | 317 |
| 14 | Speed / torque gradient | rpm/mNm | 3.27 |
| 15 | Mechanical time constant | ms | 4.85 |
| 16 | Rotor inertia | $gcm^2$ | 142 |

# DC motor data

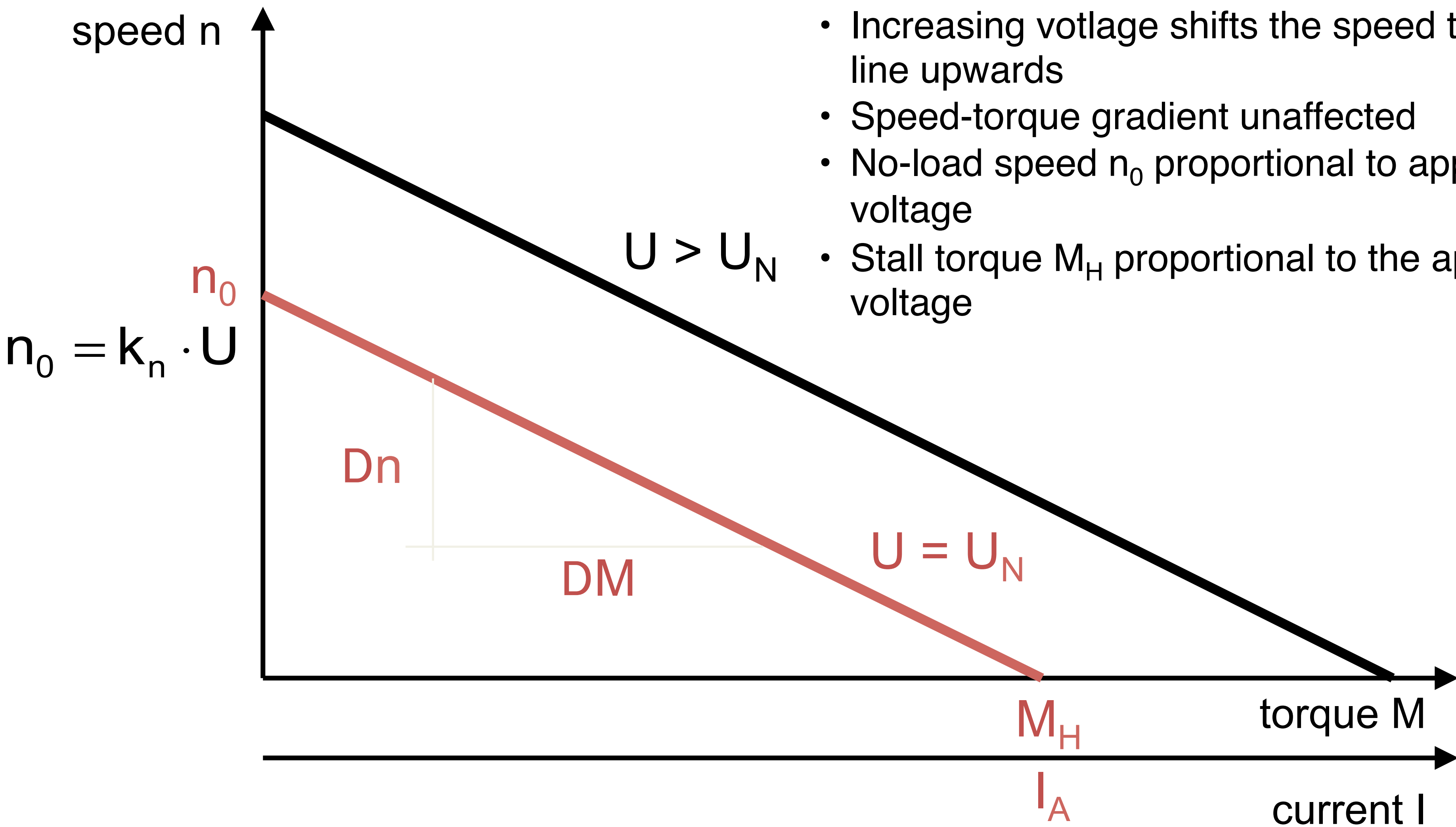
## Plot of motor rotational speed against torque




Power = Speed ($Rads^{-1}$) x Torque (NM)
Cannot specify a motor simply on its power.
Require a certain torque at a certain speed.
Motor may be powerful enough but not have the torque available at required speed

# Speed-voltage characteristic

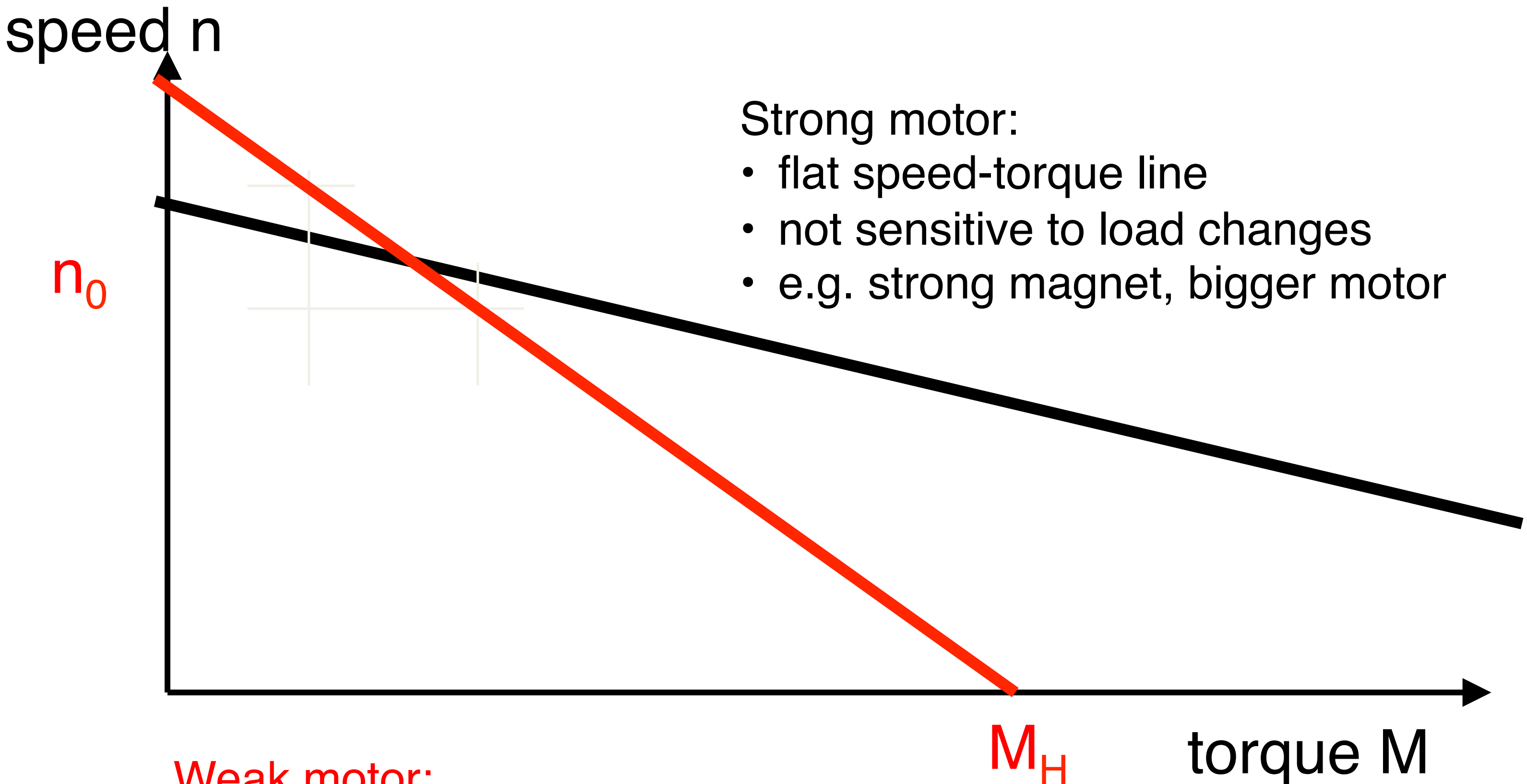
## Influence of applied voltage on speed




- Increasing votlage shifts the speed torque line upwards
- Speed-torque gradient unaffected
- No-load speed $n_0$ proportional to applied voltage
- Stall torque $M_H$ proportional to the applied voltage

# Speed-torque characteristic

Speed reduced as output motor torque is increased




Strong motor:

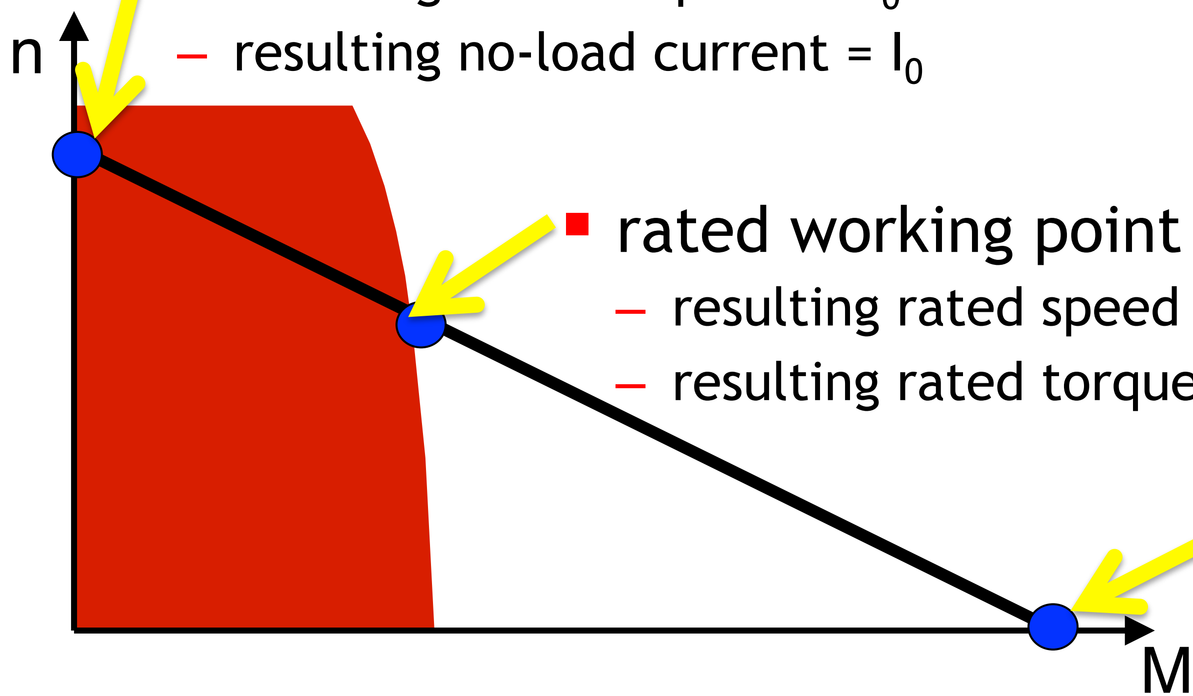
- flat speed-torque line
- not sensitive to load changes
- e.g. strong magnet, bigger motor

Weak motor:

- steep speed-torque line
- sensitive to load changes
- e.g. weak magnet, smaller motor

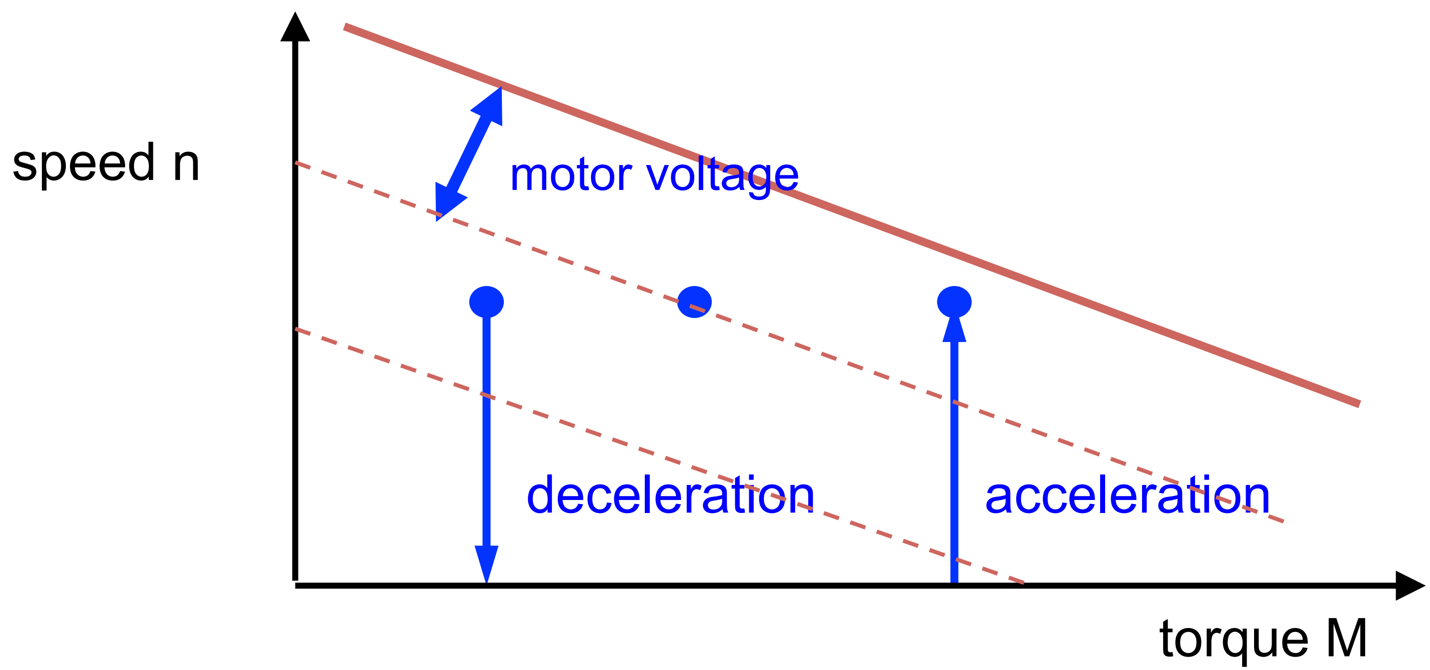
# Motor values at nominal voltage

- No-load operating point
  - resulting no-load speed = $n_0$
  - resulting no-load current = $I_0$
- rated working point
  - resulting rated speed = $n_N$
  - resulting rated torque = $M_N$
- Motor at stall
  - resulting stall torque = $M_H$
  - resulting starting current = $I_A$

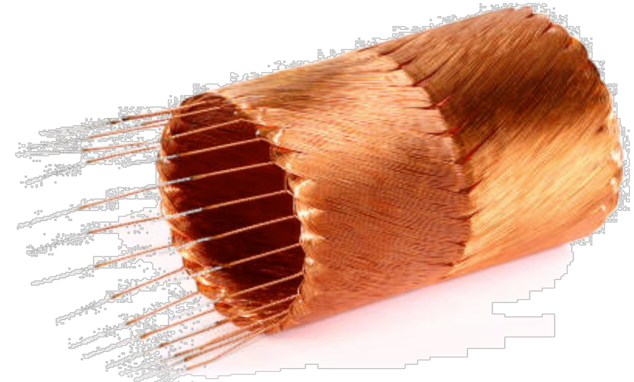


# Operating points

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



# Effect of changing the windings

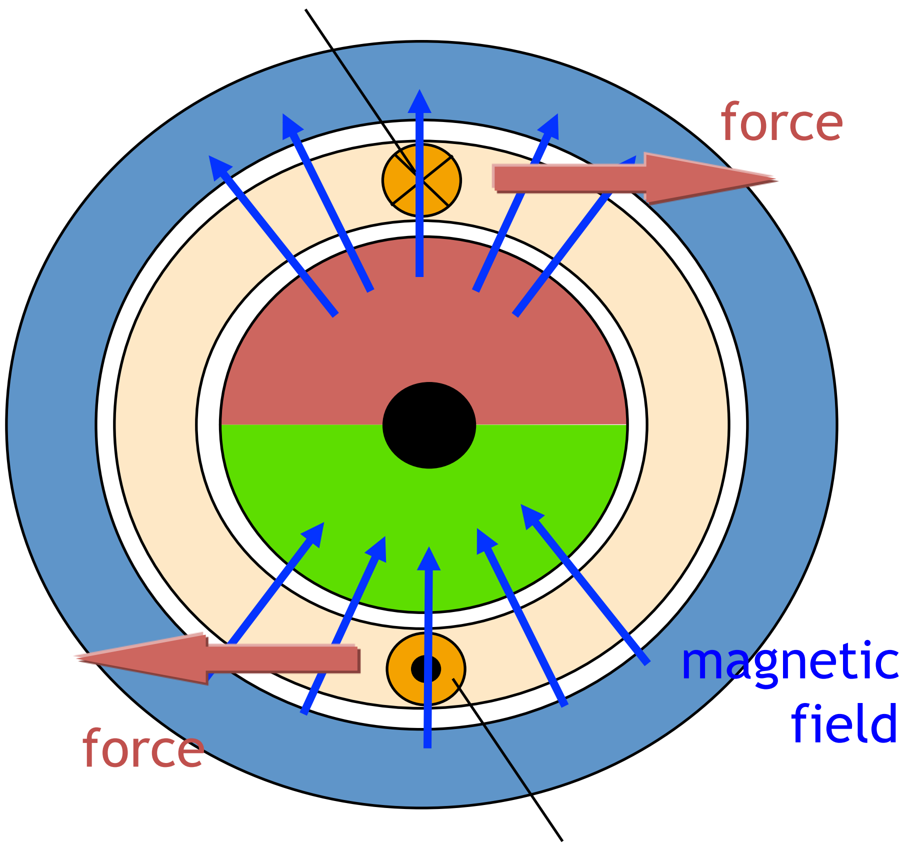



| ving | 273752 | 323890 | 273753 | 273754 | 273755 | 273756 | 273757 | 273758 | 273759 | 273760 | 273761 | 273762 | 273763 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mm | 285785 | 323891 | 285786 | 285787 | 285788 | 285789 | 285790 | 285791 | 285792 | 285793 | 285794 | 285795 | 285796 |
| V | 15.0 | 24.0 | 30.0 | 42.0 | 48.0 | 48.0 | 48.0 | 48.0 | 48.0 | 48.0 | 48.0 | 48.0 | 48.0 |
| rpm | 7070 | 7670 | 7220 | 7530 | 7270 | 6650 | 5960 | 4740 | 3810 | 3140 | 2570 | 2100 | 1620 |
| mA | 245 | [illegible] | [illegible] | [illegible] | [illegible] | 68.7 | 59.7 | 44.7 | 34.2 | 27.1 | 21.6 | 17.2 | 12.9 |
| rpm | 6270 | 6910 | 6420 | 6770 | 6490 | [illegible] | 5150 | [illegible] | 2970 | 2280 | [illegible] | 1220 | 732 |
| Nm | 73.2 | 93.3 | 92.4 | 97.7 | 96.5 | 98.2 | 98.8 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 104 |
| A | 4.00 | [illegible] | [illegible] | [illegible] | [illegible] | 1.51 | 1.36 | 1.12 | 0.915 | 0.752 | 0.621 | 0.503 | 0.391 |
| Nm | 874 | 1160 | 949 | 1070 | 967 | 878 | 766 | [illegible] | [illegible] | [illegible] | [illegible] | 253 | [illegible] |
| A | 45.0 | 39.7 | [illegible] | [illegible] | [illegible] | 12.9 | 10.1 | 6.43 | 4.16 | 2.74 | 1.83 | 1.18 | [illegible] |
| % | 81 | 84 | 84 | 86 | 85 | 85 | 84 | 83 | [illegible] | [illegible] | [illegible] | 77 | 74 |
| Ω | 0.334 | 0.605 | [illegible] | [illegible] | [illegible] | [illegible] | 4.75 | 7.46 | 14.5 | 17.5 | 26.2 | 40.5 | 68.2 |
| mH | 0.085 | 0.191 | 0.340 | [illegible] | 0.870 | 1.04 | 1.29 | 2.04 | 3.10 | [illegible] | [illegible] | [illegible] | [illegible] |
| / A | 19.4 | 29.2 | 38.9 | 52.5 | 62.2 | 68 | 75.8 | 95.2 | 119 | 144 | 175 | 214 | 276 |
| / V | 491 | 328 | 246 | 182 | 154 | 140 | 126 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 34.6 |
| Nm | 8.43 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 7.89 | 7.85 | 7.84 | 8.08 | 8.19 | 8.46 | 8.55 |
| ms | 5.97 | 5.60 | 5.50 | 5.40 | 5.38 | 5.38 | 5.39 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 5.41 |
| cm² | 67.6 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 65.2 | [illegible] | 65.5 | 63.6 | 62.8 | 60.8 | 60.4 |

- **low 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)

- **high resistance winding**
- thin wire, many turns
- high rated voltage
- low rated and starting currents
- low specific speed (min$^{-1}$/V)
- high specific torque (mNm/A)

# Torque constant $K_M$




**forces:**
force on current leading conductor in a magnetic field

**torque:**
sum of all forces at the distance to the rotating axis

**influencing parameters:**

geometry
field density
winding number

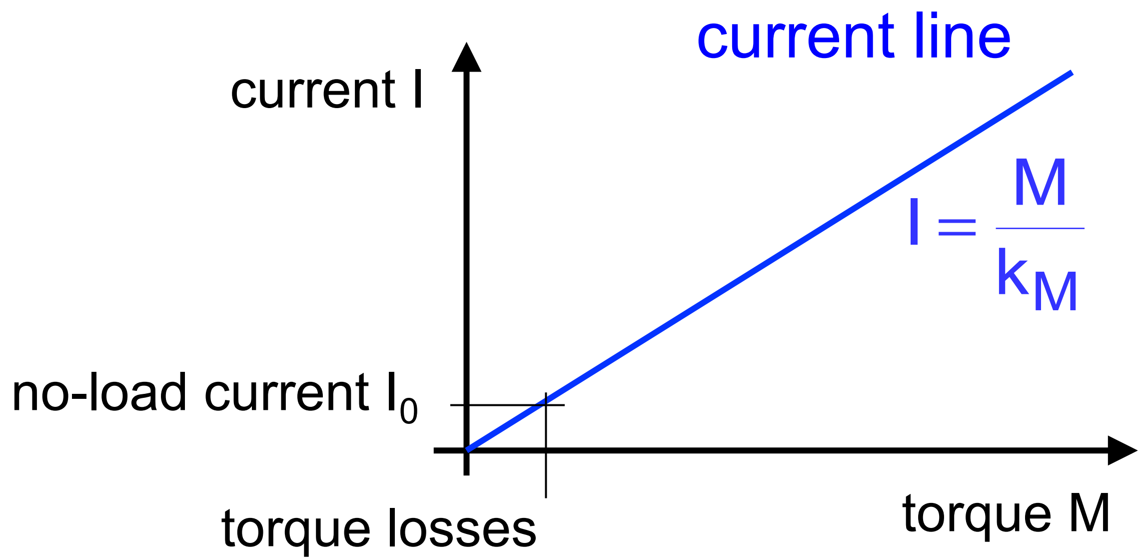
**Depend on the design**

$$M = k_M \cdot I$$

# Torque constant $K_M$

- **Torque constant $K_M$** is determined by motor geometry and magnetic flux densities (Unit: mNm/A)
- Enables calculation of the motor torque for given motor current

$$M = k_M \cdot I$$



# Speed constant $K_n$

- Speed constant $k_n$
  - mostly used for calculating no-load speeds $n_0$
  - unit: $min^{-1}$ / V

$$n_0 = k_n \cdot V$$

- Induced voltage $V_{ind}$ is proportional to motor speed n
  - law of induction: changing flux in a conductor loop
  - induced voltage proportional to speed

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

- Generator constant $k_e$
  - inverse of $k_n$: motor as a generator (e.g. DC-Tacho).
  - Gives how much voltage is produced per rpm
  - units: mV / $min^{-1}$

# Nominal motor characteristics

- Nominal voltage (V) – operating voltage of motor
- No load speed (rpm) – rotational speed at operating voltage of motor with no load
- No load current (mA) – current taken at operating voltage of motor with no load
- Nominal speed (rpm) – rotational speed at operating voltage of motor with no load
- Nominal torque (max. continuous torque) (mNm) – max torque
- Nominal current (max. continuous current) (A) - max continuous current that can be passed through motor
- Stall torque (mNm) – torque generated at operating voltage of motor when motor is held stationary
- Starting current (A) – current draw when motor starts when operating voltage of motor applied
- Max. efficiency (%) – energy efficiency of the motor

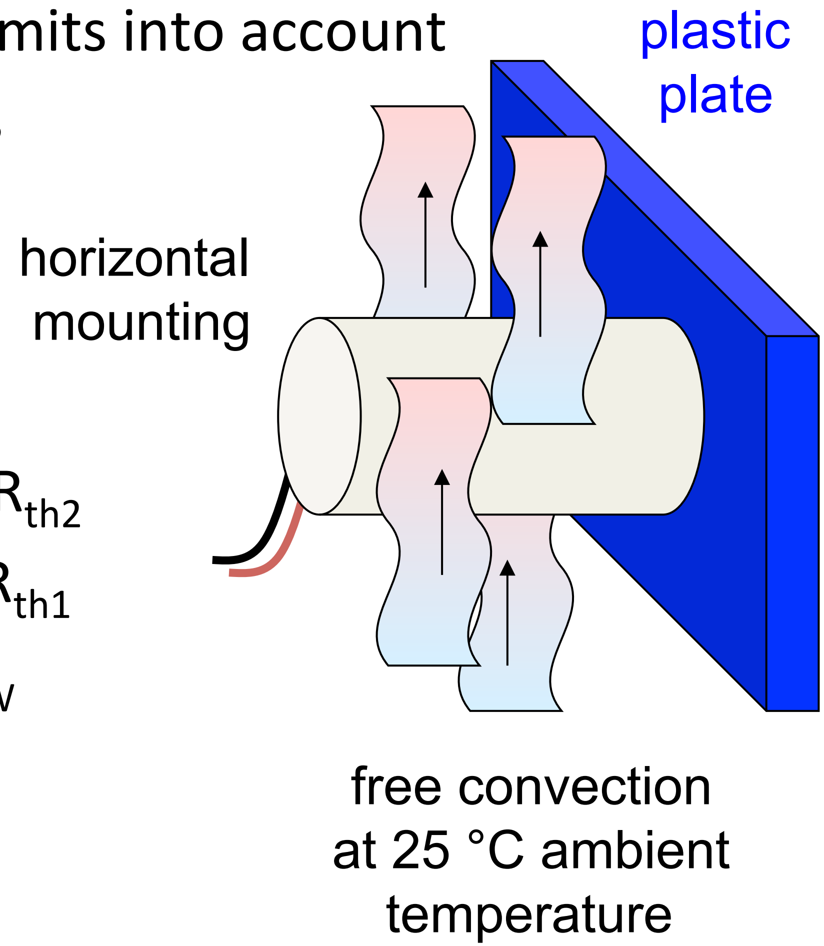
# List of main motor parameters

- Terminal resistance (phase to phase for EC) (Ω)
- Terminal inductance (phase to phase for EC) (mH)
- Torque constant (mNm/A)
- Speed constant (rpm/V)
- Speed / torque gradient (rpm/mNm)
- Mechanical time constant (ms)
- Rotor inertia ($gcm^2$)

# Motor thermal considerations

We must take motor heating and thermal limits into account

- 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 $T_{max}$

# Influence of temperature on motor operation

Temperature coefficients

| | |
|---|---|
| Resistivity ρ for Cu | + 0.39 % per K |
| Flux density B for AlNiCo | - 0.02 % per K |
| Flux density B for Ferrite | - 0.2 % per K |
| Flux density B for NdFeB | - 0.1 % per K |

**As temperature goes up**

**Resistance goes up**

**Desirable magnetic properties go down**

For example: RE motor

If $\Delta T$ = + 50K

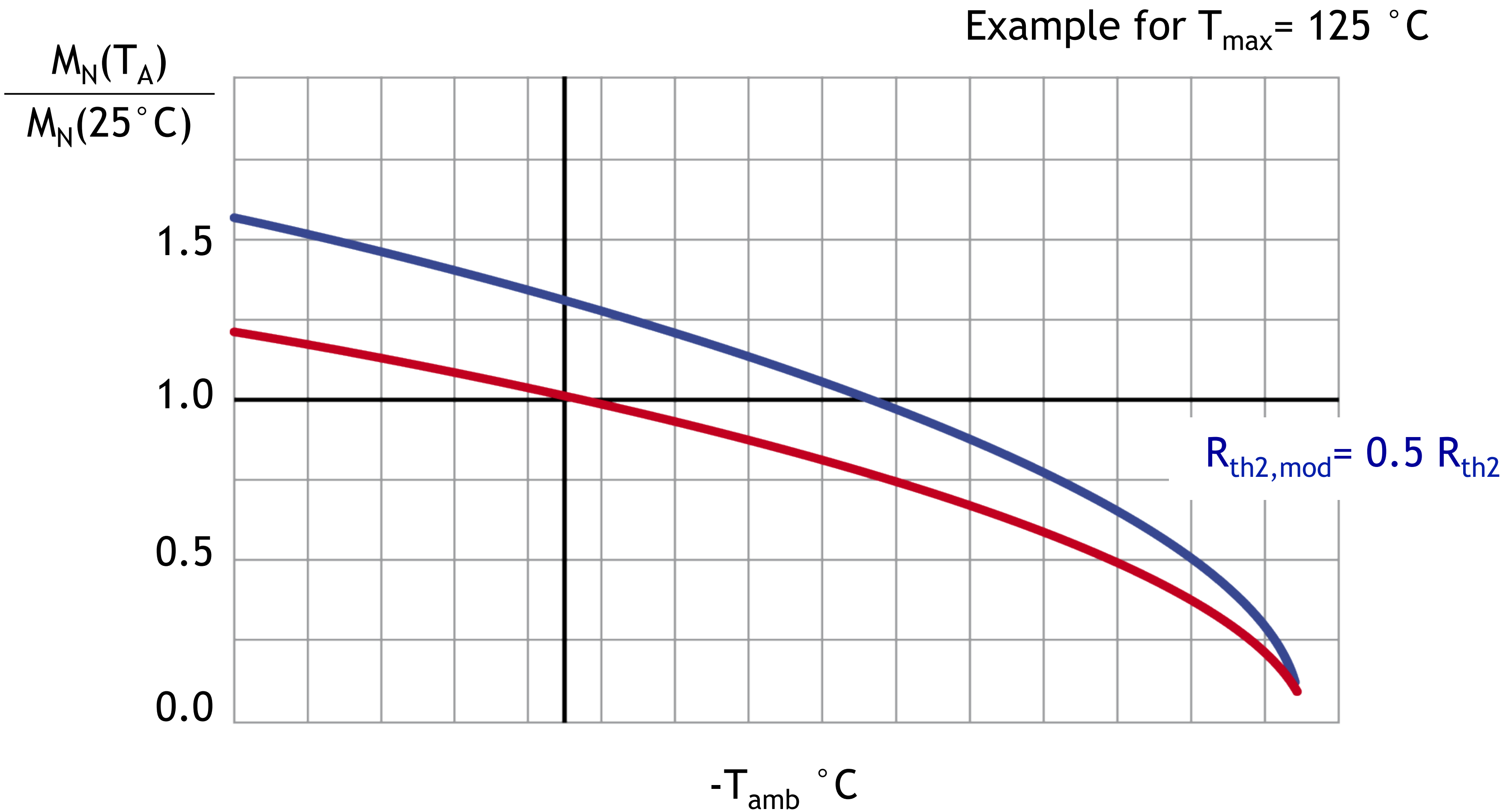
R: + 19.5 %

$K_n$:+ 5 % (no-load speed)

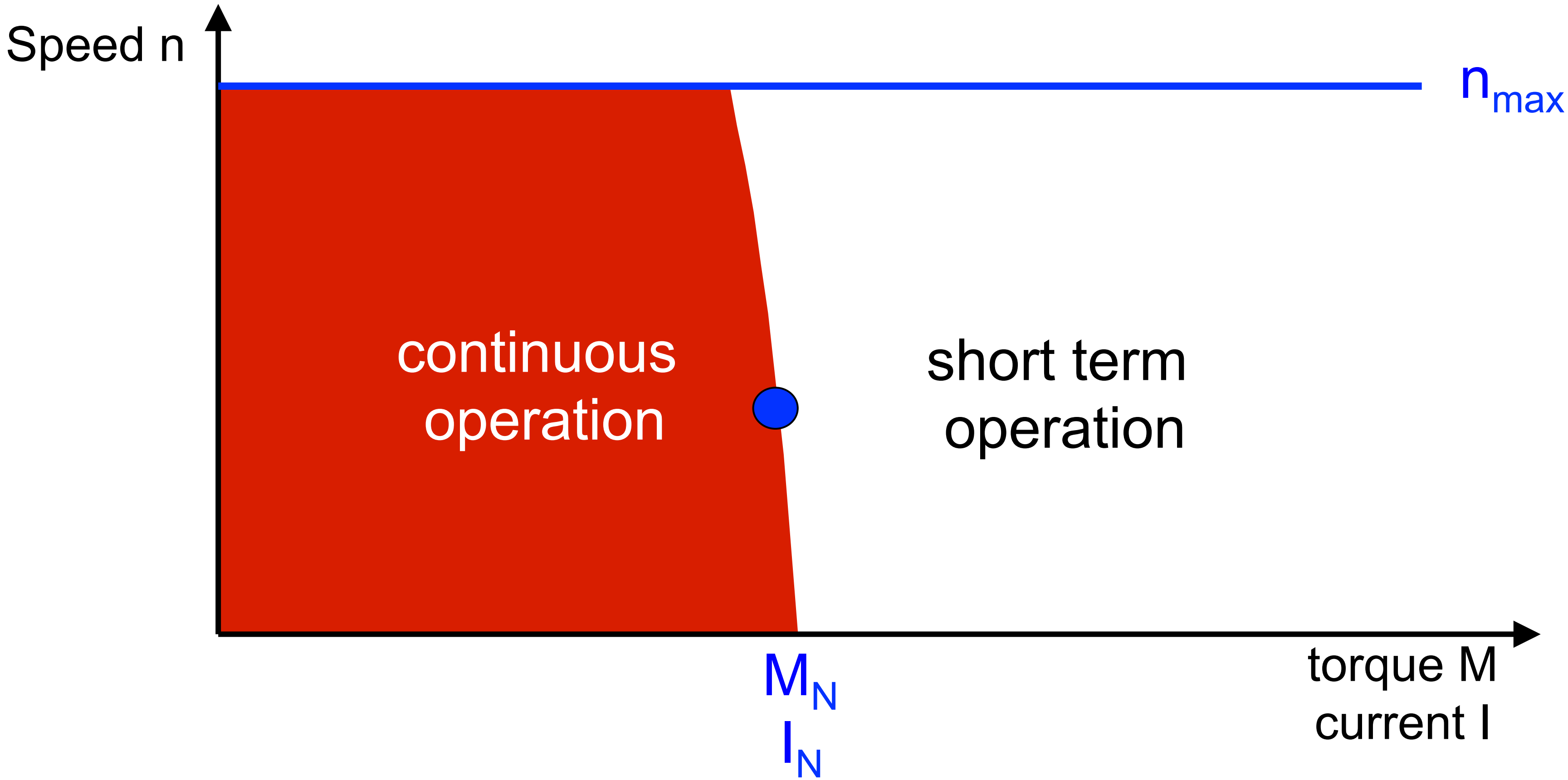
$k_M$: - 5 % (more current!)

Stall torque $M_H$ : - 22 %

# Nominal torque and temperature



# Motor limits: Operation ranges



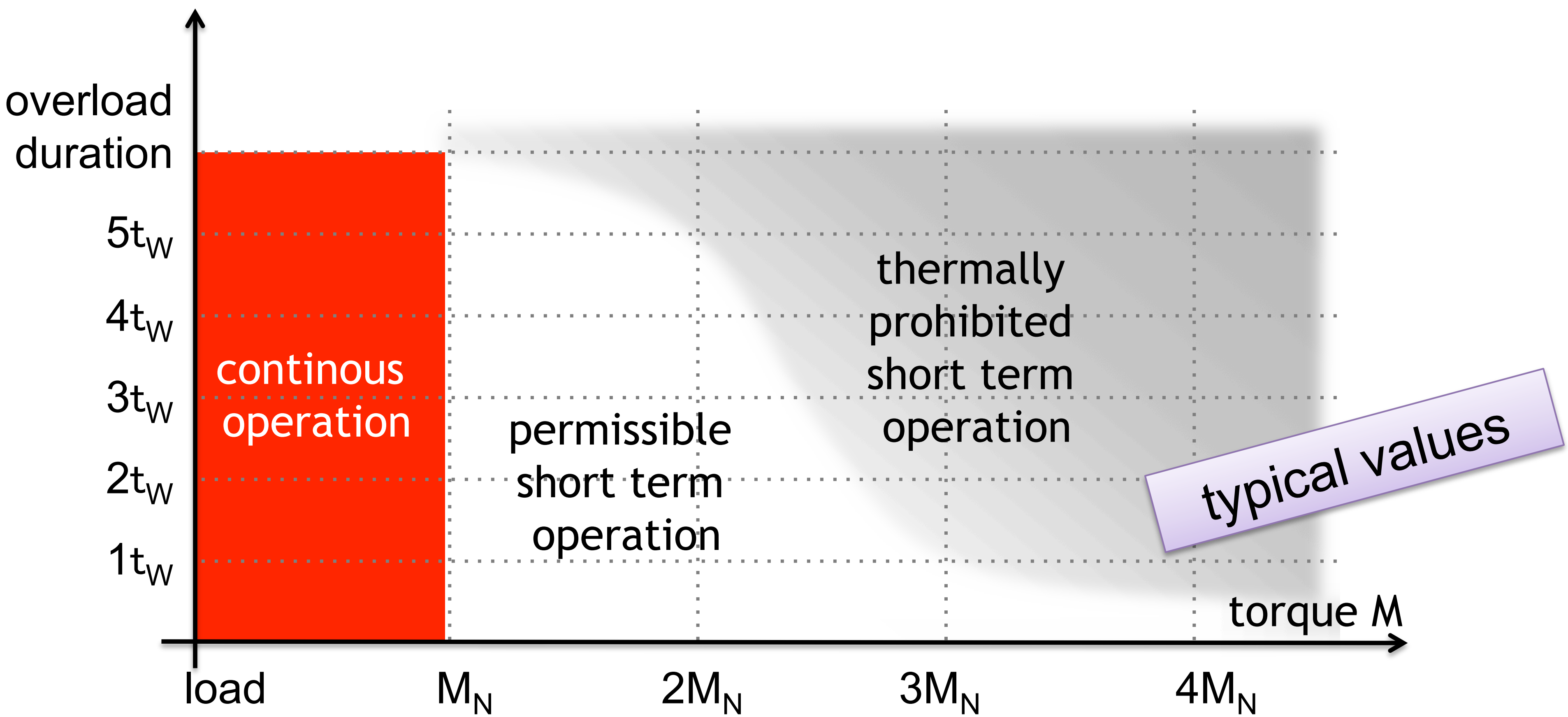

- higher ambient temperature
- heat accumulation

- lower ambient temperature
- good heat dissipation

# Short-term overload operation

Motor may be overloaded for a short time and repeatedly

- Limit: max. permissible winding temperature
- Depends on thermal time constant of winding tW and amount of overload

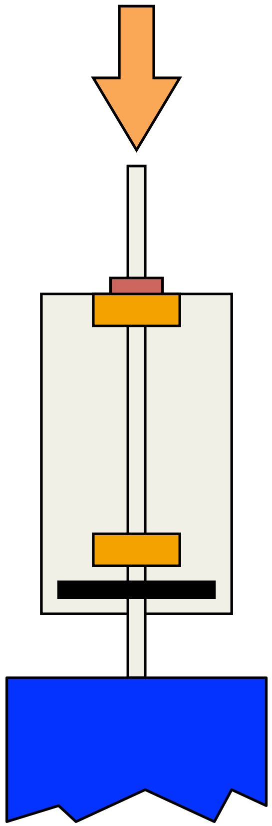


# List of main thermal motor parameters

- Thermal resistance housing-ambient (K/W)
- Thermal resistance winding-housing (K/W)
- Thermal time constant winding (s)
- Thermal time constant motor (s)
- Ambient temperature (°C)
- Max. permissible winding temperature (°C)

# List of main mechanical motor parameters

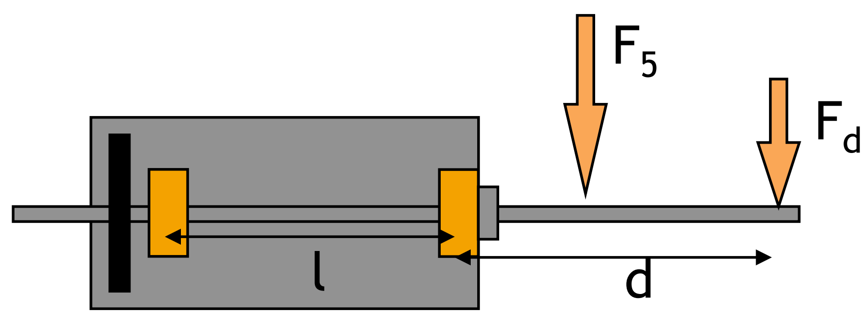
Maximum speed and mechanical properties of motor bearings



axial press fit force
(shaft supported)

- Max. permissible speed
  - Limited by bearing life considerations (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



# List of main motor mechanical parameters

Max. permissible speed (rpm)

Axial play (mm)

Radial play (mm)

Max. axial load (dynamic) (N)

Max. force for press fits (static) (N)

(static, shaft supported) (N)

Max. radial loading, 5 mm from flange (N)

# Other specifications

Rates power (W)
Life expectancy (h)
Weight of motor (g)
Direction of rotation
Number of pole pairs
Number of commutator segments
Commutator material
Insulation class
Protection class
Armature details
Magnet system
Bearing type
Housing

# Motor size selection

- Energy balancing act
- Undersized servo motor cant meet requirement
- Oversized would provide the additional capacity

- For optimum performance at the lowest cost
- choose the smallest servo motor that matches requirements
- Smaller will lower costs and power consumption