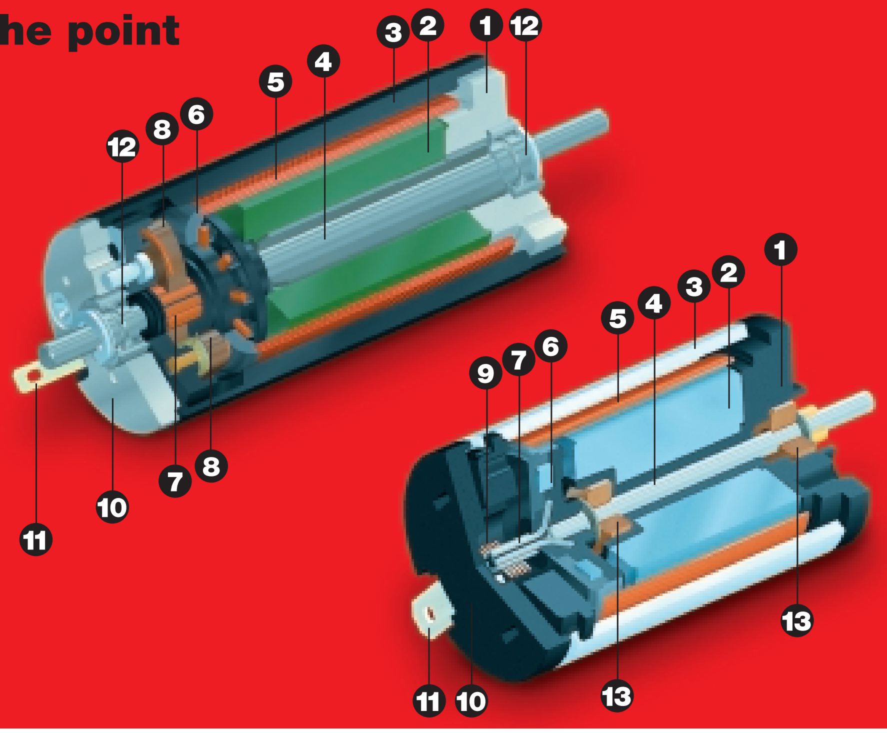
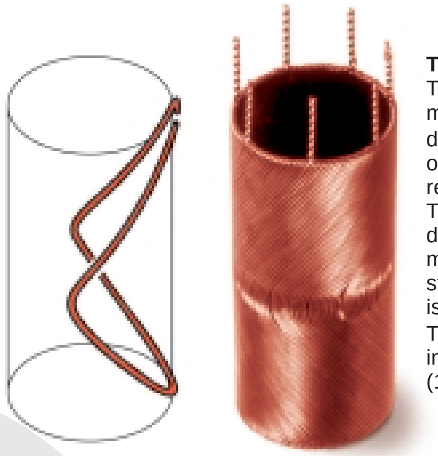
Technology – **short and to the point**

The outstanding technical features of
maxon DC motors:

- no magnetic cogging
- high acceleration thanks to a low mass inertia
- low electromagnetic interference
- low inductance
- high efficiency
- linearity between voltage and speed
- linearity between load and speed
- linearity between load and current
- small torque ripple thanks to multi-segment commutator
- able to bear high overloads for short periods
- compact design - small dimensions
- multiple combination possibilities with gears as well as DC tachometers and encoders.





Low terminal resistance (low resistance winding)	High terminal resistance (high resistance winding)
=	=
thick wire few turns	thin wire many turns
=	=
high starting currents high specific speed (rpm per volt)	low starting currents low specific speed (rpm per volt)

Standard wire diameters from 0.032 to 0.45 mm.

The maxon winding
There are numerous winding variants for each motor type (see motor data sheets). They are differentiated by the wire diameter and number of turns. This results in various motor terminal resistances.
This influences the motor parameters that describe the transformation of electrical and mechanical energy (torque and speed constants). This allows you to select the motor that is best suited to your application.
The maximum permissible winding temperature in high-temperature applications is 125°C (155°C in special cases), otherwise 85°C.

Mechanical commutation
Precious metal brushes and commutator
Our precious metal combinations ensure a highly constant and low contact resistance, even after a prolonged standstill time. The motors work with very low starting voltages and electrical interferences.

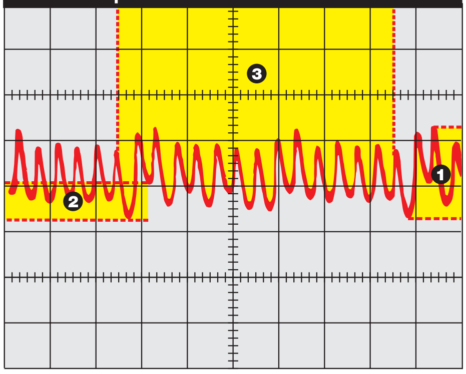
Precious metal brushes are typically used:

- in small motors
- in continuous operation
- with small current loads
- in DC tachometers
- with battery operation

CLL concept
The wear of commutators and brushes is mainly caused by sparks. The CLL concept suppresses spark generation to a large extent, thus greatly extending service life.

The commutation pattern is uniform and free of spikes, as opposed to that of other motors. The combination of precious metal brushes and maxon rotor system results in minimum of high-frequency interference, which otherwise leads to major problems in electronical circuits. The motors need practically no interference suppression.

Commutation pattern with precious metal brushes

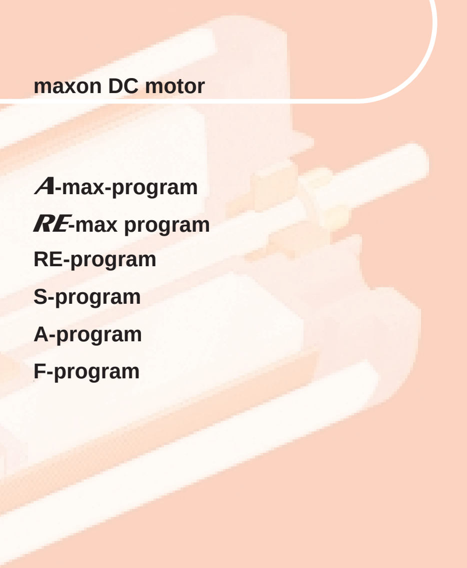


Legend:
❶ Ripple, actual peak-to-peak ripple
❷ Modulation, attributable mainly to asymmetry in the magnetic field and in the winding.
❸ Signal pattern within a revolution (number of peaks = double the number of commutator segments)

1. Flange
2. Permanent magnet
3. Housing (magnetic return)
4. Shaft
5. Winding
6. Commutator plate
7. Commutator
8. Graphite brushes
9. Precious metal brushes
10. Cover
11. Electrical connection
12. Ball bearing
13. Sintered sleeve bearing

Program

maxon DC motor



A-max-program

RE-max program

RE-program

S-program

A-program

F-program

Graphite brushes
In combination with copper commutators for the most rigorous applications.

Graphite brushes are typically used:
- in larger motors
- with high current loads
- in start/stop operation
- in reverse operation

More than 10 million cycles were attained in different applications.

The special properties of **graphite brushes** can cause so-called spikes. They are visible in the commutation pattern. Despite the high-frequency interference caused by the spikes, these motors have become popular in applications with electronic controls. Care should be taken that the contact resistance of the graphite brushes changes dependent on load.

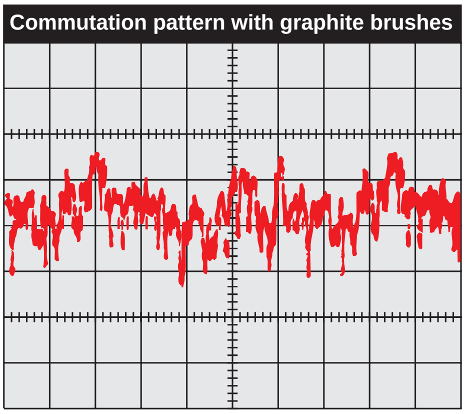
Turning speed
The optimal operating speeds are between 4000 rpm and 9000 rpm depending on the motor size. Speeds of more than 20'000 rpm have been attained with some special versions.

A physical property of a DC motor is that, at a constant voltage, the speed is reduced with increasing loads. A good adaptation to the desired conditions is possible thanks to a variety of winding variants. At lower speeds, a gear combination is often more favorable than a slowly turning motor.

Service life
A general statement about service life cannot be made due to many influencing factors. Service life can vary between more than 20'000 hours under favorable conditions, and less than 100 hours under extreme conditions (in rare cases). Roughly 1000 to 3000 hours are attained with average requirements.

The following have an influence:
1. The electric load: higher current loads result in greater electric wear. Therefore, it may be advisable to select a somewhat stronger motor for certain applications. We would be happy to advise you.
2. Speed: the higher the speed, the greater the mechanical wear.
3. Type of operation: extreme start/stop, left/right operation leads to a reduction in service life.
4. Environmental influences: temperature, humidity, vibration, type of installation, etc.
5. In the case of precious metal brushes, **the CLL concept** increases service life at higher loads and the benefits of precious metal brushes are retained.
6. Combinations **of graphite brushes** and ball bearings lead to a long service life, even under extreme conditions.

Commutation pattern with graphite brushes



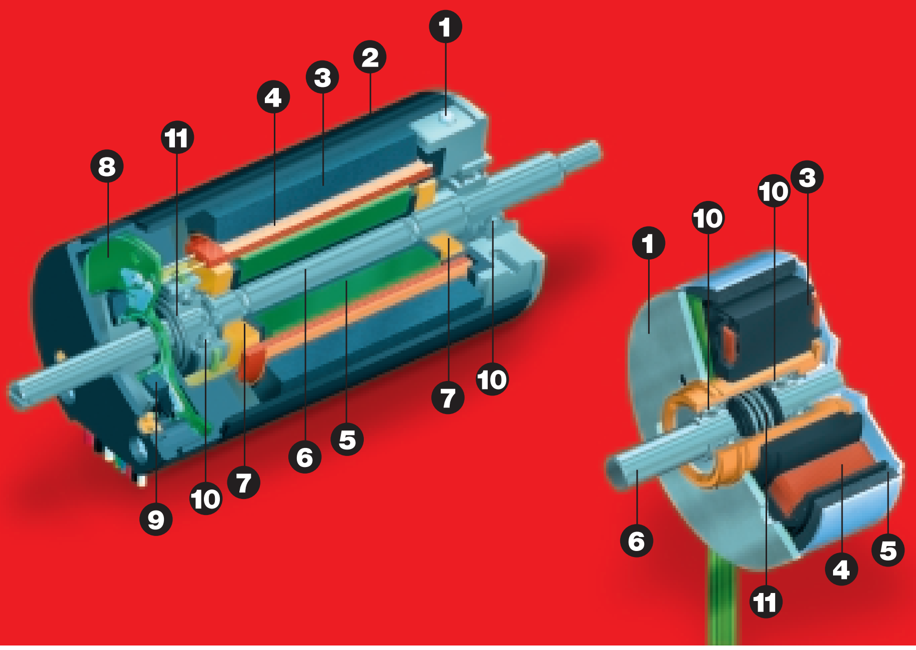
Commutation pattern
The commutation pattern shows the current pattern of a maxon DC motor over one motor revolution.
Please place a low-ohm series resistor in series with the motor (approx. 50 times smaller than the motor resistance). Observe the voltage drop over the resistor on the oscilloscope.

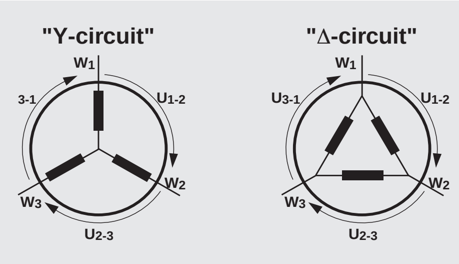
Technology – **short and to the point**

Special technical features of
maxon EC motors:

- no mechanical commutation
- long service life - only limited by bearing
- without cogging
- high speeds even at low voltages
- The maxon winding technology allows the winding to be optimized for specific applications
- good heat dissipation, high overload ability
- mainly linear motor characteristics, excellent control properties
- high efficiency
- very small electrical time constants and low inductance

The electronically commuted EC motors from maxon are high quality DC motors with neodymium magnets. Unlike maxon DC motors, the iron-less winding ❹ is stationary in this case. Instead, the permanent magnet ❺ turns in the electrically generated rotating field of the three-phase winding.





Y-circuit	Δ-circuit
lower motor currents	higher motor currents
higher voltage	lower voltage
high torque applications	high speed applications

Winding arrangement
The maxon rhombic winding is divided into three partial windings, each shifted by 120°. The partial windings can be connected in two different manners - "Y" or "Δ." This changes the speed and torque inversely proportional by the factor $\sqrt{3}$.
However, the winding arrangement does not play a decisive role in the selection of the motor. It is important for the motor specific parameters to match the requirements.

The maximum permissible winding temperature is 125°C.

Electronical commutation
Block commutation
The feedback of the rotor position is done by three Hall sensors installed in the motor. The two-pole control magnet and the hall sensors arranged offset by 120°, provide six different signal combinations per revolution. The three partial windings are now supplied in six different conducting phases in accordance with the sensor information. The current and voltage curves are block-shaped. The switching position of each electronic commutation is offset by 30° from the respective torque maximum.

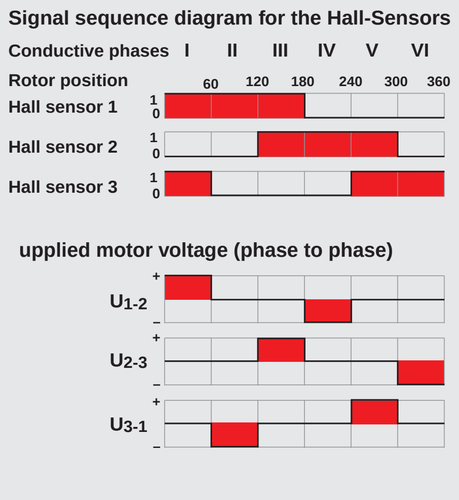
Properties of block commutation

- relatively simple and favorably priced electronics
- torque ripple of 14%
- controlled motor start-up
- high starting torques and accelerations possible
- The data of the maxon EC motors are determined with block commutation.

Possible applications

- highly dynamic servo drives
- start/stop operation
- positioning tasks

Block commutation



❶ Flange
❷ Housing
❸ Laminated steel stack
❹ Winding
❺ Permanent magnet
❻ Shaft
❼ Balancing disks
❽ Print with hall sensors
❾ Control magnet
❿ Ball bearing
⓫ Spring (bearing preload)

Program

maxon EC motor

with hall sensors

sensorless

with integrated electronics

EC flat motor

Sinusoidal commutation

The high resolution signals from the encoder or resolver are used for generating sine-shape motor currents in the electronics. The currents through the three motor windings are dependent on the rotor position and are shifted at each phase by 120 degrees (sinusoidal commutation). This results in the very smooth, precise running of the motor and, in a very precise, high quality control.

Properties of sinusoidal commutation

- more expensive electronics
- no torque ripple
- very smooth running, even at very low speeds
- high starting torques and accelerations possible

Possible applications

- highly dynamic servo drives
- positioning tasks

Sensorless commutation

The rotor position is determined using the progression of the induced voltage. The electronics evaluate the zero crossing of the induced voltage (EMF) and commute the motor current after a speed dependent pause (30° after EMF zero crossing). The amplitude of the induced voltage is dependent on the speed. When stalled or at low speed, the voltage signal is too small and the zero crossing cannot be detected precisely. This is why special algorithms are required for starting (similar to stepper motor control).
To allow EC motors to be commuted without sensors in a Δ arrangement, a virtual star point is usually created in the electronics.

Properties of sensorless commutation

- torque ripple of 14% (block commutation)
- no defined start-up
- not suitable for low speeds
- not suitable for dynamic applications

Possible applications

- continuous operation at higher speeds
- fans

Bearing

The EC motor only provides real benefits in conjunction with ball bearings. Most maxon EC motors have preloaded ball bearings.

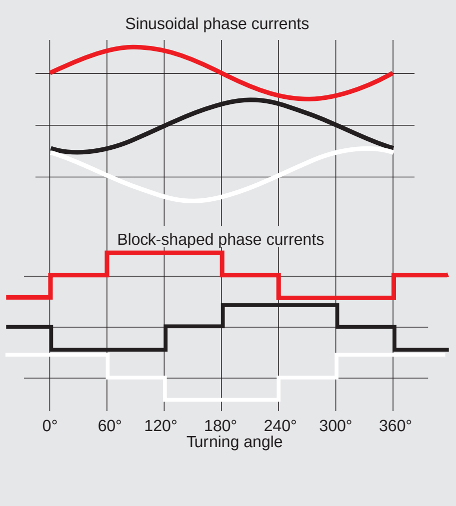
Turning speed

Operating speeds of up to 50’000 rpm are possible. In the case of multi-pole motors the electronics (max. switching frequency) can limit the speed, since more commutation cycles must be run through per motor revolution.
The maximum speed is calculated with the service life considerations of the ball bearing (20’000 hours) at the maximum permissible residual unbalance of the rotor.

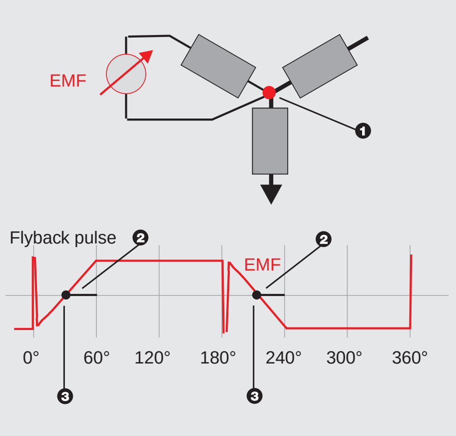
Service life

This is principally limited only by the service life of the bearing. Together with the expected service life of the electronic components used (industrial standards) the EC motor achieves a service life of several 10’000 hours.

Currents in sine and block commutation

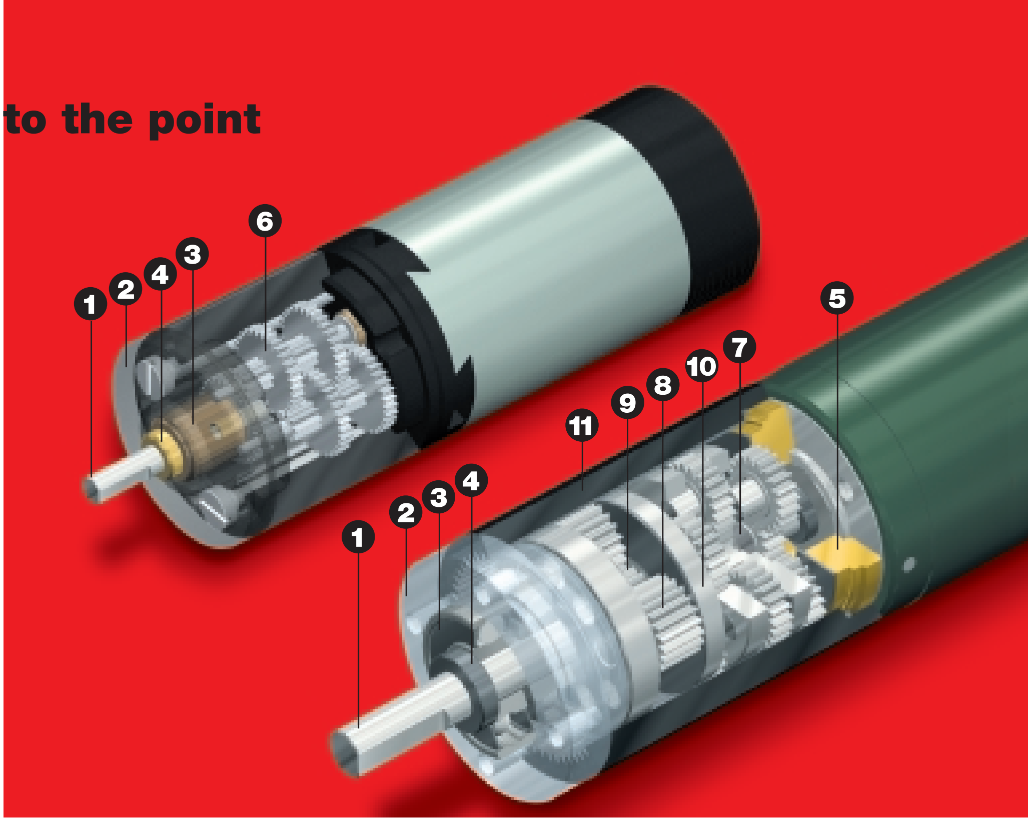


Sensorless commutation



Legend:
❶ Star point
❷ Time delay 30°
❸ Zero crossing of EMF

Technology – **short and to the point**



Gears
If mechanical power is required at a high torque and correspondingly reduced speed, a maxon precision gear is recommended. According to the gear ratio the output speed is reduced while the output torque is enhanced. For a more precise determination of the latter, efficiency must be taken into consideration.

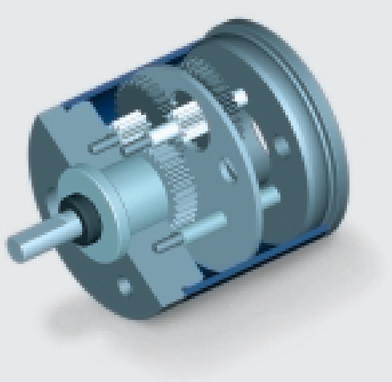
Spur gearhead
The gear consists of one or more stages. One stage represents the pairing of two cogwheels. The first cogwheel (pinion) is mounted directly on the motor shaft. The bearing of the output shaft is usually made of sintered material.

- favorably priced
- for low torques
- output torque up to 0.6 Nm
- reduction ratios of 4 : 1 to 5752 : 1
- external-∅12 - 38 mm
- low noise level
- high efficiency

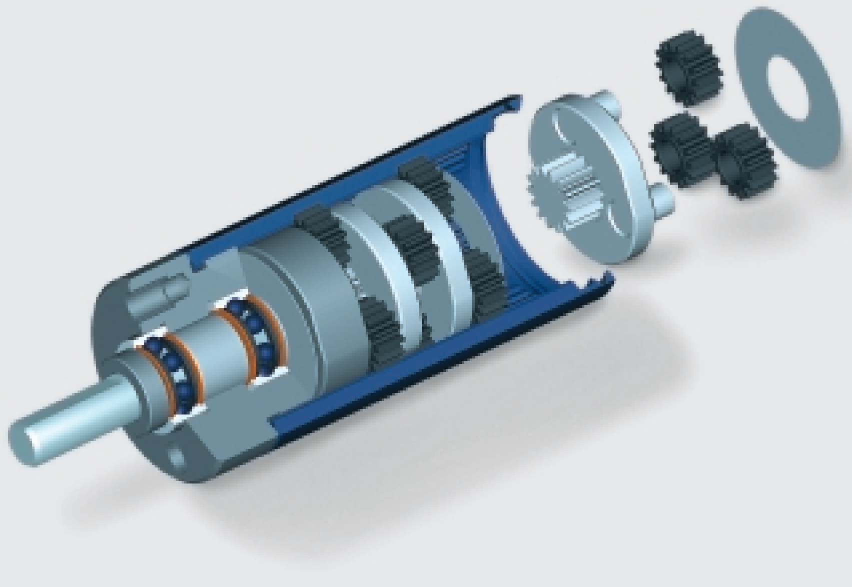
Planetary gearhead
Planetary gears are particularly suitable for the transfer of high torques. Larger gearheads starting at 22 mm diameter are equipped with ball bearings.

- for transferring high torques up to 180 Nm
- reduction ratios of 4 : 1 to 6285 : 1
- external-∅6 - 81 mm
- high performance in a small space
- high reduction ratio in a small space
- concentric gear input and output

Spur gearhead



Planetary gearhead



① **Output shaft**
② **Mounting flange**
③ **Bearing of the output shaft**
④ **Axial security**
⑤ **Intermediate plate**
⑥ **Cogwheel**
⑦ **Motor pinion**
⑧ **Planetary gearwheel**
⑨ **Sun gearwheel**
⑩ **Planet carrier**
⑪ **Internal gear**

Program

maxon gear

planetary gearhead
spur gearhead

Conversion

The conversion of speed and torque of the gear output (n_B, M_B) to the motor shaft (n_{mot}, M_{mot}) follows the following equations:

$$n_{mot} = i \cdot n_B$$

$$M_{mot} = \frac{M_B}{i \cdot \eta_g}$$

where:
i: ratio reduction
η_g: gearhead efficiency

Selection of gears

As with motors, speed and torque limits also apply to gearheads. The operating torque must lie below the continuous torque of the gear $M_{cont.,g}$.

$$M_{cont.,g} > M_B$$

With short-term loads, the intermittent torque of the gear should also be taken into consideration.

Note that the continuous torque of the gear is dependent on the number of stages. Where possible, the input speed of the gear $n_{max,g}$ should not be exceeded. This limits the maximum possible reduction i_{max} at a given operating speed. The following applies to the selection of the reduction i.

$$i \le i_{max} = \frac{n_{max,g}}{n_B}$$

If the gear is selected, the data conversed to the motor axis (n_{mot}, M_{mot}) are used to select the motor. The maxon modular system defines the proper motor/gear combinations.

Service life

The gears usually achieve 1’000 to 3’000 operating hours in continuous operation at the maximum permissible load and recommended input speed.

The following have an influence:

- exceeding maximum torque can lead to excessive wear.
- local temperature peaks in the area of tooth contact can destroy the lubricant.
- massively exceeding the gear input speed reduces the service life.
- radial and axial loads on the bearing.

Temperature/lubrication

maxon gears are lubricated for life. The lubricants used are especially effective in the recommended temperature range. At higher or lower operating temperatures we offer recommendations for special lubricants.

Ceramics

Ceramic components are increasingly used planetary gears, as they can significantly improve the wear characteristics of critical components.

This results in:

- longer service life
- higher continuous torques
- higher intermittent torques
- higher input speeds

Planetary gears made of plastic

Favorably priced and yet compact drives can be realized with plastic gears. The mechanical load is slightly smaller than that of metal designs, however, it is significantly higher than that of spur gears.

Technology – **short and to the point**

Sensors

maxon offers a series of sensors. Their characteristics are:

Digital incremental encoder

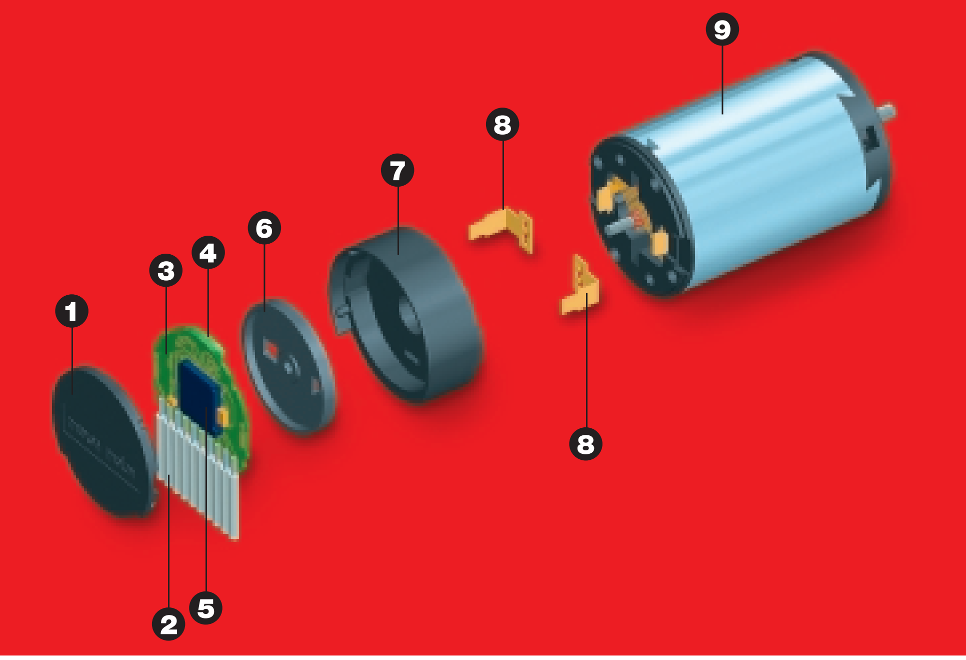
- relative position signal suitable for positioning tasks
- rotation direction recognition
- speed information from number of pulses per time unit
- standard solution for many applications

DC tachometer

- analog speed signal
- rotation direction recognition
- not suitable for positioning tasks

Resolver

- analog rotor position
- analog speed signal
- extensive evaluation electronics required in the control system
- for special solutions in conjunction with sinusoidal commutation in EC motors



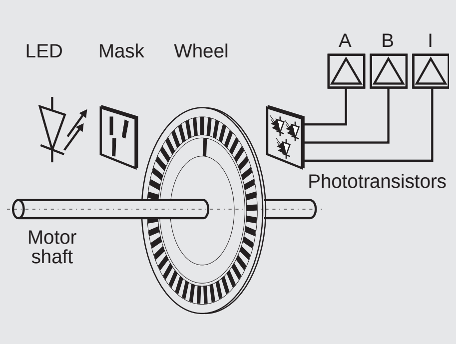
DC tachometer

As a rule, each maxon DC motor can be used as a DC tachometer. For motor/tachometer combinations we offer a DC tachometer that features significant voltage stability even with temperature fluctuations thanks to its AlNiCo magnets. The specified DC voltage is proportional to the speed. The tachometer rotor is directly mounted on the through motor shaft, resulting in a high resonant frequency. Additional tacho bearings, couplings and friction are eliminated.

Digital encoder, optical principle

The opto-electronic principle sends an LED light through a finely screened code wheel that is rigidly mounted onto the motor shaft. The receiver (photo transistor) changes light/dark signals into corresponding electrical impulses that are amplified and processed in the corresponding electronics.

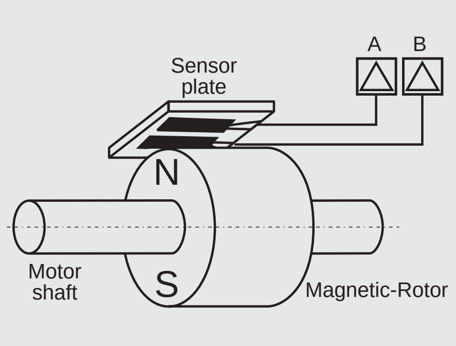
Schematic design of an opto-electronic encoder



Magnetic principle

In the magnetic encoder principle, a small, multi-pole permanent magnet sits on the motor shaft. The changes in magnetic flux are detected by magnetic sensors and are also fed to the electronics.

Schematic design of a magnetic encoder



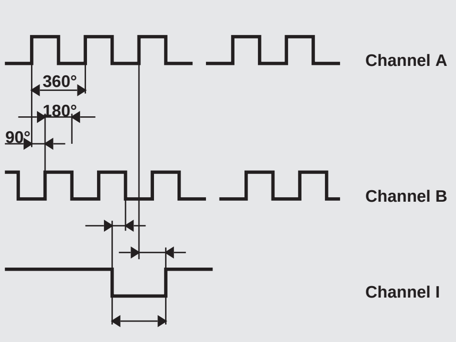
Encoder signals

The encoders provide a simple square signal for further processing in the control system. Its impulses can be counted for exact positioning or determining speed. Channels A and B pick up phase shifted signals, which are compared with one another to determine the rotation direction.

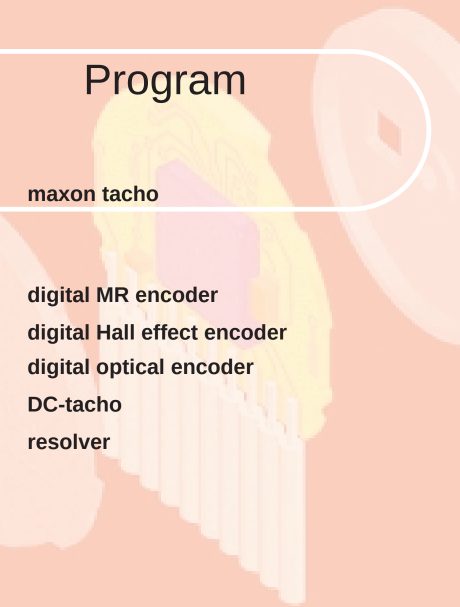
A "home" pulse (channel I) then provides zero crossing and is used as a reference point for precise determination of angular change.

The line driver generates complementary signals, with which the interference signals picked up in long signal lines can be eliminated.
In addition, this electronic driver installed in the encoder improves signal quality with steeper signal edges.

Representation of the output signal of a digital encoder



① End cap
② Electrical connections motor and encoder
③ Print
④ MR sensor
⑤ ASIC
⑥ Magnetic multi-pole wheel
⑦ Encoder housing
⑧ Motor connections
⑨ Motor



Program

maxon tacho

digital MR encoder
digital Hall effect encoder
digital optical encoder
DC-tacho
resolver

Important points for encoder selection

The main features of the maxon incremental encoder are the number of pulses per revolution (increments), the number and phase shift of the channels as well as the use of a line driver.

- The maxon controllers are optimally designed for encoders with 500 increments. Due to installation conditions, sometimes encoders with smaller pulse counts must be selected.
- The higher the pulse count, the better a smooth, jerk-free operation can be achieved even at low speeds.
- The frequency restrictions of the encoders and subsequent controller, limit the maximum speed up to which the encoder signals can be processed. The frequency limit of maxon encoders is typically 100 kHz, which is equivalent to a speed of 12'000 rpm with a 500 pulse encoder.

The following applies especially to positioning systems:

- All maxon positioning systems evaluate the rising and falling signal edges. With regard to encoder pulse count, this results in a four times higher positioning precision. This is what is referred to as quad counts.
- The higher the pulse count, the more precise the position that can be reached. At 500 pulses (2000 quad counts) an angle resolution of 0.18° is achieved, which is usually much better than the precision of the mechanical drive components (e.g. due to gear play or elasticity of drive belts).
- Only encoders with an integrated line driver (RS422) should be used in positioning controls. This prevents electromagnetic interference signals from causing signal loss and accumulated positioning errors. Positioning applications often require the index channel of the encoder for precise reference point detection.

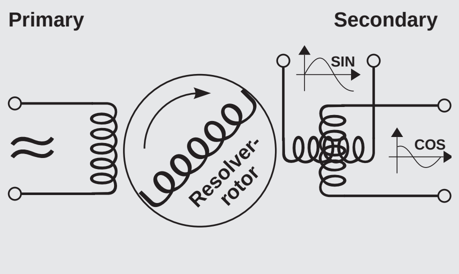
Resolver

The resolver is mounted on the through shaft of the motor and is adjusted according to the magnetic field of the motor rotor. It signals the current motor rotor position to the sinusoidal EC controller.
The resolver has a rotating primary coil (rotor) and two secondary coils (stator) offset by 90°. The alternating current connected to the primary coil is transferred to the secondary coils. The amplitudes of the secondary voltages are sine φ and cos φ, where φ is the rotation angle.

Benefits and features:

- robust, for industrial use
- long service life
- only one sensor needed
- no sensitive electronics
- no mechanical wear
- for positioning and speed information
- output signal can be transmitted over long distances without problems
- interference free transmission

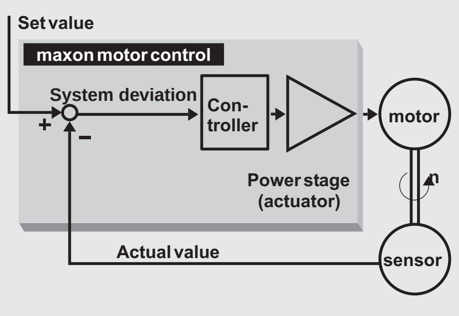
Schematic design of a resolver



Technology – **short and to the point**

The **maxon motor control** program contains servo amplifiers for controlling the fast reacting maxon DC and EC motors.

Principle of a control circuit



Speed control

The function of the speed servo amplifier is to keep the prescribed motor speed constant and independent of load changes. To achieve this, the set value (desired speed) is continuously compared with the actual value (actual speed) in the control electronics of the servo amplifier. The controller difference determined in this way is used by the controller to regulate the power stage of the servo amplifier in such a manner that the motor reduces the controller difference. This represents a closed speed regulating circuit.

Position control

The positioning control ensures a match between the currently measured position with a target position, by providing the motor with the corresponding correction values, as with a speed controller. The position data are usually obtained from a digital encoder.

Current control

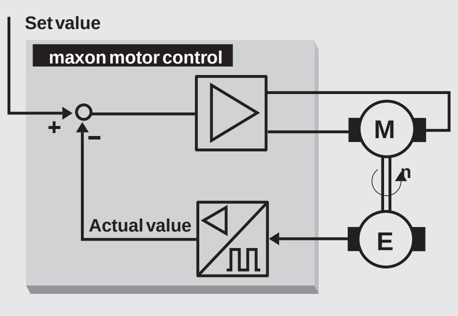
The current control provides the motor with a current proportional to the set value. Accordingly, the motor torque changes proportionally to the set value.
The current controller also improves the dynamics of a superior positioning or speed control circuit.

Digital encoder control

The motor is equipped with a digital encoder that provides a certain number of pulses per revolution. The turning direction is detected with the square pulses of channels A and B offset by 90 electric degrees.

- Digital encoders are often found in positioning controls, in order to derive and measure the travel or angle.
- Digital encoders are not subject to mechanical wear.
- In conjunction with digital controllers there are no drift effects.

Principle: Encoder control

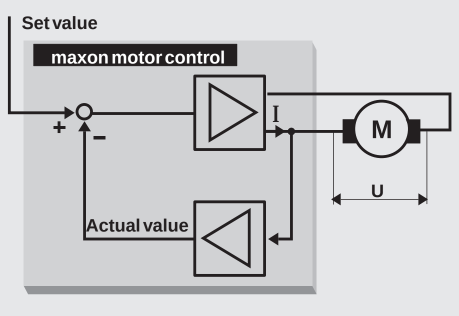


I x R compensation

The motor is provided with a voltage that is proportional to the applied speed set value. The speed would drop with increasing motor load. The compensation circuitry increases the output voltage with increasing motor current. The compensation must be adjusted to the terminal resistance of the motor which depends on temperature and load. The attainable speed precision of such a system is subject to limits in the percent range.

- favorably priced and space-saving
- no tacho-generator or encoder required
- less precise control when there is a load change
- only speed control possible
- ideal for low-cost applications without high demands on speed accuracy

Principle: I x R compensation



Motor type

- maxon DC motor
- maxon EC motor
  with or without sensor

Type of control

- Speed
- Position
- Current

Feedback

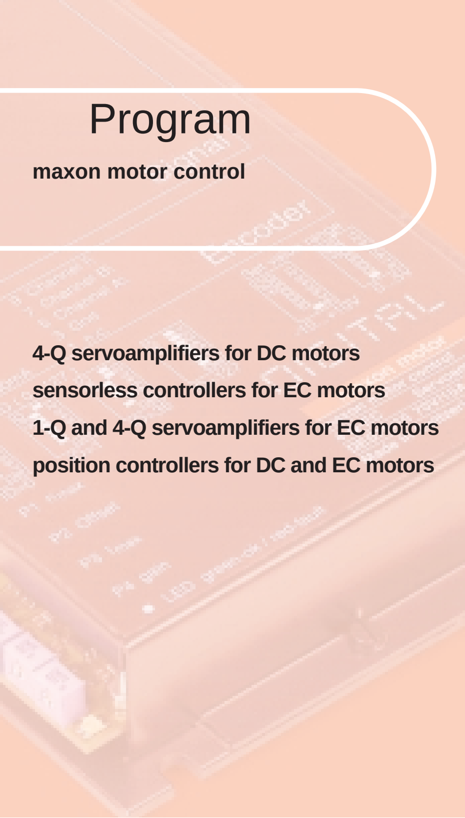
- Encoder
- DC Tacho
- I x R compensation
- Hall sensors
- Resolver

Power amplifiers

- Linear
- Pulsed
- 1 quadrant
- 4 quadrant

Circuit technology

- Digital
- Analog



Program

maxon motor control

4-Q servoamplifiers for DC motors

sensorless controllers for EC motors

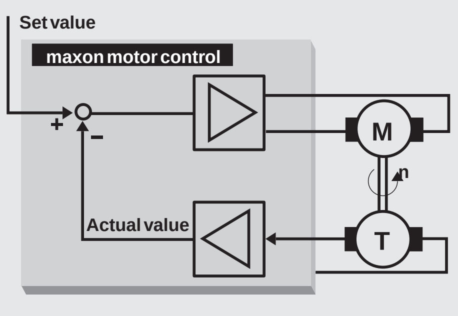
1-Q and 4-Q servoamplifiers for EC motors

position controllers for DC and EC motors

DC tacho control
The motor must be equipped with a DC tachometer that provides a speed proportional signal. In the maxon modular system, the tachometer rotor is mounted directly on the through motor shaft, resulting in a high resonant frequency.

- classical solution of a very precise control
- limited service life of the DC tacho generator
- not suitable for positioning tasks
- not digital
- ideal for stringent demands on speed dynamics

Principle: DC tachometer control



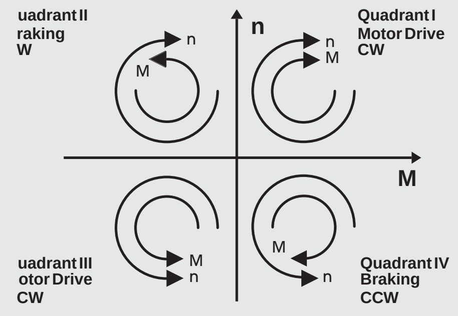
4-Q operation:

- controlled motor operation and braking operation in both rotation directions
- a must for positioning tasks

1-Q operation:

- only motor operation (Quadrant I or Quadrant III)
- direction reverse via digital signal
- typical: amplifier for EC motors

4-Q operation

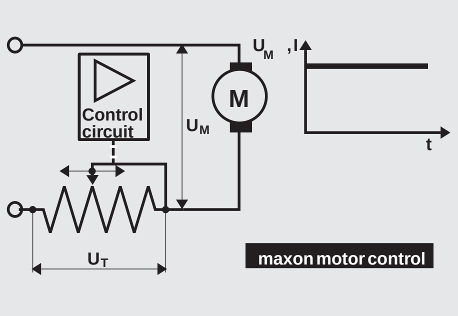


Power amplifiers
One of the following two principles to control the power stage transistors is used in maxon controllers:

a) Linear power stage
The operating voltage is divided between the motor and the power amplifier. The controller changes the voltage on the motor (U_M) linearly and proportionally. The voltage applied to the power amplifier (U_T) causes power dissipation

- high currents and low motor voltages cause significant power dissipation
- simple and favorably priced design of the power amplifier

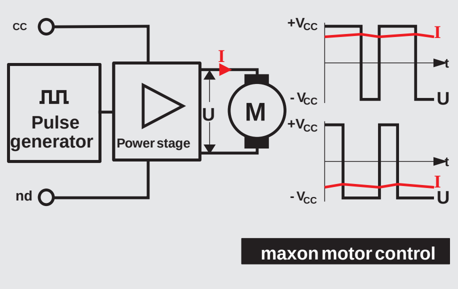
Principle: Linear power amplifier



b) Pulsed power stage (PWM)
The controller switches the motor on and off in short intervals (pulses/cycles). If the off interval is longer, the motor loses speed. The decisive average value of the voltage changes in relation to the on-to-off time. Only little energy is converted into heat.

- more expensive power amplifier
- high efficiency

Principle: Pulsed power amplifier



Key information on – **maxon DC motor and maxon EC motor**

See also: Technology - short and to the point, explanation of the motor data

The motor as an energy converter

The electrical motor converts electrical power P_{el} (current I and voltage U) into mechanical power P_{mech} (speed n and torque M). The losses that arise are divided into frictional losses, attributable to P_{mech} and in Joule power losses P_J of the winding (resistance R). Iron losses do not occur in the coreless maxon DC motors. In maxon EC motors, they are treated formally like an additional friction torque. The power balance can therefore be formulated as:

$$P_{el} = P_{mech} + P_J$$

The detailed result is as follows:

$$U \cdot I = \frac{\pi}{30'000} n \cdot M + R \cdot I^2$$

Electromechanical motor constants
The geometric arrangement of the magnetic circuit and winding defines in detail how the motor converts the electrical input power (current, voltage) into mechanical output power (speed, torque). Two important characteristic values of this energy conversion are the speed constant k_n and the torque constant k_M. The speed constant combines the speed n with the voltage induced in the winding U_{ind} (=EMF). U_{ind} is proportional to the speed; the following applies:

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

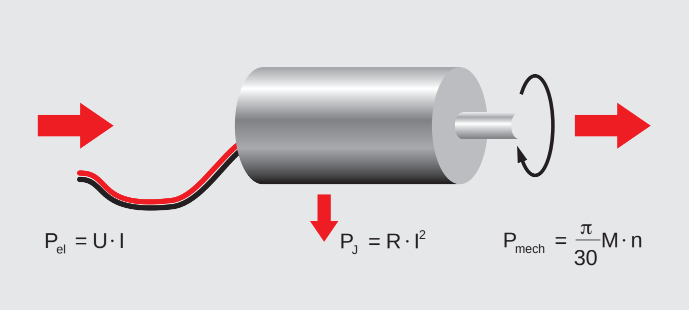
Similarly, the torque constant links the mechanical torque M with the electrical current I.

$$M = k_M \cdot I$$

The core statement of this proportionality is that the variables torque and current are equivalent for the maxon motors.

Units
In all formulas, the variables are to be used in the units according to the catalog (cf. physical variables and their units on page 40).

The following applies in particular:
- all torques in mNm
- all currents in A (even no-load currents)
- speeds (rpm) instead of angular velocity (rad/s)



Motor constants
Speed constant k_n and torque constant k_m are not independent of one another. The following applies:

$$k_n \cdot k_M = \frac{30'000}{\pi}$$

The speed constant is also called specific speed. Specific voltage, generator or voltage constants are mainly the reciprocal value of the speed constant and describe the voltage induced in the motor per speed.
The torque constant is also called specific torque. The reciprocal value is called specific current or current constant.

Motor diagrams

A diagram can be drawn for every maxon DC and EC motor, from which key motor data can be taken.
Although tolerances and temperature influences are not taken into consideration, the values are sufficient for a first estimation in most applications. In the diagram, speed n, current I, output power P_2 and efficiency η are drawn as a function of the torque M.

Speed-torque line
This curve describes the mechanical behavior of the motor at a constant voltage U:
- Speed decreases linearly with increasing torque.
- The faster the motor turns, the less torque it can provide.

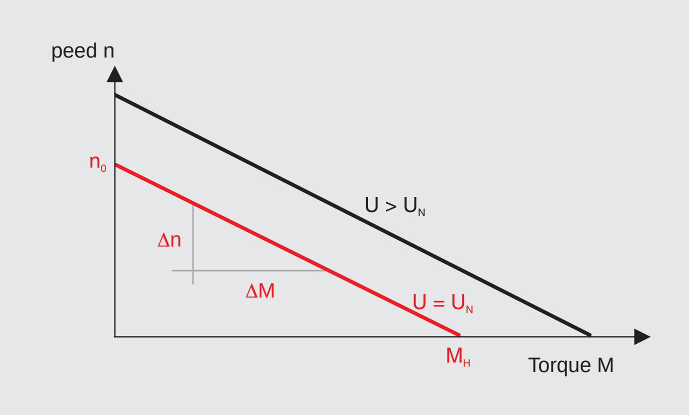
The curve can be described with the help of the two end points, no-load speed n_o and stall torque M_B (cf. lines 3 and 4 in the motor data).
DC motors can be operated at any voltage. No-load speed and stall torque change proportionally to the applied voltage. This is equivalent to a parallel shift of the speed-torque line in the diagram. Between the no-load speed and voltage, the following proportionality applies in good approximation

$$n_0 \approx k_n \cdot U$$

where k_n is the speed constant (line 15 of the motor data).

Independent of the voltage, the speed-torque line is described most practically by the slope or gradient of the curve (line 5 of the motor data).

$$\frac{\Delta n}{\Delta M} = \frac{n_0}{M_H}$$



Derivation of the speed-torque line
The following occurs if one replaces current I with torque M using the torque constant in the detailed power balance:

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

Transformed and taking account of the close relationship of k_M and k_n, an equation is produced of a straight line between speed n and torque M.

$$n = k_n \cdot U - \frac{30'000}{\pi} \cdot \frac{R}{k_m^2} \cdot M$$

or with the gradient $\frac{\Delta n}{\Delta M}$ and the no-load speed n_0

$$n = n_0 - \frac{\Delta n}{\Delta M} \cdot M$$

The speed-torque gradient is one of the most informative pieces of data and allows direct comparison between different motors. The smaller the speed-torque gradient, the less sensitive the speed reacts to torque (load) changes and the stronger the motor. With the maxon motor, the speed-torque gradient within the winding series of a motor type (i.e. on one catalog page) remains practically constant.

Current curve

The current curve represents the equivalence of current and torque: the more current that flows through the motor, the more torque is produced. The current curve can be easily drawn through the two end points no-load current I_0 and starting current I_A (lines 6 and 7 of the motor data). The no-load current is equivalent to the friction torque M_R, that describes the internal friction in the bearings and commutation system.

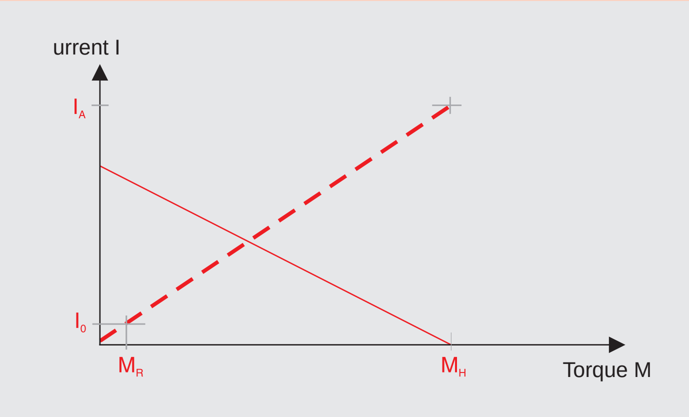
$$M_R = k_M \cdot I_0$$

In the maxon EC motor, there are strong, speed dependent iron losses in the stator iron stack instead of friction losses in the commutation system.

The motors develop the highest torque when starting. It is many times greater than the normal operating torque, so the current uptake is the greatest as well.

The following applies for the stall torque M_H and starting current I_A:

$$M_H = k_M \cdot I_A$$

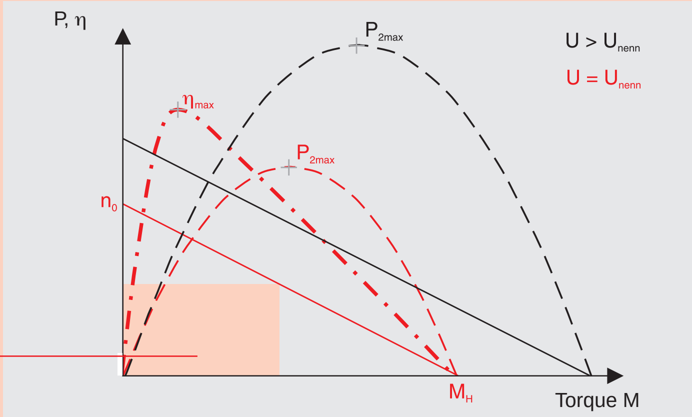


Output power curve

The mechanical output power P_2 is calculated from the speed n and the torque M

$$P_2 = \frac{\pi}{30'000} n \cdot M$$

In the speed-torque diagram, the output power is equivalent to the area of the rectangle below the speed-torque line. This rectangle and, thus, the output power, is greatest at half stall torque and half no-load speed. The power curve is a parabola, whose maximum value (line 12 of the motor data) depends quadratically on the applied motor voltage.



Efficiency curve

The efficiency η describes the relationship of mechanical power delivered to electrical power consumed.

$$\eta = \frac{\pi}{30'000} \cdot \frac{n \cdot M}{U \cdot I}$$

One can see that at constant applied voltage U and due to the proportionality of torque and current, the efficiency increases with increasing speed (decreasing torque). At low torques, friction losses become increasingly significant and efficiency rapidly approaches zero. Maximum efficiency (line 13 of motor data) is calculated using the starting current and no-load current and is dependent on voltage

$$\eta_{max} = \left(1 - \sqrt{\frac{I_0}{I_A}}\right)^2$$

A rule of thumb is that maximum efficiency occurs at roughly one seventh of the stall torque. This means that maximum efficiency and maximum output power do not occur at the same torque.

Operating ranges: the limits of the motor

In the catalog, there is a diagram that covers the winding range for every maxon DC and EC motor type. The limits of the operating ranges are:

The maximum permissible speed
is primarily limited by the commutation system. The commutator and brushes wear more rapidly at very high speeds. The reasons are:

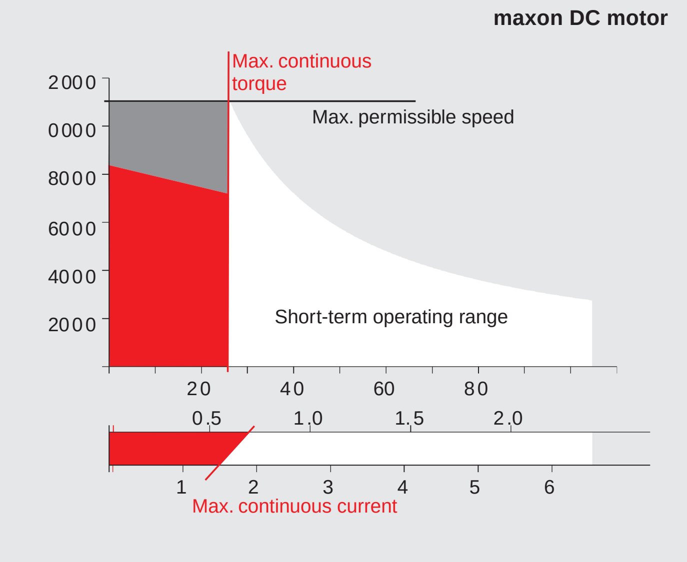
- increased mechanical wear because of the large traveled path of the commutator
- increased electro-erosion because of brush vibration and spark formation.

A further reason for limiting the speed is the rotor's residual mechanical imbalance which shortens the service life of the bearings. Higher speeds than the limit speed n_{max} (line 9) are possible, however, they are "paid for" by a reduced service life expectancy.

Maximum continuous current, maximum continuous torque
Due to the maximum winding temperature, a maximum current must not be exceeded in continuous operation. The heat produced must be able to dissipate and the maximum rotor temperature should not be exceeded. This results in a maximum continuous current $I_{cont.}$ (line 10 of the motor data), at which the maximum winding temperature is attained under standard conditions (25°C ambient temperature, no heat dissipation via the flange, free air circulation). Higher motor currents cause excessive winding temperatures.
The maximum continuous current is heavily dependent on the winding. Thin wire windings have smaller continuous currents than thick wire windings. In the case of low-resistance windings, the current bearing ability of the commutation system further limits the continuous current. Based on the equivalence of the motor current and torque, each motor is assigned a maximum continuous torque (line 11 of the motor data). It is practically constant within the winding series of a motor type and represents a characteristic parameter for each motor type.

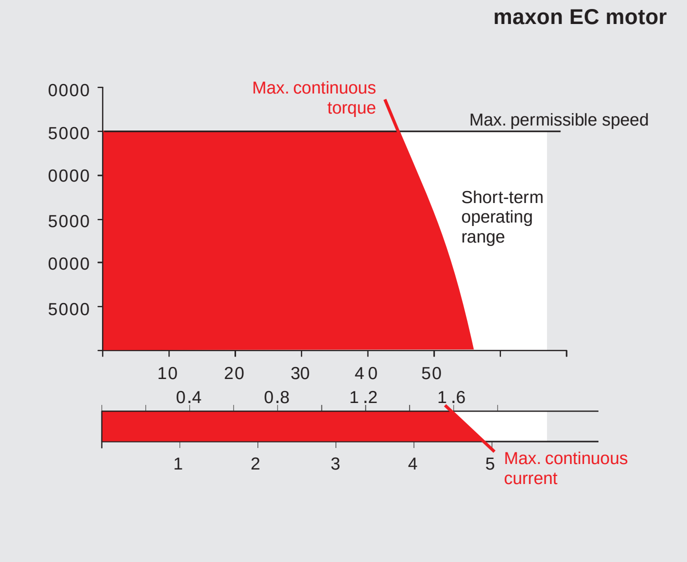
Permanent operating range
The two criteria "maximum continuous torque" and "maximum permissible speed" limit the continuous operating range. Operating points within this range are not critical thermally and do not generally cause increased wear of the commutation system. For many DC motors, it is recommended for service life reasons that the speed limit should not be fully exploited, but the motor operated below the nominal voltage instead. This operating range is called the recommended operating range.

Short-term operating range
The motor may only be loaded with the maximum continuous current for thermal reasons. However, temporary higher currents (torques) are allowed. As long as the winding temperature is below the critical value, the winding will not be damaged.
Phases with increased currents are time limited. A measure of how long the temporary overload can last is provided by the thermal time constant of the winding. The magnitude of the times with overload ranges from several seconds for the smallest motors (10 mm to 13 mm diameter) up to roughly one minute for the largest (60 mm, 75 mm diameter). The calculation of the exact overload time is heavily dependent on the motor current and the rotor's starting temperature.
In order not to overload the commutation system, it is recommended that the speed be reduced with increasing overload. The upper limit of the short-term operating range is, therefore, formed by a hyperbola of constant mechanical energy.



Maximum winding temperature

The motor current causes the winding to heat up due to the winding's resistance. To prevent the motor from overheating, this heat must dissipate to the environment via the stator. The coreless winding is the thermally critical point. The maximum rotor temperature must not be exceeded, even temporarily. With graphite brush motors which tend to have higher current loads, the maximum rotor temperature is 125°C (in individual cases up to 155°C). Motors with precious metal commutators only allow lower current loads, so that the rotor temperatures must not exceed 85°C.
Favourable mounting conditions, such as good air circulation or cooling plates, can significantly lower temperatures.



Operating ranges of the maxon EC motor

The maximum permissible speed is calculated using the service life considerations of the ball bearings (at least 20'000 hours) at the maximum residual unbalance of the rotor.
The limit of the continuous operating range is formed by the maximum winding temperature. With increasing speed eddy current losses grow in the magnetic return, causing additional heating. Thus, at higher speeds, the maximum continuous current and the maximum continuous torque decrease.

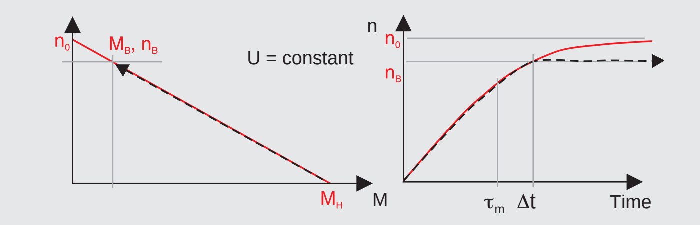
Acceleration

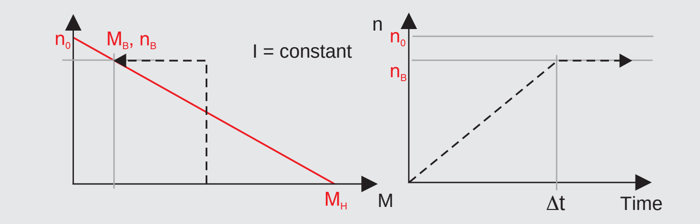
In accordance with the electrical boundary conditions (power supply, control, battery), a distinction is principally made between two different starting processes:

- Start under constant voltage (without current limitation)
- Start under constant current (with current limitation)

Start with constant terminal voltage
Here, the speed increases from the stall torque along the speed-torque line. The greatest torque and thus the greatest acceleration is effective at the start. The faster the motor turns, the lower the acceleration. The speed increases more slowly. This exponentially flattening increase is described by the mechanical time constant τ_m (line 16 of the motor data). After this time, the rotor at the free shaft end has attained 63% of the no-load speed. After roughly three mechanical time constants, the rotor has almost reached the no-load speed.

Start with constant current
A current limit always means that the motor can only deliver a limited torque. In the speed-torque diagram, the speed increases on a vertical line with a constant torque. Acceleration is also constant, thus simplifying the calculation.
Start at constant current is usually found in applications with servo amplifiers, where acceleration torques are limited by the amplifier's peak current.





Several useful formulas for acceleration
(all variables in units according to the catalog)

Under constant current:

- Mechanical time constant τ_m (in ms) of the unloaded motor:

$$\tau_m = 100 \cdot \frac{J_R \cdot R}{k_M^2}$$

- Mechanical time constants τ_m' (in ms) with an additional load inertia J_L:

$$\tau_m' = 100 \cdot \frac{J_R \cdot R}{k_M^2}\left(1 + \frac{J_L}{J_R}\right)$$

- Maximum angular acceleration α_{max} (in rad/s^2) of the unloaded motor:

$$\alpha_{max} = 10^4 \cdot \frac{M_H}{J_R}$$

- Maximum angular acceleration α_{max} (in rad/s^2) with an additional load inertia J_L:

$$\alpha_{max} = 10^4 \cdot \frac{M_H}{J_R + J_L}$$

- Run-up time (in ms) at constant voltage up to the operating point (M_B, n_B):

$$\Delta t = \tau_m' \cdot \ln\left(\frac{\left(1 - \frac{M_B + M_R}{M_H}\right) \cdot n_0}{\left(1 - \frac{M_B + M_R}{M_H}\right) \cdot n_0 - n_B}\right)$$

Under constant current:

- Angular acceleration α (in rad/s^2) at constant current I or constant torque M with an additional load of inertia J_L:

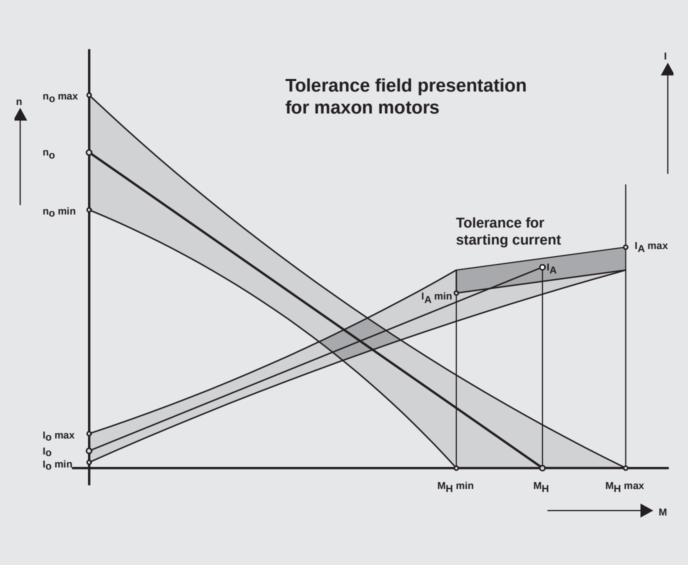
$$\alpha = 10^4 \cdot \frac{k_M \cdot I}{J_R + J_L} = 10^4 \cdot \frac{M}{J_R + J_L}$$

- Run-up time Δt (in ms) at a speed change Δn with an additional load inertia J_L:

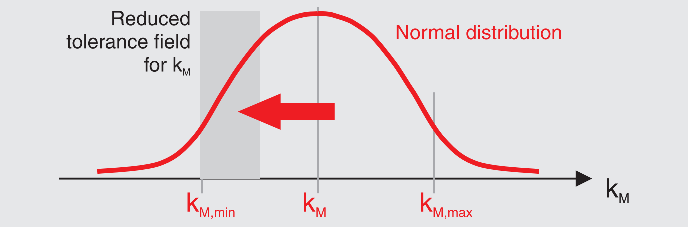
$$\Delta t = \frac{\pi}{300} \cdot \Delta n \cdot \frac{J_R + J_L}{k_M \cdot I}$$

Tolerances

Tolerances must be considered in critical ranges. The possible deviations of the mechanical dimensions can be found in the overview drawings. The motor data are average values: the adjacent diagram shows the effect of tolerances on the curve characteristics. They are mainly caused by differences in the magnetic field strength and in wire resistance, and not so much by mechanical influences. The changes are heavily exaggerated in the diagram and are simplified to improve understanding. It is clear, however, that in the motor's actual operating range, the tolerance range is more limited than at start or at no-load. Our computer sheets contain all detailed specifications.



Calibrating
The tolerances can be limited by controlled de-magnetization of the motors. Motor data can be accurately specified down to 1 to 3%. However, the motor characteristic values lie in the lower portion of the standard tolerance range.



Thermal behavior

The Joule power losses P_J in the winding determine heating of the motor. This heat energy must be dissipated via the surfaces of the winding and motor.
The increase ΔT_W of the winding temperature T_W with regard to the ambient temperature arises from heat losses P_J and thermal resistances R_{th1} and R_{th2}.

$$T_W - T_U = \Delta T_W = (R_{th1} + R_{th2}) \cdot P_J$$

Here, thermal resistance R_{th1} relates to the heat transfer between the winding and the stator (magnetic return and magnet), whereas R_{th2} describes the heat transfer from the housing to the environment. Mounting the motor on a heat dissipating chassis noticeably lowers thermal resistance R_{th2}. The values specified in the data sheets for thermal resistances and the maximum continuous current were determined in a series of tests, in which the motor was end-mounted onto a vertical plastic plate. The modified thermal resistance R_{th2} that occurs in a particular application must be determined using original installation and ambient conditions.

The heating runs at different rates for the winding and stator due to the different masses. After switching on the current, the winding heats up first (with time constants from several seconds to half a minute). The stator reacts much slower, with time constants ranging from 1 to 30 minutes depending on motor size. A thermal balance is gradually established. The temperature difference of the winding compared to the ambient temperature can be determined with the value of the current I (or in intermittent operation with the effective value of the current $I = I_{RMS}$).

$$\Delta T_W = \frac{(R_{th1} + R_{th2}) \cdot R \cdot I^2}{1 - \alpha_{Cu} \cdot (R_{th1} + R_{th2}) \cdot R \cdot I^2}$$

Here, electrical resistance R must be applied at the actual ambient temperature.

Influence of temperature
An increased motor temperature affects winding resistance and magnetic characteristic values.

Winding resistance increases linearly according to the thermal resistance coefficient for copper: $\left(\alpha_{Cu} = 0.00392 \frac{1}{K}\right)$:
$$R_T = R_{25} \cdot \left(1 + \alpha_{Cu}\left(T - 25°C\right)\right)$$
Example: a winding temperature of 75°C causes the winding resistance to increase by nearly 40%.

The magnet becomes weaker at higher temperatures. The reduction is 1 to 10% at 75°C depending on the magnet material.

The most important consequence of increased motor temperature is that the speed curve becomes steeper which reduces the stall torque. The changed stall torque can be calculated in first approximation from the voltage and increased winding resistance.

$$M_{HT} = k_M \cdot I_{AT} = k_M \cdot \frac{U}{R_T}$$

Motor selection

The drive requirements must be defined before proceeding to motor selection.

- How fast and at which torques does the load move?
- How long do the individual load phases last?
- What accelerations take place?
- How great are the mass inertias?

Often the drive is indirect, this means that there is a mechanical transformation of the motor output power using belts, gears, screws and the like. The drive parameters, therefore, are to be calculated to the motor shaft. Additional steps for gear selection are listed below. Furthermore, the power supply requirements need to be checked.

- Which maximum voltage is available at the motor terminals?
- Which limitations apply with regard to current?

The current and voltage of motors supplied with batteries or solar cells are very limited. In the case of control of the unit via a servo amplifier, the amplifier's maximum current is often an important limit.

Selection of motor types

The possible motor types are selected using the required torque. On the one hand, the peak torque, M_{max}, is to be taken into consideration and on the other, the effective torque M_{RMS}.

Continuous operation is characterized by a single operating point (M_B, n_B). The motor types in question must feature a continuous torque, M_{cont} that is larger than the operating torque MB.

$$M_{cont.} > M_B$$

Unlike continuous operation, in work cycles such as start/stop operation, the effective torque must be less than the motor's continuous torque. This prevents the motor from overheating.

$$M_{cont.} > M_{RMS}$$

The stall torque of the selected motor should usually exceed the required peak torque.

$$M_H > M_{max}$$

Selection of the winding: electric requirement

In selecting the winding, it must be ensured that the voltage applied directly to the motor is sufficient for attaining the required speed in all operating points.

Unregulated operation

In applications with only one operating point, this is often achieved with a fixed voltage U. A winding is sought with a speed-torque line that passes through the operating point at the specified voltage. The calculation uses the fact that all motors of a type feature practically the same speed-torque gradient. A target no-load speed $n_{0,\ set}$ is calculated from operating point (n_B, M_B).

$$n_{0,set} = n_B + \frac{\Delta n}{\Delta M} M_B$$

This target no-load speed must be achieved with the existing voltage U, which defines the target speed constant.

$$k_{n,set} = \frac{n_{0,set}}{U}$$

Those windings whose k_n is as close to $k_{n,\ set}$ as possible, will approximate the operating point the best at the specified voltage. A somewhat larger speed constant results in a somewhat higher speed, a smaller speed constant results in a lower one. The variation of the voltage adjusts the speed to the required value, a principle that servo amplifiers also use.

Motor current I is calculated from the torque constant k_M of the selected winding and the operating torque M_B.

$$I = \frac{M_B}{k_M}$$

Tips for evaluating the requirements:

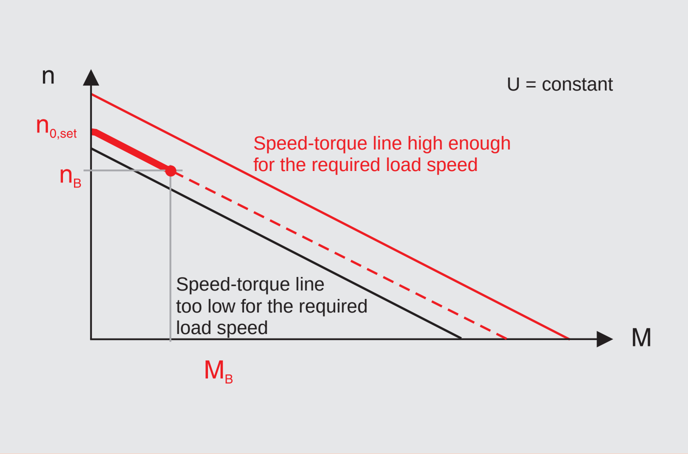
Often the load points (especially the torque) are not known or are difficult determine. In such cases you can operate your device with a measuring motor roughly estimated according to size and power. Vary the voltage until the desired operating points and motion sequences have been achieved. Measure the voltage and current flow. Using these specifications and the order number of the measuring motor, our engineers can often specify the suitable motor for your application.

Additional optimization criteria are, for example:

- mass to be accelerated (type, mass inertia)
- type of operation (continuous, intermittent, reversing)
- ambient conditions (temperature, humidity, medium)
- power supply, battery

When selecting the motor type, other constraints also play a major role?

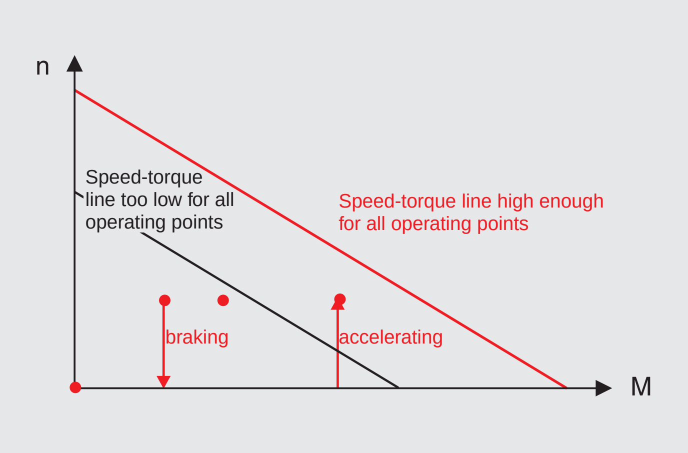
- What maximum length should the drive unit have, including gear and encoder?
- What diameter? What service life is expected from the motor and which commutation system should be used?
- Precious metal commutation for continuous operation at low currents (rule of thumb for longest service life: up to approx. 50% of $I_{cont.}$)
- Graphite commutation for high continuous currents (rule of thumb: 50% to approx. 75% of $I_{cont.}$) and frequent current peaks (start/stop operation, reversing operation).
- Electronic commutation for highest speeds and longest service life.
- How great are the forces on the shaft, do ball bearings have to be used or are less expensive sintered bearings sufficient?



Regulated servo drives
In work cycles, all operating points must lie beneath the curve at a maximum voltage U_{max}. Mathematically, this means that the following must apply for all operating points (n_B, M_B):

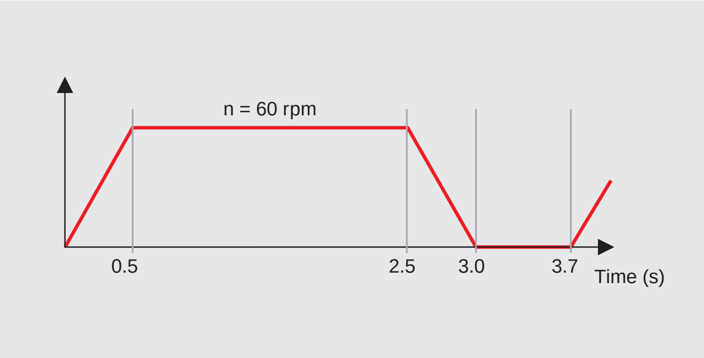
$$k_n \cdot U_{max} = n_0 > n_B + \frac{\Delta n}{\Delta M} M_B$$

When using servo amplifiers, a voltage drop occurs at the power stage, so that the effective voltage applied to the motor is lower. This must be taken into consideration when determining the maximum supply voltage U_{max}. It is recommended that a regulating reserve of some 20% be included, so that regulation is even ensured with an unfavorable tolerance situation of motor, load, amplifier and supply voltage.
Finally, the average current load and peak current are calculated ensuring that the servo amplifier used can deliver these currents. In some cases, a higher resistance winding must be selected, so that the currents are lower. However, the required voltage is then increased.



Example for motor/gear selection

A drive should move cyclically in accordance with the following speed diagram.



The inertia of load J_L to be accelerated is 120,000 gcm². The constant friction torque is 300 mNm. The motor is to be driven with the linear 4-Q servo amplifier from maxon (LSC). The power supply delivers max. 5A and 24V.

Calculation of load data
The torque required for acceleration and braking is calculated as (motor and gear inertia are ignored).

$$M_\alpha = J_L \cdot \alpha = J_L \cdot \tfrac{\pi}{30} \frac{\Delta n}{\Delta t} = 0.012 \cdot \tfrac{\pi}{30} \cdot \frac{60}{0.5} = 0.15\text{Nm} = 150\text{mNm}$$

Together with the friction torque, the following torques result for the different phases of motion.

– acceleration phase	(duration 0.5 s)	450 mNm
– constant speed	(duration 2 s)	300 mNm
– braking (friction helps braking)	(duration 0.5 s)	-150 mNm
– standstill	(duration 0.7 s)	0 mNm

Peak torque occurs during acceleration. The RMS determined torque of the entire work cycle is

$$M_{RMS} = \sqrt{\frac{1}{t_{tot}}\left(t_1 M_1^2 + t_2 M_2^2 + t_3 M_3^2 + t_4 M_4^2\right)}$$

$$= \sqrt{\frac{1}{3.7}\left(0.5 \cdot 450^2 + 2 \cdot 300^2 + 0.5 \cdot 150^2 + 0.7 \cdot 0^2\right)} \approx 280\text{mNm}$$

The maximum speed (60 rpm) occurs at the end of the acceleration phase at maximum torque (450 Nm). Thus, the peak mechanical power is.

$$P_{max} = M_{max} \cdot n_{max} \cdot \tfrac{\pi}{30} = 0{,}45 \cdot 60 \cdot \tfrac{\pi}{30} \approx 2.8\text{W}$$

Physical variables		and their units	
		SI	catalog
i	Gear reduction *		
I	motor current	A	A, mA
I_A	starting current *	A	A, mA
I_0	no-load current *	A	mA
I_{RMS}	RMS determined current	A	A, mA
$I_{cont.}$	maximum continuous current	A	A, mA
J_R	moment of inertia of the rotor *	kgm²	gcm²
J_L	moment of inertia of the load	kgm²	gcm²
k_M	torque constant *	Nm/A	mNm/A
k_n	speed constant *		rpm/V
M	(motor) torque	Nm	mNm
M_B	operating torque	Nm	mNm
M_H	stall torque *	Nm	mNm
M_{mot}	motor torque	Nm	mNm
M_R	moment of friction	Nm	mNm
M_{RMS}	RMS determined torque	Nm	mNm
$M_{cont.}$	maximum continuous torque *	Nm	mNm
$M_{cont.,g}$	max. torque of gear *	Nm	Nm
n	speed		rpm
n_B	operating speed		rpm
n_{max}	limit speed of motor *		rpm
$n_{max,g}$	limit speed of gear *		rpm
n_{mot}	motor speed		rpm
n_0	no-load speed *		rpm
P_{el}	electrical power	W	W
P_J	Joule power loss	W	W
P_{mech}	mechanical power	W	W
R	terminal resistance	Ω	Ω
R_{25}	resistance at 25°C *	Ω	Ω
R_T	resistance at temperature T	Ω	Ω
R_{th1}	heat resistance winding housing		K/W
R_{th2}	heat resistance housing/air *		K/W
t	time	s	s
T	temperature	K	°C
T_{max}	max. maximum winding temperature *	K	°C
T_U	ambient temperature	K	°C
T_W	winding temperature	K	°C
U	motor voltage	V	V
U_{ind}	induced voltage (EMF)	V	V
U_{max}	max. supplied voltage	V	V
U_N	nominal voltage *	V	V
α_{Cu}	resistance coefficient of Cu		
α_{max}	maximum angle acceleration		rad/s²
$\Delta n/\Delta M$	curve gradient *		rpm/mNm
ΔT_W	temperature difference winding/ambient	K	K
Δt	run up time	s	ms
η	(motor) efficiency		%
η_G	(gear) efficiency *		%
η_{max}	maximum efficiency *		%
τ_m	mechanical time constant *	s	ms
τ_S	therm. Time constant of the stator	s	
τ_W	therm. Time constant of the winding *	s	s

(* specified in the motor data)

Gear selection

A gear is required with a maximum continuous torque of at least 0.28 Nm and an intermittent torque of at least 0.45 Nm. This requirement is fulfilled, for example, by a planetary gear with 22 mm diameter (metal version).
The recommended input speed of 6000 rpm allows a maximum reduction of

$$i_{max} = \frac{n_{max,G}}{n_B} = \frac{6000}{60} = 100 : 1$$

We select the three-stage gear with the next smallst reduction of 84:1 (stock program). Efficiency is max. 59%.

Motor type selection

Speed and torque are calculated to the motor shaft

$$n_{mot} = i \cdot n_B = 84 \cdot 60 = 5040 \text{ rpm}$$

$$M_{mot,RMS} = \frac{M_{RMS}}{i \cdot \eta} = \frac{280}{84 \cdot 0.59} \approx 5.7 \text{mNm}$$

$$M_{mot,max} = \frac{M_{max}}{i \cdot \eta} = \frac{450}{84 \cdot 0.59} = 9.1 \text{mNm}$$

The possible motors, which match the selected gears in accordance with the maxon modular system, are summarized in the table opposite. The table only contains motors with graphite commutation which are better suited to start/stop operation.

Motor	$M_{cont.}$	Suitability
S2322, 6W	13 mNm	rather too strong, long
A-max 22, 6W	7.5 mNm	good
A-max 19, 2.5W	4.4 mNm	too weak
RE-max 21, 6W	8 mNm	good

Selection falls on an Amax 22, 6W, which demonstrates a sufficiently high continuous torque. The motor should have a torque reserve so that it can even function with a somewhat unfavorable gear efficiency. The additional torque requirement during acceleration can easily be delivered by the motor. The temporary peak torque is not even twice as high as the required RMS continuous torque (or the continuous torque of the motor).

Selection of the winding

The motor type Amax 22, 6W has an average speed-torque gradient of some 480 rpm/mNm. However, it should be noted that the two lowest resistance windings have a somewhat steeper gradient. The desired no-load speed is calculated as follows:

$$n_{0,set} = n_{max} + \frac{\Delta n}{\Delta M} M_{max} = 5040 + 480 \cdot 9.1 = 9400 \text{ rpm}$$

The extreme working point should of course be used in the calculation (max. speed and max. torque), since the speed-torque line of the winding must run above all working points in the speed/torque diagram. This target no-load speed must be achieved with the maximum voltage U = 18V supplied by the control (LSC), (voltage drop of the power amplifier of the LSC 6V), which defines the minimum target speed constant $k_{n,\,set}$ of the motor.

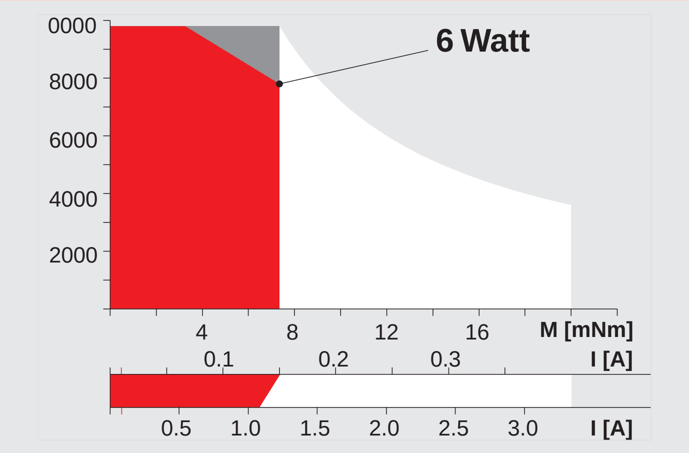
$$k_{n,set} = \frac{n_{0,set}}{U} = \frac{9400}{18} = 522 \frac{\text{rpm}}{\text{V}}$$

Based on the calculation, motor 110162 is chosen which corresponds to the winding with the next highest speed constant (689 rpm/V) and has a second shaft end for mounting the encoder. The winding's higher speed constant compared to the target value means that the motor runs faster than required at 18V which, however, can be compensated for by the controller. This selection also ensures that there is a speed regulating reserve of more than 20%. Thus, even unfavorable tolerances are not a problem.
The torque constant of this winding is 13.9 mNm/A. The maximum torque corresponds to a peak current of

$$I_{max} = \frac{M_{max}}{k_M} = \frac{9.1}{13.9} < 0.7\text{A}.$$

This current is lower than the maximum current (2A) of the controller (LSC).

Therefore, a gear motor combination has been found that fulfills the requirements (torque and speed) and can be operated with the controller provided.

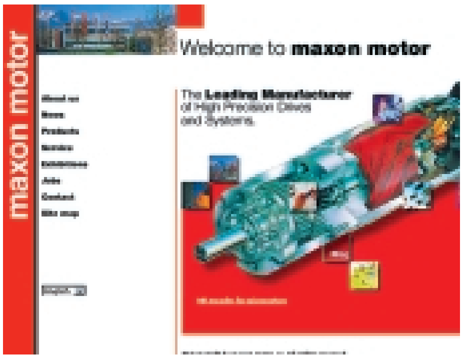


maxon e-media

1. The electronic catalog

All the information in this printed catalog are stored independently from the maxon selection program on the CD-ROM.

The electronic catalog can be used as a hybrid even under Windows and Apple Macintosh. For full functionality the Adobe Acrobat Reader is required. It is inculded on the CD-ROM and can be installed if desired.



2. maxon on the Internet

In a new configuration, even more structured, www.maxonmotor.com serves up all of the advantages of our system technology to your PC with a click of the mouse.

...Click and enter!

www.**maxonmotor**.com

3. maxon selection program

The CD-ROM comprises the maxon selection program and the electronic catalog.
The maxon selection program calculates a possible drive solution for you. The input of some known data are sufficient and the optimum drive components, for you, appear on your screen.

The programm saves you time and gives a reliable selection from our large product range.

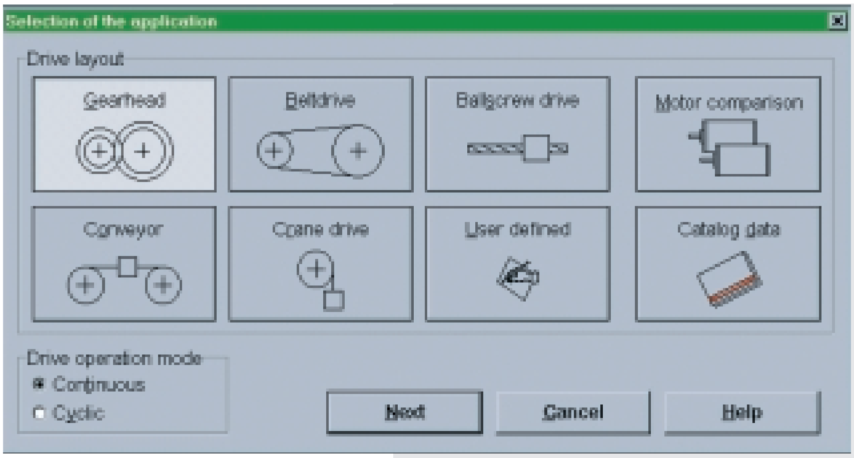
- several input parameters
- general conditions: max. dimension, temperature, speed etc.
- several windows for data sheets and diagrams
- user friendly display of the solution, checklist, nominal data and tolerances, graphical description
- display of matching DC tachos or encoders
- fast comparison of several motors
- practical on-line help with additional information on the **maxon motor** products

System requirements for Windows

- 486er Processor, or Pentium
- 4 MB RAM memory
- Windows 3.x or Win95/98/NT possible
- The installation of the maxon selection program uses approximatly 10 MB on your hard disc.
- Display resolution of min. 640 x 480 pixel / 256 colours.

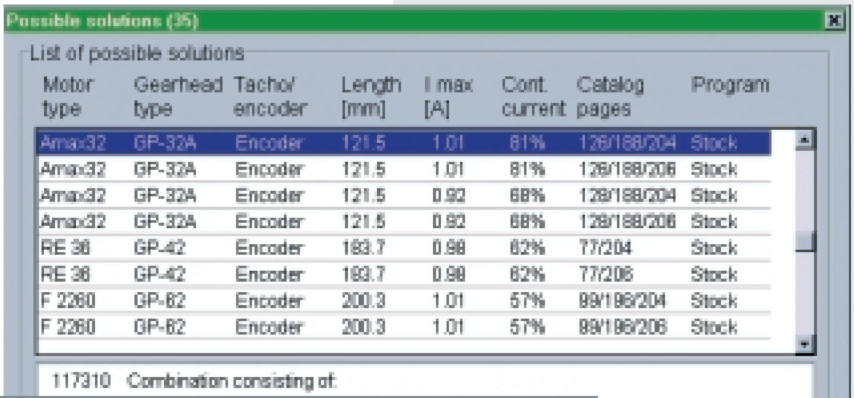
Installation:

Insert CD-ROM. Start under Windows in the main index the programm „install.exe“, or in program manager, in menu „File“ the option „Execute“.



Drive operation mode
● Continuous
○ Cyclic

Selection menu for a discrete application



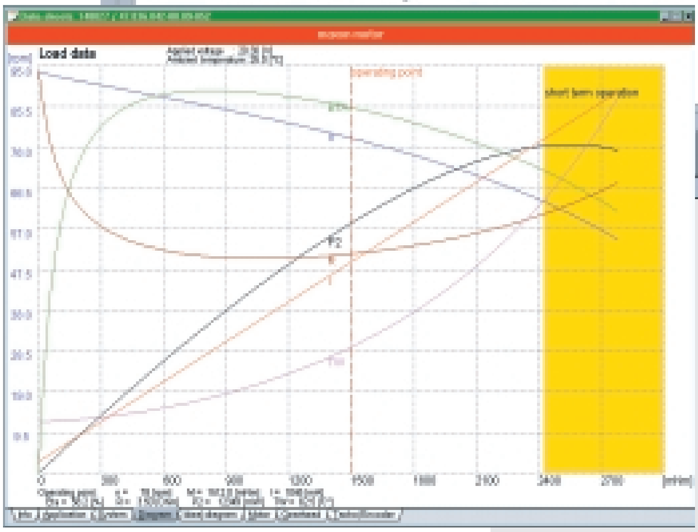
List of possible solutions

Motor type	Gearhead type	Tacho/ encoder	Length [mm]	I max [A]	Cont. current	Catalog pages	Program
Amax32	GP-32A	Encoder	121.5	1.01	81%	126/188/204	Stock
Amax32	GP-32A	Encoder	121.5	1.01	81%	126/188/206	Stock
Amax32	GP-32A	Encoder	121.5	0.92	68%	128/188/204	Stock
Amax32	GP-32A	Encoder	121.5	0.92	68%	128/188/206	Stock
RE 36	GP-42	Encoder	183.7	0.98	62%	77/204	Stock
RE 36	GP-42	Encoder	183.7	0.98	62%	77/206	Stock
F 2260	GP-62	Encoder	200.3	1.01	57%	99/196/204	Stock
F 2260	GP-62	Encoder	200.3	1.01	57%	99/196/206	Stock

117310 Combination consisting of:

3409.040-0500.1-000

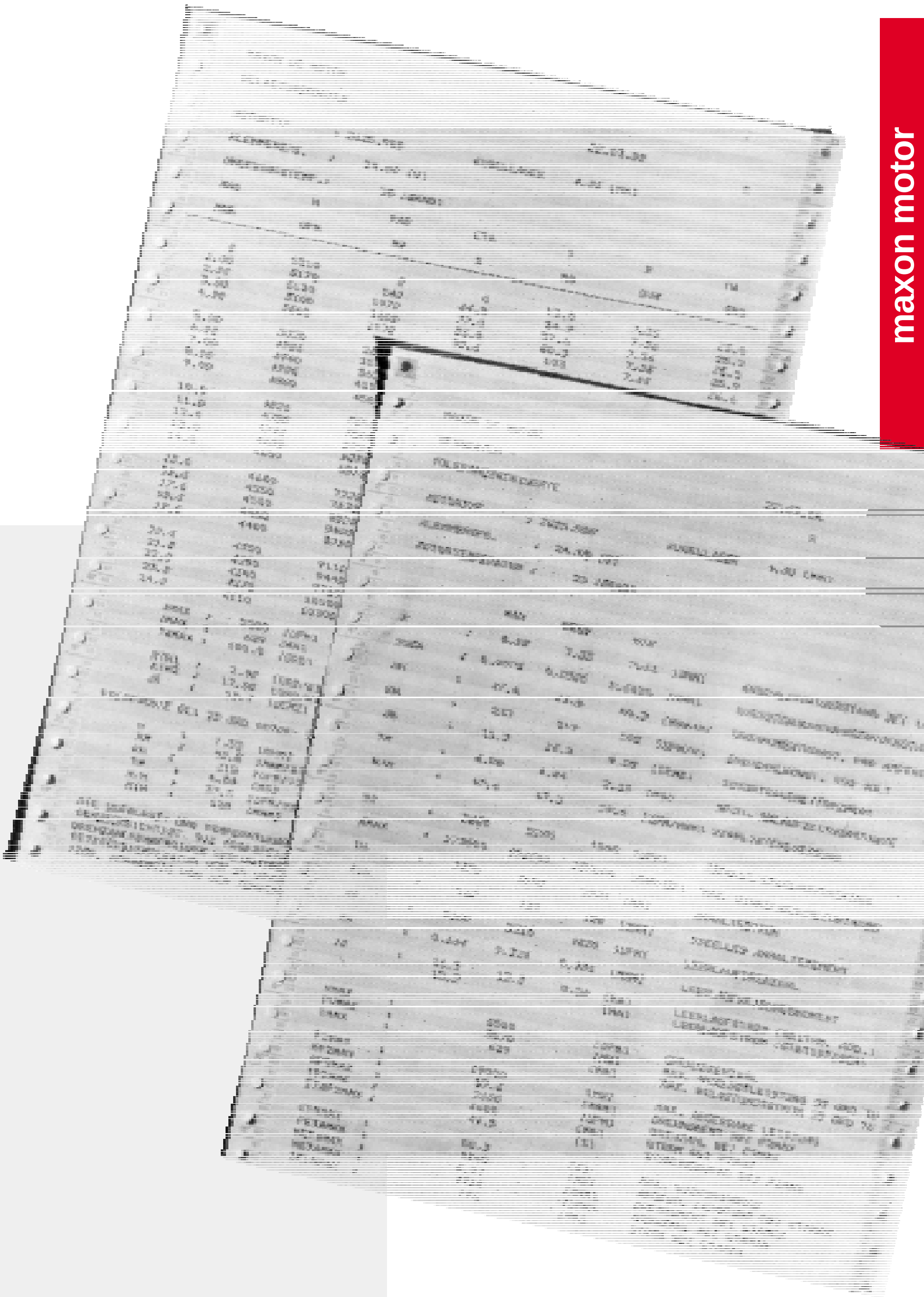
Display of possible drive solutions



Graphical description of a particular drive solution

maxon Computer Service

Our Computer Service is at your disposal and at no charge. On request, you will receive all nominal data with applicable tolerances as well as operational values for your specific application for any motor manufactured by maxon.



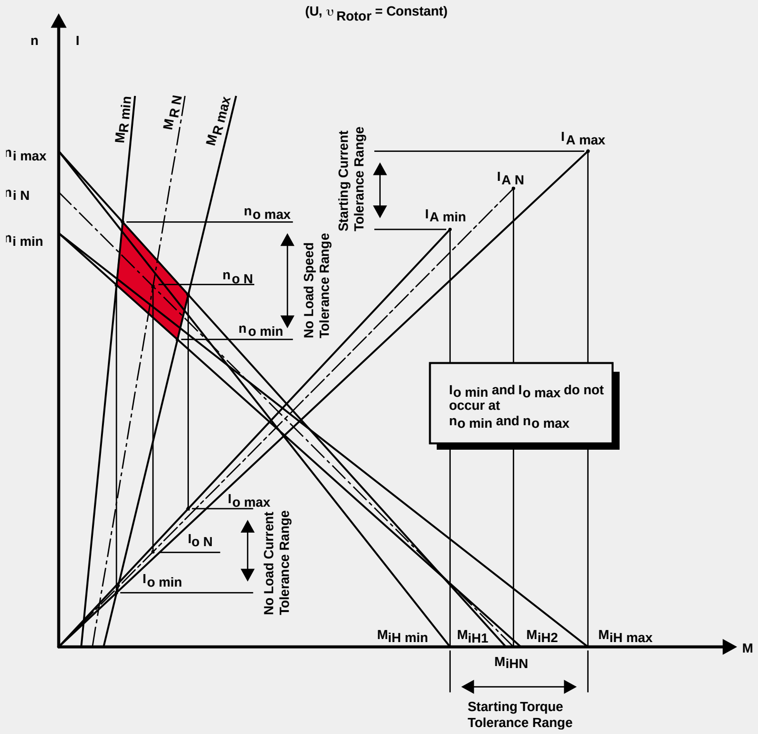
1. Nominal Data and Tolerances

We provide comprehensive information pertaining to all motor parameters of consequence. This can be of invaluable assistance when working out drive concepts using **maxon DC motors.**

You simply provide us with the motor type chosen and the opeating voltage(s) in your application. We deliver nominal data and inform you of the min/max. deviations in each case,
specific to the selected motor.

2. Operational Data

The data provided is based on continuous operation. If requested, the information can be tailored to your individual needs.



Notes:
The tolerances indicated in this diagram are shown in exaggerated fashion for better clarity. (See preceeding page).

n_i	«ideal» or theoretical no load speed [rpm]
n_o	no load speed [rpm]
M_{iH}	Stall torque, also called Starting torque [mNm]
M_R	Frictional torque, caused by brushes and bearing friction [mNm]
I_o	no load current [mA]
I_A, I_H	Starting current, Stall current [mA]

Indexes:

N	Nominal
max	Max. value
min	Min. value

The new **maxon numbersystem**

In April 1997 we introduced new article numbers for a large part of the present maxon product range and for all future products. The new number system is a future oriented, modern numbering technique and is a basis for rational order processing. The new, 6-digit item number and a descriptive, easy to understand article text satisfies all requirements.

Some Advantages:

- clear item number for each article
- very short, only 6 digits
- modern and efficient
- customer friendly

Example motors:

Type number	Item					
123456	**Type**	**Diameter**	**Commutation**	**Power Rating**	**Bearings**	**Shaft Ends**
118401	maxon DC motor RE	∅13 mm	Precious metal brushes	1.2 Watt	Sleeve bearings	1 Shaft Ends

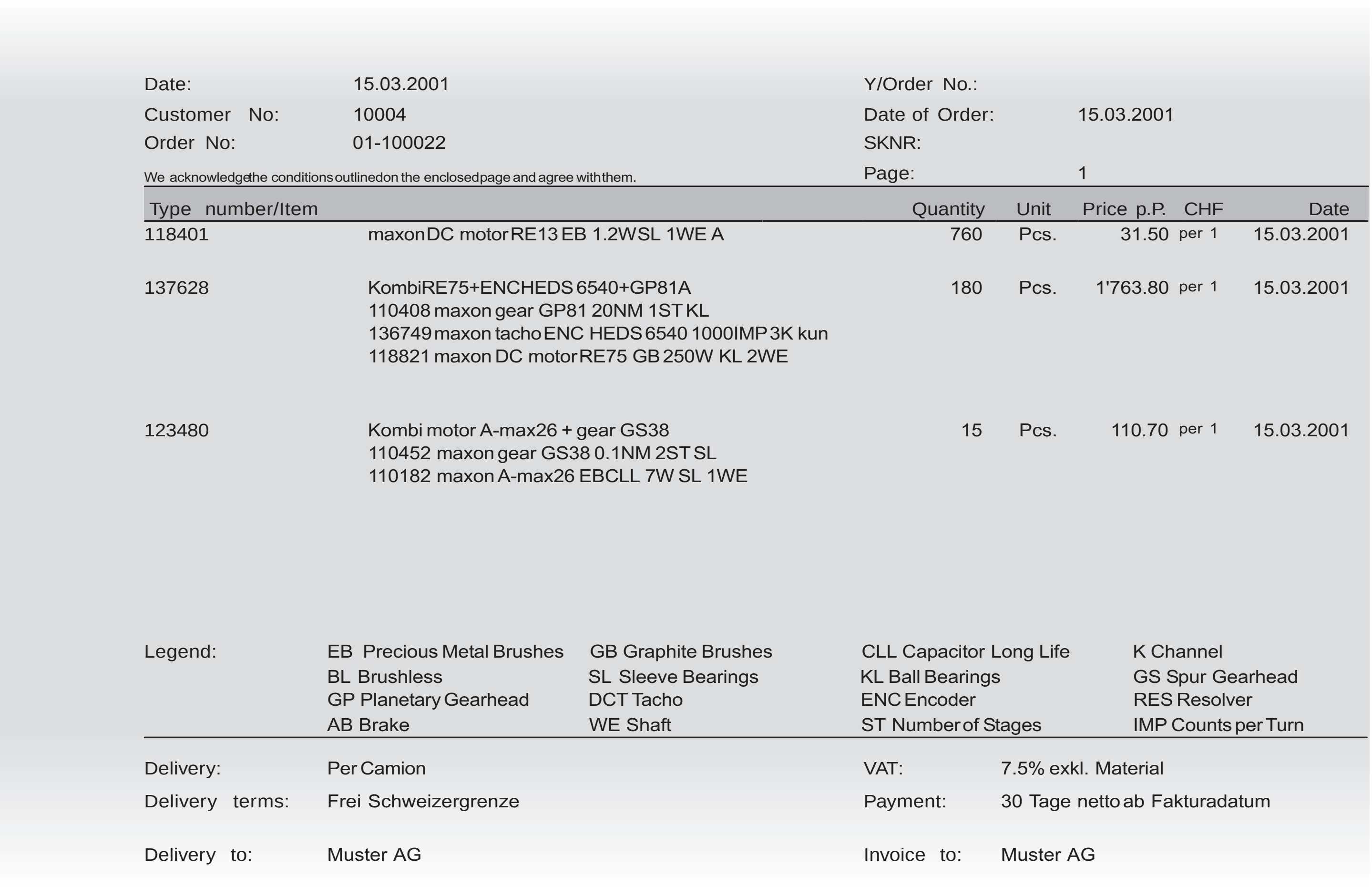
Example gearhead:

Type number	Item					
123456	**Type**	**Diameter**	**Continuous torque**	**No. of stages**	**Bearings**	
110321	Planetary Gearhead	∅16 mm	0.1 Nm	1 stages	Sleeve bearings	

Example tachos:

Type number	Item			
123456	**Type**	**Dimension or make**	**Number of impulses**	**Number of channels**
110778	Digital Magnetic Encoder	∅13 mm	16 impulses	2 channels

Combinations of motors with gearhead and encoder etc. are so allocated, that all possible crosswise comparisons can be made. The products are indelibly marked with a unique order number.



Date: 15.03.2001
Customer No: 10004
Order No: 01-100022
We acknowledge the conditions outlined on the enclosed page and agree with them.

Y/Order No.:
Date of Order: 15.03.2001
SKNR:
Page: 1

Type number/Item		Quantity	Unit	Price p.P. CHF		Date
118401	maxon DC motor RE13 EB 1.2W SL 1WE A	760	Pcs.	31.50	per 1	15.03.2001
137628	Kombi RE75+ENC HEDS 6540+GP81A 110408 maxon gear GP81 20NM 1ST KL 136749 maxon tacho ENC HEDS 6540 1000IMP 3K kun 118821 maxon DC motor RE75 GB 250W KL 2WE	180	Pcs.	1'763.80	per 1	15.03.2001
123480	Kombi motor A-max26 + gear GS38 110452 maxon gear GS38 0.1NM 2ST SL 110182 maxon A-max26 EBCLL 7W SL 1WE	15	Pcs.	110.70	per 1	15.03.2001

Legend:

EB Precious Metal Brushes	GB Graphite Brushes	CLL Capacitor Long Life	K Channel
BL Brushless	SL Sleeve Bearings	KL Ball Bearings	GS Spur Gearhead
GP Planetary Gearhead	DCT Tacho	ENC Encoder	RES Resolver
AB Brake	WE Shaft	ST Number of Stages	IMP Counts per Turn

Delivery: Per Camion
Delivery terms: Frei Schweizergrenze
Delivery to: Muster AG

VAT: 7.5% exkl. Material
Payment: 30 Tage netto ab Fakturadatum
Invoice to: Muster AG

Structure of Order Numbers old numbering system

Motor Type Designation:
20 **A**-Program
25 **A**-Program
21 **F**-Program
22 **F**-Program
23 **S**-Program

Motor diameter in mm

Winding Number:
Specifies number of turns
and wire diameter.

Commutation System Code:
1/2 Precious metal brushes
5/6/7 Graphite brushes

Version

20 23 . 916 - 61 . 5 2 1 - 000

Mounting Code:
Indicates thread style,
pitch circle and pilot hole.

Bearing Code:
1/5 Sintered sleeve bearings
2 Ball bearings

Shaft Version Code:
According to diameter, length and drive element.

Please note:
Always order according to motor, gearhead and tacho numbers indicated in the data sheets.
If a combination is ordered, the following code details ▨ may be assigned differently by maxon for internal reasons:

Example:

20 23 . 916 - 61 . 5 2 1 - 000

The marking on the product and delivery documents will always reflect these factory assigned numbers.

Structure of combination numbers old numbering system

41 Motor-gearhead combination
43 Motor-DC-tacho combination
44 Motor-encoder combination
46 Motor-gearhead-DC-tacho combination
47 Motor-gearhead-encoder-combination
49 Motor-brake (also with gearhead, DC-tacho or encoder)
40 Motor-DC-tacho/encoder (with or without gearhead)

Motor diameter in mm

Gearhead diameter in mm

Specification; consecutive number

41 . 002 . 026 - 00 . 00 - 001

Encoder:
00 without encoder
07 digital encoder 3407.., HP HEDS 5010
09 digital encoder 3409.., HP HEDS 5500
16 digital encoder 3416..
17 digital encoder 3417.., HP HEDS 6010
19 digital encoder 3419..
20 digital magnetic encoder 3420...

36.03 DC-tacho/encoder 3603
32.04 DC-tacho/encoder 3604

DC-tacho
00 without DC-tacho
22 DC-tacho 2822

maxon Conversion Tables

General Information

Quantities and their basic units in the International System of Measurements (SI)

Quantity	Basic-unit	Sign
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electrical current	Ampere	A
Thermodynamic temperature	Kelvin	K

Conversion Example

A known unit
B unit sought

known:	multiply by	sought:
oz-in	7.06	mNm

Factors used for . . .

. . . conversions:

1 oz = 2.834952313 · 10^{-2} kg
1 in = 2.54 · 10^{-2} m

. . . gravitational acceleration:

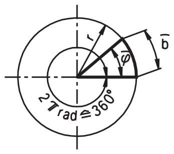
g = 9.80665 m s^{-2}
= 386.08858 in s^{-2}

. . . derived units:
1 yd = 3 ft = 36 in
1 lb = 16 oz = 7000 gr (grains)
1 kp = 1 kg · 9.80665 ms^{-2}
1 N = 1 kgms^{-2}
1 W = 1 Nms^{-1} = 1kgm^{-2}s^{-3}
1 J = 1 Nm = 1 Ws

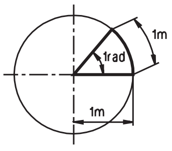
Decimal multiples and fractions of units

Prefix	Abbre-vation	Multiply	Prefix	Abbre-vation	Multiply
Deka . .	da	10^{1}	Dezi . .	d	10^{-1}
Hekto. .	h	10^{2}	Zenti . .	c	10^{-2}
Kilo . .	k	10^{3}	Milli . .	m	10^{-3}
Mega . .	M	10^{6}	Mikro . .	μ	10^{-6}
Giga . .	G	10^{9}	Nano . .	n	10^{-9}
Tera . .	T	10^{12}	Piko . .	p	10^{-12}

Arc definition



$$\overline{\varphi} = \frac{\overset{\frown}{b}}{r}$$



$$1\text{rad} = \frac{1\text{m}}{1\text{m}} \mathrel{\widehat{=}} 57.2958°$$

▨ Units used in this brochure

Power

P [W]

B A	oz-in-s^{-1}	oz-in-rpm	in-lbf-s^{-1}	ft-lbf-s^{-1}	Nm s^{-1} = W	mW	kpm s^{-1}	mNm rpm
W = Nm s^{-1}	7,06 · ·10^{-3}	1,17 · 10^{-4}	0,113	1,356	1	1 · 10^{-3}	9,807	$^{1}/_{60000}$
mW	7,06	0,117	112,9	1,356 · 10^{3}	1 · 10^{3}	1	9,807 · 10^{3}	$^{1}/_{60}$
oz-in-s^{-1}	1	$^{1}/_{60}$	16	192	141,6	0,142	1,39 · 10^{3}	2,36 · 10^{-3}
ft-lbf-s^{-1}	$^{1}/_{192}$	$^{1}/_{11520}$	$^{1}/_{12}$	1	0,737	0,737 · 10^{-3}	7,233	1,23 · 10^{-5}
kpm s^{-1}	7,20 · 10^{-4}	1,2 · 10^{-5}	1,15 · 10^{-2}	0,138	0,102	0,102 · 10^{-3}	1	1,70 · 10^{-6}

Torque

M [Nm]

B A	oz-in	ft-lbf	Nm = Ws	Ncm	mNm	kpm	pcm	
Nm	7,06 · 10^{-3}	1,356	1	1 · 10^{-2}	1 · 10^{-3}	9,807	9,807 · 10^{-5}	
mNm	7,06	1,356 · 10^{3}	1 · 10^{3}	10	1	9,807 · 10^{3}	9,807 ·10^{-2}	
kpm	7,20 · 10^{-4}	0,138	0,102	0,102 · 10^{-2}	0,102 · 10^{-3}	1	1 · 10^{-5}	
oz-in	1	192	141,6	1,416	0,142	1,39 · 10^{3}	1,39 · 10^{-2}	
ft-lbf	$^{1}/_{192}$	1	0,737	0,737 · 10^{-2}	0,737 ·10^{-3}	7,233	7,233 · 10^{-5}	

Moment of Inertia

J [kg m^{2}]

B A	oz-in^{2}	oz-in-s^{2}	lb-in^{2}	lb-in-s^{2}	Nms^{2}=kgm^{2}	mNm s^{2}	gcm^{2}	kpm s^{2}
g cm^{2}	182,9	7,06 · 10^{4}	2,93 · 10^{3}	1,13 · 10^{6}	1 · 10^{7}	1 · 10^{4}	1	9,807 · 10^{7}
kgm^{2}=Nms^{2}	1,83 · 10^{-5}	7,06 · 10^{-3}	2,93 · 10^{-4}	0,113	1	1 · 10^{-3}	1 · 10^{-7}	9,807
oz-in^{2}	1	386,08	16	6,18 · 10^{3}	5,46 · 10^{4}	54,6	5,46 ·10^{-3}	5,35 · 10^{5}
lb-in^{2}	$^{1}/_{16}$	24,130	1	386,08	3,41 · 10^{3}	3,41	3,41 ·10^{-4}	3,35 · 10^{4}

Mass

m [kg]

B A	oz	lb	gr (grain)	kg	g
kg	28,35 ·10^{-3}	0,454	64,79·10^{-6}	1	1 · 10^{3}
g	28,35	0,454 · 10^{3}	64,79·10^{-3}	1 · 10^{3}	1
oz	1	16	2,28 · 10^{-3}	35,27	35,27 · 10^{3}
lb	$^{1}/_{16}$	1	$^{1}/_{7000}$	2,205	2,205 · 10^{3}
gr (grain)	437,5	7000	1	15,43 · 10^{3}	15,43 · 10^{6}

Force

F [N]

B A	oz	lbf	N	kp	p
N	0,278	4,448	1	9,807	9,807·10^{-3}
kp	0,028	0,454	0,102	1	1 · 10^{-3}
oz	1	16	3,600	35,27	35,27·10^{-3}
lbf	$^{1}/_{16}$	1	0,225	2,205	2,205·10^{-3}
pdl	2,011	32,17	7,233	70,93	70,93·10^{-3}

Length

l [m]

B A	in	ft	yd	Mil	m	cm	mm	μ
m	25,4 · 10^{-3}	0,305	0,914	25,4 · 10^{-6}	1	0,01	1 · 10^{-3}	1 · 10^{-6}
cm	2,54	30,5	91,4	25,4 · 10^{-4}	1 · 10^{2}	1	0,1	1 · 10^{-4}
mm	25,4	305	914	25,4 · 10^{-3}	1 · 10^{3}	10	1	1 · 10^{-3}
in	1	12	36	1 · 10^{-3}	39,37	0,394	3,94 · 10^{-2}	3,94 · 10^{-5}
ft	$^{1}/_{12}$	1	3	$^{1}/_{12}$ · 10^{-3}	3,281	3,281 · 10^{-2}	3,281 · 10^{-3}	3,281 · 10^{-6}

Angular Velocity

ω [s^{-1}]

B A	s^{-1} = Hz	rpm	rad s^{-1}
rad s^{-1}	2π	$^{\pi}/_{30}$	1
rpm	$^{1}/_{60}$	1	$^{30}/_{\pi}$

Angular Acceleration

α [s^{-2}]

B A	min^{-2}	s^{-2}	rad s^{-2}	
s^{-2}	$^{1}/_{60}$	1	$^{1}/_{2\pi}$	
rad s^{-2}	$^{\pi}/_{30}$	2π	1	

Linear Velocity

v [m s^{-1}]

B A	in-s^{-1}	in-rpm	ft-s^{-1}	ft-min^{-1}	m s^{-1}	cm s^{-1}	mm s^{-1}	m rpm
m s^{-1}	2,54 · 10^{-2}	4,23 · 10^{-4}	0,305	5,08 · 10^{-3}	1	1 · 10^{-2}	1 · 10^{-3}	$^{1}/_{60}$
in-s^{-1}	1	60	12	720	39,37	39,37 · 10^{-2}	39,37 · 10^{-3}	0,656
ft-s^{-1}	$^{1}/_{12}$	5	1	60	3,281	3,281 · 10^{-2}	3,281 · 10^{-3}	5,46 · 10^{-2}

Temperature

T [K]

B A	° Fahrenheit	° Celsius = Centigrade	Kelvin
Kelvin	(°F -305,15)/1,8	+ 273,15	1
° Celsius	(°F -32)/1,8	1	-273,15
° Fahrenheit	1	1,8 °C +32	1,8 K +305,15