3 Project Planning

3.1 Additional documentation

In addition to the information in this catalog, SEW-EURODRIVE offers extensive documentation covering the entire topic of electrical drive engineering. These are mainly the publications in the "Drive Engineering – Practical Implementation" series as well as the manuals and catalogs for electronically controlled drives. You will find additional links to a wide selection of our documentation in many languages for download on the SEW-EURODRIVE homepage (http://www.sew-eurodrive.com). The list below includes other documents that are of interest in terms of project planning. You can order these publications from SEW-EURODRIVE.

Drive Engineering - Practical Implementation

- Drive Planning
- Controlled AC Drives
- Servo Drives
- EMC in Drive Engineering
- Explosion-Proof Drives to EU Directive 94/9/EC

Electronic documentation

- MOVIDRIVE® MD_60A system manual
- MOVIDRIVE® MDX60/61B system manual
- MOVIDRIVE® compact system manual

Mechanical brakes

- "Brakes and Accessories" manual

3.2 Drive and gear unit selection data

Certain data is essential to specify the components for your drive precisely. These are:

Data for drive dimensioning			**Your entry**
i	Gear ratio		
φ	Circumferential backlash	[']	
η_G	Efficiency of gear units		
$n_{a\,max}$	Maximum output speed	[min^{-1}]	
n_{am}	Mean output speed of the gear unit	[min^{-1}]	
n_e	Input speed	[min^{-1}]	
n_{em}	Mean input speed	[min^{-1}]	
J_G	Mass moment of inertia of the gear unit	[kgm^2]	
J_{ext}	Mass moment of inertia (external) reduced on motor shaft	[kgm^2]	
J_{Mot}	Mass moment of inertia of the motor	[kgm^2]	
J_{load}	Mass moment of inertia of the load	[kgm^2]	
k	Mass moment of inertia ratio J_{ext} / J_{Mot}		
$M_1...M_n$	Output torque in time period t_1 to t_n	[Nm]	
M_{DYN}	Dynamic limit torque of the servomotor	[Nm]	
$M_{a\,max}$	Maximum output torque	[Nm]	
$M_{e\,max}$	Maximum input torque	[Nm]	
M_{max}	Maximum output torque assumed for the drive in project planning	[Nm]	
$M_{a\,(t)}$	Acceleration and braking torque	[Nm]	
M_{eff}	Effective torque requirement (in relation to the motor)	[Nm]	
P_{Br}	Braking power	[W]	
P_{Br_peak}	Peak braking power	[W]	
P_{Br_tn}	Braking power in section t_n	[W]	
$t_1...t_n$	Time period 1 to n	[min]	
t_z	Cycle time	[s]	
F_{Ax}	Axial load (tension and compression) on the output shaft	[N]	
F_R	Overhung load on the output shaft	[N]	
F_{Ra}	Permitted overhung load on the output shaft. Assumes force application in center of shaft. If not, please specify the exact application point giving the application angle and direction of rotation of the shaft for recalculation.	[N]	
F_{RxL}	Permitted overhung load at point x based on the bearing service life	[N]	
F_{RxW}	Permitted overhung load at point x based on the shaft strength	[N]	
x	Distance between overhung load application point and shaft shoulder	[mm]	
a, b, c, f	Gear unit constants as regards the overhung load conversion		
S.., ..%cdf	Duty type and cyclic duration factor (cdf) or exact load cycle can be entered.	-	
Required positioning accuracy and speed range			
R, F, K, S	Required gear unit type and mounting position	-	
M1 - M6	Mounting position (→ Sec. Mounting Positions)	-	
IP..	Required enclosure	-	
ϑ_{Umg}	Ambient temperature	[°C]	
H	Installation altitude	[m above sea level]	

Determining application data

It is first necessary to have data on the machine to be driven (mass, speed, setting range, etc.) to design the drive correctly.

These data help determine the required power, torque and speed. Refer to the "Drive Engineering - Practical Implementation, Drive Planning" publication or the PRODRIVE® project planning software for assistance.

3.3 Project planning procedure

Example

The following flowchart displays a schematic view of the procedure for planning a project incorporating a positioning drive. The drive consists of a gearmotor that is powered by an inverter.

Necessary information about the machine to be driven
- Technical data and environmental conditions
- Positioning accuracy
- Speed setting range
- Calculation of the travel cycle

↓

Calculation of the relevant application data
- Travel cycle
- Speeds
- Static, dynamic torques
- Regenerative power

↓

Gear unit selection
- Definition of gear unit size, gear unit reduction ratio and gear unit type
- Check the positioning accuracy
- Check for gear unit utilization ($M_{a\ max} \geq M_{a\ (t)}$).
- Check the input speed (churning losses)

↓

Motor selection
- Maximum torque
- In dynamic drives: Effective torque at medium speed
- Maximum speed
- Observe dynamic and thermal torque curves
- Select the correct encoder
- Motor equipment (brake, plug connector, TF selection, etc.)

↓

Selecting the inverter
- Motor/inverter assignment
- Continuous current and peak current in current-controlled inverters

↓

Selecting the braking resistor
- based on the calculated regenerative power, cdf and peak breaking power.

↓

Options
- EMC measures
- Operation/communication
- Additional functions

↓

Make sure that all requirements have been met.

3.4 Project planning for gear units

Features of the gear units

The efficiency of gear units is mainly determined by the gearing and bearing friction. Keep in mind that the starting efficiency of a gear unit is always less than its efficiency at operating speed. This factor is especially pronounced in the case of helical-worm gear units.

R, F, K gear units

The efficiency of helical, parallel shaft and helical-bevel gear units varies with the number of gear stages, between 94 % (3-stage) and 98 % (1-stage).

S gear units

The gearing of helical-worm gear units produces a high proportion of sliding friction. As a result, these gear units may have higher gearing losses than R, F or K gear units and thus be less efficient.

The efficiency depends on the following factors:

- Gear ratio of the helical-worm gear stage
- Input speed
- Gear unit temperature

SEW gear units are designed as helical worm which makes them significantly more efficient than straightforward worm gear units. The efficiency may reach $\eta < 0.5$ if the helical-worm gear stage has a very high gear ratio.

Self-locking

Retrodriving torques on helical-worm gear units produce an efficiency of $\eta' = 2 - 1/\eta$, which is significantly less favorable than the forward efficiency η. The helical-worm gear unit is self-locking if the forward efficiency $\eta \leq 0.5$. Contact SEW-EURODRIVE if you wish to make technical use of the braking effect of self-locking characteristics.

Run-in phase

The tooth flanks of new helical-worm gear units are not yet completely smooth. That fact makes for a greater friction angle and less efficiency than during later operation. This effect becomes more apparent the greater the gear ratio. Subtract the following values from the listed efficiency during the run-in phase:

No. of starts	i range	η-reduction
2 start	ca. 20 ... 75	ca. 6 %
5 start	ca. 6 ... 25	ca. 3 %

The run-in phase usually lasts 24 hours. The helical-worm gear units achieve their listed rated efficiency values when:

- the gear unit has been run in completely,
- the gear unit has reached nominal operating temperature,
- the recommended lubricant has been filled in and
- the gear unit is working within the rated load range.

Churning losses

Churning losses in R, F, K and S gear units are caused by the circulating lubricant. Churning losses depend on the mounting position of the gear unit and the input speed.

If possible, use the basic mounting position M1 for R, F, K and S gear units to reduce churning losses to a minimum.

Mean speeds higher than 1500 min^{-1} or mounting positions other than M1 require for checking churning losses and the thermal rating. Contact SEW-EURODRIVE in such cases.

Maximum speeds

Maximum speeds	
Gear unit sizes	**Max. speed**
up to 77	4500 min^{-1}
87	3900 min^{-1}
97	3100 min^{-1}
107	2700 min^{-1}
127 - 167	2500 min^{-1}
187	2000 min^{-1}

It is essential to contact SEW-EURODRIVE if higher maximum speeds are involved.

Design and operating notes

When input and output elements are mounted on SEW gear units, the **shaft can be used as a stop** for transmission elements (belt pulley, pinion, etc.).

R, F, K gear units can be operated at **ambient temperatures of** between **– 10 °C and + 40 °C**. S gear units can be operated at **ambient temperatures of** between **0 °C and + 40 °C**. Contact SEW-EURODRIVE if ambient temperatures exceed this temperature range!

SEW gear units can be operated up to **altitudes** of **1000 m above sea level**. For operation at altitudes above 1000 m above sea level, contact SEW-EURODRIVE.

3.5 Overhung and axial loads

Determining overhung load

When determining the resulting overhung load, the type of transmission element mounted on the shaft end must be considered. The following transmission element factors f_Z also have to be considered for various transmission elements:

Transmission element	Transmission element factor f_{Z1}	Comments
Gears	1.15	< 17 teeth
Chain sprockets	1.40	< 13 teeth
Chain sprockets	1.25	< 20 teeth
Narrow V-belt pulleys	1.75	Depending on the pre-tensioning force
Flat belt pulleys	2.50	Depending on the pre-tensioning force
Toothed belt pulleys	2.00 - 2.50	Depending on the pre-tensioning force

The overhung load exerted on the motor or gear shaft is calculated as follows:

$$F_R = \frac{M_d \times 2000}{d_0} \times fz$$

F_R = Overhung load in N
M_d = Torque in Nm
d_0 = Mean diameter of the mounted transmission element in mm
f_Z = Transmission element factor

Permitted overhung load

The basis for determining the permitted overhung loads is the computation of the rated bearing service life L_{H10} of the anti-friction bearings (according to ISO 281).

For special operating conditions, the permitted overhung loads can be determined with regard to the modified bearing service life L_{na} on request.

The data refer to gearmotors with the force acting midway on the shaft end. Worst case conditions have been assumed for the force application angle α and the direction of rotation.

- Only 50 % of the F_{Ra} value specified in the selection tables is permitted in mounting position M1 with wall attachment on the front face for K and S gear units.
- With foot-mounted and flange-mounted R gearmotors, a maximum of 50 % of the overhung load F_{Ra} specified in the selection tables is permitted in the case of torque transmission via the flange mounting.

The overhung load is specified for foot-mounted gear units as standard. If the overhung load values of other versions differ from those of the foot-mounted version, these values will appear in a separate column in the selection tables.

Higher permitted overhung loads

Exactly considering the force application angle α and the direction of rotation makes it possible to achieve a higher overhung load. Higher output shaft loads are permitted if heavy duty bearings are installed, especially with R, F and K gear units. Contact SEW-EURODRIVE in such cases.

Definition of force application

Force application is defined according to the following figure:

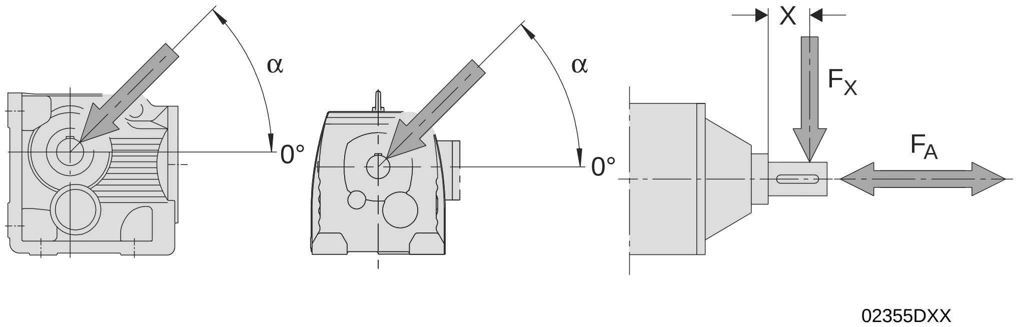

Figure 1: Definition of force application point

F_X = Permitted overhung load at point x [N]

F_A = Permitted axial load [N]

Permitted axial forces

If there is no overhung load, then an axial force F_A (tension or compression) amounting to 50 % of the overhung load given in the selection tables is permitted. This condition applies to the following gearmotors:

- Helical gearmotors except for R..137... to R..167...
- Parallel shaft and helical-bevel gearmotors with solid shaft except for F97...
- Helical-worm gearmotors with solid shaft.

Contact SEW-EURODRIVE for all other types of gear units and in the event of significantly greater axial forces or combinations of overhung load and axial force.

Overhung load conversion for off-center force application

The permitted overhung loads given in the selection tables must be calculated using the following formulae if force is applied at a point other than the center of the shaft end or if it is applied at a specific distance from the shaft end. The smaller of the two values F_{RxL} (according to bearing service life) and F_{RxW} (according to shaft strength) is the permitted value for the overhung load at point x. Note that the gear unit constant c must be different for M_N and M_B.

Overhung load conversion based on bearing service life:

$$F_{RxL} = F_{Ra} \times \frac{a}{b + x}$$

Overhung load conversion based on shaft strength:

$$F_{RxW} = \frac{c}{f + x}$$

x	= Distance between overhung load application point and shaft shoulder [mm]
F_{Ra}	= permitted overhung load [N] (see the rated torque tables)
F_{RxL}	= permitted overhung load [N] at point x based on bearing service life
F_{RxW}	= permitted overhung load [N] at point x based on shaft strength
a, b, c, f	= gear unit constants for overhung load conversion
F_{Rx}	= minimum of F_{RxL} and $F_{RxW[N]}$

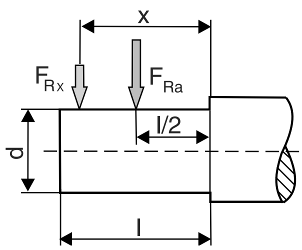

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Figure 2: Overhung load F_{Rx} for off-center force application on a solid shaft

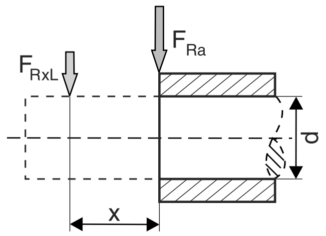

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Figure 3: Overhung load F_{RxL} for off-center force application on a hollow shaft

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Gear unit constants for overhung load conversion

Gear unit type	Gear unit constants for overhung load conversion					
	a [mm]	b [mm]	c [Nmm]	f [mm]	d [mm]	l [mm]
R17	88.5	68.5	$6.527 \bullet 10^4$	17	20	40
R27	106.5	81.5	$1.56 \bullet 10^5$	11.8	25	50
R37	118	93	$1.24 \bullet 10^5$	0	25	50
R47	137	107	$2.44 \bullet 10^5$	15	30	60
R57	147.5	112.5	$3.77 \bullet 10^5$	18	35	70
R67	168.5	133.5	$2.65 \bullet 10^5$	0	35	70
R77	173.7	133.7	$3.97 \bullet 10^5$	0	40	80
R87	216.7	166.7	$8.47 \bullet 10^5$	0	50	100
R97	255.5	195.5	$1.19 \bullet 10^6$	0	60	120
R107	285.5	215.5	$2.06 \bullet 10^6$	0	70	140
R137	343.5	258.5	$6.14 \bullet 10^6$	30	90	170
R147	402	297	$8.65 \bullet 10^6$	33	110	210
R167	450	345	$1.26 \bullet 10^7$	0	120	210
RX57	43.5	23.5	$1.51 \bullet 10^5$	34.2	20	40
RX67	52.5	27.5	$2.42 \bullet 10^5$	39.7	25	50
RX77	60.5	30.5	$1.95 \bullet 10^5$	0	30	60
RX87	73.5	33.5	$7.69 \bullet 10^5$	48.9	40	80
RX97	86.5	36.5	$1.43 \bullet 10^6$	53.9	50	100
RX107	102.5	42.5	$2.47 \bullet 10^6$	62.3	60	120
F27	109.5	84.5	$1.13 \bullet 10^5$	0	25	50
F37	123.5	98.5	$1.07 \bullet 10^5$	0	25	50
F47	153.5	123.5	$1.78 \bullet 10^5$	0	30	60
F57	170.7	135.7	$5.49 \bullet 10^5$	32	35	70
F67	181.3	141.3	$4.12 \bullet 10^5$	0	40	80
F77	215.8	165.8	$7.87 \bullet 10^5$	0	50	100
F87	263	203	$1.19 \bullet 10^6$	0	60	120
F97	350	280	$2.09 \bullet 10^6$	0	70	140
F107	373.5	288.5	$4.23 \bullet 10^6$	0	90	170
F127	442.5	337.5	$9.45 \bullet 10^6$	0	110	210
F157	512	407	$1.05 \bullet 10^7$	0	120	210
K37	123.5	98.5	$1.41 \bullet 10^5$	0	25	50
K47	153.5	123.5	$1.78 \bullet 10^5$	0	30	60
K57	169.7	134.7	$6.8 \bullet 10^5$	31	35	70
K67	181.3	141.3	$4.12 \bullet 10^5$	0	40	80
K77	215.8	165.8	$7.69 \bullet 10^5$	0	50	100
K87	252	192	$1.64 \bullet 10^6$	0	60	120
K97	319	249	$2.8 \bullet 10^6$	0	70	140
K107	373.5	288.5	$5.53 \bullet 10^6$	0	90	170
K127	443.5	338.5	$8.31 \bullet 10^6$	0	110	210
K157	509	404	$1.18 \bullet 10^7$	0	120	210
K167	621.5	496.5	$1.88 \bullet 10^7$	0	160	250
K187	720.5	560.5	$3.04 \bullet 10^7$	0	190	320
S37	118.5	98.5	$6.0 \bullet 10^4$	0	20	40
S47	130	105	$1.33 \bullet 10^5$	0	25	50
S57	150	120	$2.14 \bullet 10^5$	0	30	60
S67	184	149	$3.04 \bullet 10^5$	0	35	70

Values for types not listed are available on request.

3.6 Project planning for servomotors

Features of synchronous and asynchronous servomotors

Synchronous servomotors

Synchronous servomotors are permanent-field synchronous motors. Features of SEW synchronous servomotors:

- Standstill torque of 1 Nm up to 68 Nm, with forced cooling fan up to 95 Nm
- High dynamics (rated torque / mass moment of inertia of the motor)
- High level of enclosure (IP65)
- Robust encoder system (resolver)
- The optimal encoder system with sine/cosine encoder allows for a very wide setting range up to 1:5000
- Motor can be run at slow speeds with high accuracy with the optimal encoder system
- High speeds up to 6000 min^{-1} can be set without operation in the field weakening range
- High continuous torque at low speeds and at standstill, without forced cooling fan
- High overload capability
- NeFeB magnets, permanent magnets with high magnetic field density

Asynchronous servomotors

Asynchronous servomotors are dynamic AC asynchronous machines with the following features:

- Rated motor torques of 2.5 to 200 Nm
- Applications with very high load moment of inertia are possible
- The encoder system permits a very broad setting range (up to 1:5000)
- Motor can be run at speeds below 1 min^{-1} with high accuracy.

Protection rating according to IEC 34-5 (EN 60034-5)

- Synchronous servomotors are supplied with IP65 enclosure as standard.
- Asynchronous servomotors are supplied with IP54 enclosure as standard. IP55 or IP65 enclosure is also available on request.

IP	1st digit Protection against foreign objects	2nd digit Protection against water
0	No special protection	No special protection
1	Protection against solid objects ∅ 50 mm and larger	Protection against dripping water
2	Protection against solid objects ∅ 12 mm and larger	Protection against dripping water when tilted up to 15°
3	Protection against solid objects ∅ 12 mm and larger	Protection against solid objects ∅ 12 mm and larger
4	Protection against solid objects ∅ 12 mm and larger	Protection against splashing water
5	Protection against dust	Protection against water jets
6	Dust-proof	Protection against powerful water jets
7	-	Protection against temporary immersion in water
8	-	Protection against permanent immersion in water

Applications

Acceleration greater than 5 m/s²

The rotor of the synchronous servomotor is designed to be extremely low-inertia. This motor is the optimum choice in very dynamic applications. For accelerations greater than 5 m/s², the **synchronous servomotor** is usually the technically and economically best solution.

Positioning heavy masses accurately

If the inertia ratio J_{ext} / J_{Mot} is unfavorably high with the low-inertia rotor of the synchronous servomotor (k > 10...15), an asynchronous servomotor with a higher mass moment of inertia J_{Mot} may represent the better solution.

High motor torques

SEW asynchronous servomotors are available if servomotors with rated torques of > 95 Nm are required.

Very slow motor speeds

The asynchronous servomotor is the optimal choice for applications that require extremely low motor speeds < 2.0 min^{-1}. The encoder system used (sinusoidal encoder) permits a very high resolution of the actual speed.

A forced cooling fan is required if speeds of < 500 min^{-1} are delivered over a long time. Load and time also need to be taken into account.

Assignment of gear unit to motor

Permitted combinations of motor and gear unit are indicated by gray fields in the combination overviews.

Finite gear unit reduction ratios i

Gear units with a whole-number or finite gear ratio should be preferred for positioning tasks in one direction of rotation and synchronization to avoid the accummulation of rounding errors. Gear units with a finite gear ratio are marked with an * following the gear ratio i in the combination overviews and are given in notation with two decimal places.

Notes on selecting servomotors

Project planning for a servomotor involves the following tasks for determining the thermal and dynamic load on the motor:

- Calculating the **effective operating point** for checking the thermal load on the motor.
- Calculating the **maximum operating point** for determining the motor/inverter combination.
- Determining the **inertia ratio** J_{ext} / J_{Mot} for checking the stability of the speed control.
  - J_{ext} = Mass moment of inertia, reduced on motor shaft
  - J_{Mot} = Mass moment of inertia of the motor

Procedure

- Determining the maximum speed based on aspects of the inertia ratio k < 10...15.
- Maximum required torque M_{max} at maximum speed n_{max} (maximum operating point).

  $\mathbf{M_{max} < M_{dyn\_Mot}}$ at $\mathbf{n_{max}}$

  M_{dyn_Mot} corresponds to the maximum torque for the specific motor/inverter combination. This operating point must lie below the characteristic curve for the maximum torque of the motor/MOVIDRIVE® combination.
- Effective torque requirement at average speed of the application (effective operating point).

  $\mathbf{M_{eff} < M_{N\_Mot}}$ at $\mathbf{n_{mean}}$

  This operating point must lie below the characteristic curve for continuous torque to ensure thermal stability of the drive.

Speed classes

DFS/CFM synchronous servomotors[1)] **[min^{-1}]**			
2000	3000	4500	6000

1) The BR brake for CFM71, CFM90 and CFM112 motors can be operated up to a maximum of 4500 min^{-1}.

CT/CV asynchronous servomotors **[min^{-1}]**			
1200	1700	2100	3000

As all servomotors operate as controlled drives it is necessary to consider the inertia ratio between the load and the motor. This ratio is a decisive factor in determining the quality of closed-loop control. The inertia ratio should not exceed the values listed in the table below. Reduction of the inertia ratio using the motor speed (the selected gear unit reduction ratio) offers hardly any advantage with respect to closed-loop control starting at the value $\mathbf{J_{ext} / J_{Mot} < 8}$. Backlash and elasticity negatively influence the possible dynamic response of the driveline and must be kept to a minimum.

As a result, the maximum speed should be selected such that the following criteria are met:

Driveline	**Control characteristics**	**Inertia ratio J_{ext} / J_{Mot}**
Forged gear rack, reduced backlash gear unit	Low backlash and low elasticity drive	$J_{ext} / J_{Mot} < 15$
Toothed belt, reduced backlash gear unit	Common servo applications	$J_{ext} / J_{Mot} < 15$
Toothed belt, standard gear unit	Standard applications, couplings with torque buffer (→ elasticity)	$J_{ext} / J_{Mot} < 10$

3.7 Project planning example

Project planning for a travel drive in S3 operation

Reference data:

Weight of the load:	m_{load} =	150 kg
Weight of the carriage:	$m_{carriage}$ =	100 kg
Traveling velocity:	v_{loaded} =	1 ms^{-1}
Traveling velocity:	$v_{unloaded}$ =	1.5 ms^{-1}
Acceleration:	a_{loaded} =	5 ms^{-2}
Acceleration:	$a_{unloaded}$ =	10 ms^{-2}
Efficiency of the machine:	η_{load} =	0.9
Diameter of the carrying wheel:	D_L =	120 mm
Diameter of the belt pulley:	D_0 =	100 mm
Additional gear:	i =	1
Ambient temperature:		20°C
Transmission element overhung load:	f_z =	2.5 (helical-bevel gear unit)

Travel cycle

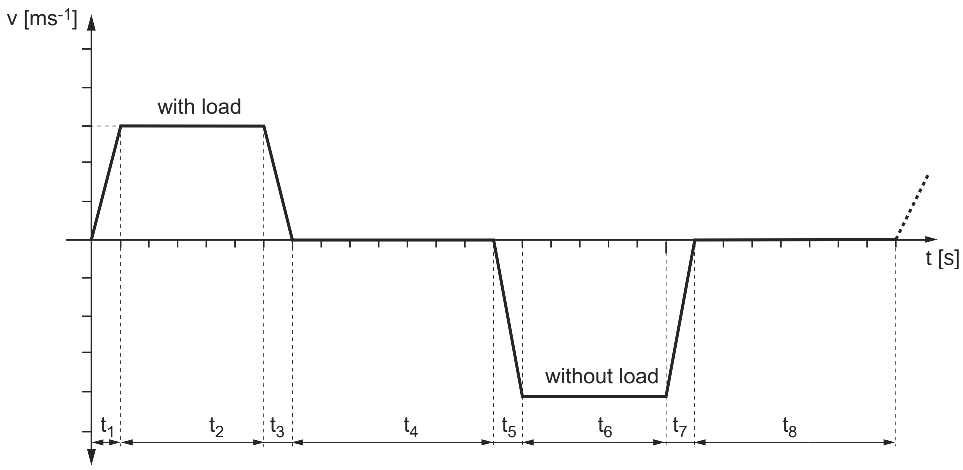

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Figure 4: Travel cycle

The following time periods result from the travel cycle:

$t_1 = t_3 = 0.2$ s	$v_2 = 1\ ms^{-1}$	$a_1 = -\ a_3 = 5\ ms^{-2}$
$t_2 = 2.9$ s	$v_4 = v_8 = 0\ ms^{-1}$	$a_2 = a_4 = a_6 = a_8 = 0\ ms^{-2}$
$t_4 = t_8 = 2$ s	$v_6 = 1.5\ ms^{-1}$	$a_5 = -\ a_7 = 10\ ms^{-2}$
$t_5 = t_7 = 0.15$ s		
$t_6 = 1{,}917$ s		

Torque diagram

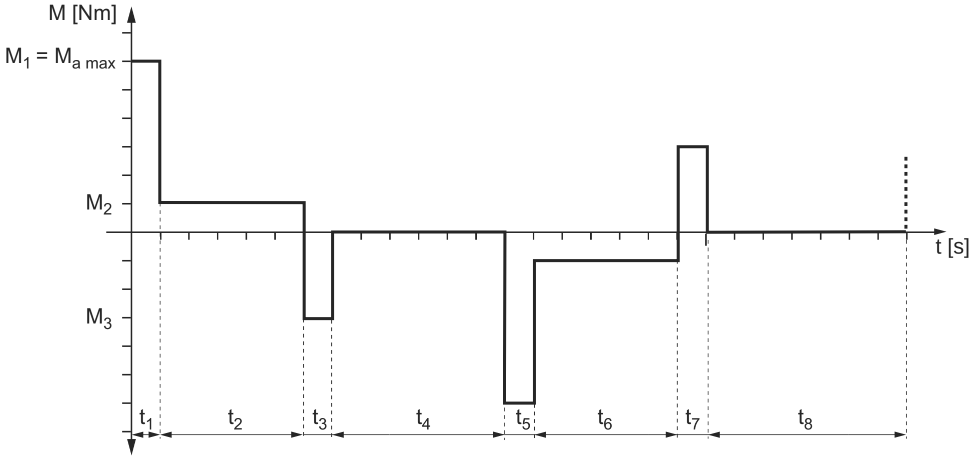


Figure 5: Torque diagram

The following time periods result from the torque diagram:

M_1 = 85.5 Nm	M_5 = -67.27 Nm
M_2 = 2.2 Nm	M_6 = -0.87 Nm
M_3 = -65.3 Nm	M_7 = 52.93 Nm
$M_4 = M_8$ = 0 Nm	

3

Selecting the helical-bevel gear unit

Max. torque M_{max}

The torque diagram shows that the maximum torque M_{max} that can occur is 85.5 Nm. The following condition must be met to select a helical-bevel gear unit from the selection tables:

Selection criterion 1

$\mathbf{M_{max} \leq M_{a\,max}}$

Overhung load F_R

The overhung load is determined by means of M_{max} and the belt pulley diameter D_0.

$$F_R = \frac{M_{max} \times 2000}{D_0} \times f_z = \frac{85.5\ \text{Nm} \times 2000}{0.1\ \text{m}} \times 2.5 = 4275\ \text{N}$$

The application point is on the midpoint of the shaft, i. e. x = l/2.

Selection criterion 2

$\mathbf{F_R \leq F_{RA}}$

Gear unit reduction ratio i

The gear unit reduction ratio is determined by approximation by means of the maximum output speed and an assumed rated motor speed of n_N = 3000 1/min. It has proven to be advantageous to take into account a speed reserve of 10 %.

$$n_{a\,max} = \frac{v_6}{D_L \times \pi} = \frac{1.5\ \text{m/s}}{0.12\ \text{m} \times \pi} = 3.979\ \text{1/s} = 238.74\ \text{1/min}$$

$$i = \frac{n_{N\,Motor} - 10\,\%}{n_{a\,max}} = \frac{2700\ \text{1/min}}{238.74\ \text{1/min}} = 11.31$$

Gear unit selection

The gear unit can now be selected by means of the determined values M_{max}, F_R and the gear unit reduction ratio i determined by approximation:

Gear unit: K57

Gear unit reduction ratio: i = 11.92

Maximum output torque: $M_{a\,max}$ = 415 Nm

Efficiency: η = 0.94

Overhung load: F_{RA} = 4960 N

Moment of inertia: $J_{gear\ unit} = 2.11 \times 10^{-4}$ kgm^2

Check the selection:

$\mathbf{M_{max} \leq M_{a\,max}}$: 85.5 Nm ≤ 415 Nm → **requirement fulfilled.**

$\mathbf{F_R \leq F_{RA}}$: 4275 Nm ≤ 4960 Nm → **requirement fulfilled.**

Above example shows how to determine a gear unit by approximation. For exact gear unit selection, contact SEW-EURODRIVE.

Selecting the motor

The maximum input torque $M_{e\ max}$ can now be determined from the maximum output torque by taking account of the gear unit efficiency.

$$M_{e\ max} = \frac{M_{max}}{i \times \eta_{gear\ unit}} = \frac{85.5\ \text{Nm}}{11.92 \times 0.94} = 7.63\ \text{Nm}$$

This maximum input torque is used for a preliminary motor selection, which still needs to be checked:

Preliminary motor selection

⇒ CM71S/BR

$n_N = 3000\ \text{min}^{-1}$

$M_0 = 5\ \text{Nm}$

$I_0 = 3.3\ \text{A}$

$J_{Mot} = 6.65 \times 10^{-4}\ \text{kgm}^2$

Calculating the input speed

$$n_{a1} = \frac{v_1}{D_L \times \pi} = \frac{1\ \text{m/s}}{0.12\ \text{m} \times \pi} = 2.6526\ \text{1/s} = 159.156\ \text{1/min}$$

$$n_{e1} = n_{a1} \times i = 159.156\ \text{1/min} \times 11.92 = 1897.13\ \text{1/min}$$

$$n_{a5} = n_{a\ max}$$

$$n_{e5} = n_{a5} \times i = 238.74\ \text{1/min} \times 11.92 = 2845.78\ \text{1/min}$$

Determining the inertia ratio "k"

$$J_{ext} = 91.2 \times m \times \left(\frac{v}{n_{Motor}}\right)^2 + J_{gear\ unit}$$

$$J_{ext} = 91.2 \times 250\ \text{kg} \times \left(\frac{1\ \text{m/s}}{1897.13\ \text{1/min}}\right)^2 + 2.11 \times 10^{-4}\ \text{kgm}^2 = 6.545913 \times 10^{-3}\ \text{kgm}^2$$

$$k = \frac{J_{ext}}{J_{Mot}} = \frac{6.545913 \times 10^{-3}\ \text{kgm}^2}{6.65 \times 10^{-4}\ \text{kgm}^2} = 9.84$$

Requirement **k ≤ 10 - 15**

Check the requirement: 9.84 ≤ 10 - 15 → **requirement fulfilled.**

The inertia ratio "k" has a major influence on all control characteristics.

Determining motor torques

In addition to the input torque, the motor must deliver a certain torque to being able to accelerate itself and the gear unit.

$$M_{1\ Mot} = (J_{Mot} + J_{gear\ unit}) \times \frac{n_{e1}}{9.55 \times t}$$

$$M_{1\ Mot} = (6.65 \times 10^{-4}\text{kgm}^2 + 2.11 \times 10^{-4}\text{kgm}^2) \times \frac{1897.13\ \text{1/min}}{9.55 \times 0.2\ \text{s}} = 0.87\ \text{Nm}$$

Section t_1 The torque to be delivered by the motor in section 1 is calculated as follows:

$$M_{t1} = M_{e\ max} + M_1 = 7.63\ \text{Nm} + 0.87\ \text{Nm} = 8.5\ \text{Nm}$$

Section t_2 The torque to be delivered by the motor in section 2 is calculated as follows:

$$M_{t2} = \frac{M_2}{i \times \eta_{gear\ unit}} = \frac{2.2\ \text{Nm}}{11.92 \times 0.94} = 0.196\ \text{Nm}$$

Section t_3

The torque to be delivered by the motor in section 3 is calculated in the same way as in section 1 but with the difference that the efficiency of the motor is advantageous due to the deceleration.

$$M_{t3} = \frac{M_3 \times \eta_{\text{gear unit}}}{i} + M_1 = \frac{-65.3\ \text{Nm} \times 0.94}{11.92} + (-0.87\ \text{Nm}) = -6.02\ \text{Nm}$$

Section t_4

As the speed in section v_4 is 0 m/s, the motor need not produce any holding torque → M_{t4} = 0 Nm. The brake is applied.

Section t_5

The torques to be delivered by the motor in sections 5 - 8 are calculated in the same way as for sections 1 - 4.

$$M_{5\ \text{Mot}} = (J_{\text{Mot}} + J_{\text{gear unit}}) \times \frac{n_{e5}}{9.55 \times t}$$

$$M_{5\ \text{Mot}} = (6.65 \times 10^{-4}\text{kgm}^2 + 2.11 \times 10^{-4}\text{kgm}^2) \times \frac{-2845{,}78\ 1/\text{min}}{9.55 \times 0.15\ \text{s}} = -1.74\ \text{Nm}$$

Input torque in section 5:

$$M_{e5} = \frac{M_5}{i \times \eta_{\text{gear unit}}} = \frac{-67.27\ \text{Nm}}{11.92 \times 0.94} = -6\ \text{Nm}$$

The torque to be delivered by the motor in section 5 is calculated as follows:

$$M_{t5} = M_{e5} + M_{5\ \text{Mot}} = -6\ \text{Nm} + (-1.74\ \text{Nm}) = -7.74\ \text{Nm}$$

Section t_6

The torque to be delivered by the motor in section 6 is calculated as follows:

$$M_{t6} = \frac{M_6}{i \times \eta_{\text{gear unit}}} = \frac{-0.87\ \text{Nm}}{11.92 \times 0.94} = -0.076\ \text{Nm}$$

Section t_7

The torque to be delivered by the motor in section 7 is calculated as follows:

$$M_{t7} = \frac{M_7 \times \eta_{\text{gear unit}}}{i} + M_{5\ \text{Mot}} = \frac{52.93\ \text{Nm} \times 0.94}{11.92} + 1.74\ \text{Nm} = 5.914\ \text{Nm}$$

Section t_8

As the speed in section v_8 is 0 m/s, the motor need not produce any holding torque → M_{t8} = 0 Nm. The brake is applied.

Determining the effective motor torque

Cycle time

$$t_{cycle} = t_1 + t_2 + \ldots + t_8$$

$$t_{cycle} = 0.2\ s + 2.9\ s + 0.2\ s + 2\ s + 0.15\ s + 1.917\ s + 0.15\ s + 2\ s = 9.517\ s$$

Effective torque

$$M_{eff} = \sqrt{\frac{1}{t_{cycle}} \times \left(M_{t1}^2 \times t_1 + M_{t2}^2 \times t_2 + \ldots + M_{t8}^2 \times t_8\right)}$$

$$M_{eff} = \sqrt{\frac{1}{9.517} \times \left(8.5^2 \times 0.2 + 0.196^2 \times 2.9 + (-6.02)^2 \times 0{,}2 + 0^2 \times 2 + (-7.74)^2 \times 0.15 + (-0.076)^2 \times 1.917 + 5.91^2 \times 0{,}15 + 0^2 \times 2\right)}$$

$$M_{eff} = 1.946\ \text{Nm}$$

Determining the mean input speed

$$\bar{n} = \frac{1}{t_{cycle}} \times \left(n_{t1} \times t_1 + n_{t2} \times t_2 + \ldots + n_{t8} \times t_8\right)$$

$$\bar{n} = \frac{1}{9.517} \times \left(\frac{1897.13}{2} \times 0.2 + 1897.13 \times 2.9 + \frac{1897.13}{2} \times 0.2 + 0 \times 2 + \frac{2845.78}{2} \times 0.15 + 2845.78 \times 1.917 + \frac{2845.78}{2} \times 0.15 + 0 \times 2\right)$$

$$\bar{n} = 1251.88\ 1/\text{min}$$

Determining the operating point

The operating point can be entered in the thermal motor characteristic curve based on the effective motor torque and the mean motor speed:

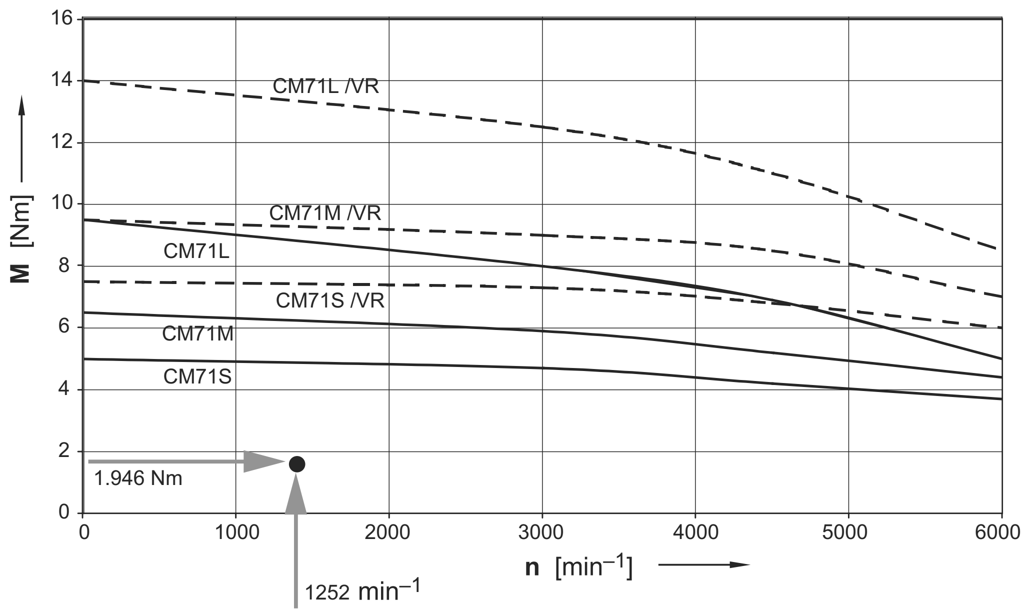


Figure 6: Operating point

The effective torque at mean speed must lie below or maximally on the thermal characteristic curve to protect the motor from thermal overload:

Requirement

$M_{eff} \leq M_0$: 1.946 Nm ≤ 5 Nm → **requirement fulfilled.**

Checking the dynamic limit torque

You have to check whether the motor is capable of delivering this dynamic torque by means of the maximum torque and the associated speed.

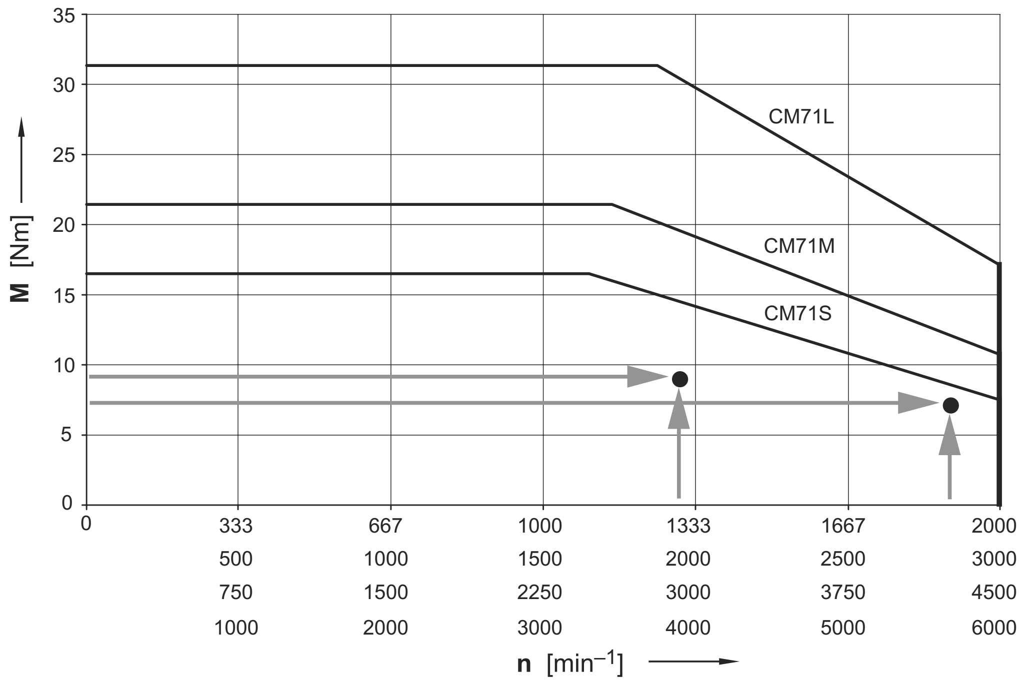


Figure 7: Maximum operating point

For this purpose, the maximum torque and the associated speed as well as the maximum speed and the associated torque are entered in the diagram as maximum operating points.

The maximum operating points must lie below or maximally on the characteristic curve of the thermal limit torque. Note that the characteristic curve declines in the upper speed range.

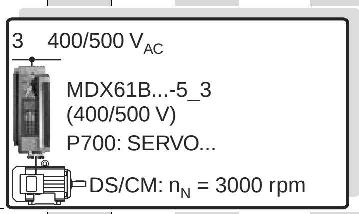
Requirement

M_{max} ≤ dynamic limit torque is fulfilled.

Selecting the inverter

Rated speed n_N = 3000 1/min.

Motor			MOVIDRIVE® MDX61B...-5_3 (400/500 V units) in SERVO operating modes (P700)															
			0005	0008	0011	0014	0015	0022	0030	0040	0055	0075	0110	0150	0220	0300	0370	0450
DS56M	M_{max}	[Nm] ([lb.in])	2.4 (21.1)	2.8 (24.6)	3.6 (31.7)	3.8 (33.4)	3.5 (30.8)	3.8 (33.4)										
DS56L	M_{max}	[Nm] ([lb.in])	3.3 (29.0)	4.0 (35.2)	5.1 (44.9)	6.4 (56.4)	4.9 (43.1)	6.6 (58.1)	7.6 (66.9)									
DS56H	M_{max}	[Nm] ([lb.in])	5.7 (50.2)	6.8 (59.9)	8.8 (77.5)	11.2 (98.7)	8.5 (74.9)	11.5 (101)	14.3 (126)	15.2 (133)								
CM71S	M_{max}	[Nm] ([lb.in])	6.0 (52.8)	7.2 (63.4)	9.2 (81.0)	11.6 (102)	8.9 (78.4)	11.9 (104)	14.3 (126)	16.5 (145)								
CM71M	M_{max}	[Nm] ([lb.in])		7.2 (63.4)	9.3 (81.9)	11.9 (104)	9.0 (79.3)	12.2 (107)	15.1 (133)	19.1 (168)	21.5 (189)							
CM71L	M_{max}	[Nm] ([lb.in])			9.5 (83.7)	12.2 (107)	9.2 (81.0)	12.6 (111)	15.9 (140)	21.0 (185)	26.2 (230)	30.8 (271)	31.5 (277)					
CM90S	M_{max}	[Nm] ([lb.in])				12.0 (105)	9.0 (79.3)	12.4 (109)	15.7 (138)	21.2 (186)	27.4 (241)	34.0 (299)	40.1 (353)					
CM90M	M_{max}	[Nm] ([lb.in])						11.8 (103)	15.0 (132)	20.4 (179)	26.6 (234)	33.7 (296)	47.8 (421)	51.6 (454)				
CM90L	M_{max}	[Nm] ([lb.in])								20.7 (182)	27.3 (240)	34.7 (305)	51.1 (450)	65.6 (578)	75.6 (666)			
CM112S	M_{max}	[Nm] ([lb.in])								22.2 (195)	29.3 (258)	37.4 (329)	54.8 (482)	69.8 (615)	81.9 (721)			
CM112M	M_{max}	[Nm] ([lb.in])									28.2 (248)	36.2 (319)	54.0 (475)	70.7 (623)	95.7 (843)	108.0 (951)		
CM112L	M_{max}	[Nm] ([lb.in])										35.8 (345)	53.9 (474)	71.6 (630)	101.0 (890)	126.9 (1118)	147.4 (1298)	156.8 (1381)



The matching inverter can now be selected from the motor selection tables on the basis of the effective torque and the peak torque.

⇒ MDX61B0011–5A3.

Determining the matching braking resistor

For project planning of the matching braking resistor, the following values must be determined from travel sections during which the motor operates as generator.

- Peak braking power
- Average braking power

Peak braking power

$$P_{Br\_peak} = \frac{M_{t7} \times n_{t5}}{9550} = \frac{5.914\ \text{Nm} \times 2845.78\ \text{1/min}}{9550} = 1.76\ \text{kW}$$

Average braking power in section t_3

$$P_{Br\_t3} = \frac{M_{t3} \times \frac{n_{e3}}{2}}{9550} = \frac{6.02\ \text{Nm} \times \frac{1897.13\ \text{1/min}}{2}}{9550} = 0.6\ \text{kW}$$

Average braking power in section t_7

$$P_{Br\_t7} = \frac{M_{t7} \times \frac{n_{e7}}{2}}{9550} = \frac{5.914\ \text{Nm} \times \frac{2845.78\ \text{1/min}}{2}}{9550} = 0.88\ \text{kW}$$

Effective braking power

$$P_{Br} = \frac{P_{Br\_t3} \times t_3 + P_{Br\_t7} \times t_2}{t_{cycle}}$$

$P_{Br\_t1} = P_{Br\_t2} = P_{Br\_t4} = P_{Br\_t6} = P_{Br\_t8} = 0\ \text{kW}$

$$P_{Br} = \frac{0.6\ \text{kW} \times 0{,}2\ \text{s} + 0.88\ \text{kW} \times 0{,}15\ \text{s}}{9{,}517\ \text{s}} = 0.0265\ \text{kW}$$

Selecting the braking resistor

A preselection of braking resistors that may be connected to the respective inverter is made based on the table "Assignment of braking resistors (see "MOVIDRIVE® MDX60/61B" system manual, Installation section):

MOVIDRIVE® MDX60/61B...-5A3			0005	0008	0011	0014
Size			0			
Braking resistors	**Trip current**	**Part number**				
BW090-P52B[1]	-	824 563 0				
BW072-003	I_F = 0.6 A_{RMS}	826 058 3				
BW072-005	I_F = 1.0 A_{RMS}	826 060 5				
BW168	I_F = 2.5 A_{RMS}	820 604 X				
BW100-006	I_F = 1.8 A_{RMS}	821 701 7				
Line chokes		**Part numbers**				
ND020-013	ΣI_{mains} = 20 A_{AC}	826 012 5				
Line filter		**Part number**				
NF009-503	V_{max} = 550 V_{AC}	827 412 6				
Output chokes	**Inside diameter**	**Part number**				
HD001	d = 50 mm (1.97 in)	813 325 5	for cable cross sections 1.5 ... 16 mm² (AWG 16 ... 6)			
HD002	d = 23 mm (0.91 in)	813 557 6	for cable cross sections ≤ 1.5 mm² (AWG 16)			
Output filters (only in VFC mode)		**Part number**				
HF008-503		826 029 X		A		
HF015-503		826 030 3		B		A
HF022-503		826 031 1				B

1) Internal, thermal overload protection, no bimetallic relay required.

The resistor is finally determined from this preselection, the calculated peak braking power and the average braking power of the application. For technical data of the braking resistors, refer to the "MOVIDRIVE® MDX60B/61B system manual, section 3 Technical Data."

Braking resistor type	BW090-P52B	BW100-005	BW100-006	BW072-003	BW072-005	BW168	BW268
Part number	824 563 0	826 269 1	821 701 7	826 058 3	826 060 5	820 604 X	820 715 1
Load capacity at 100 % cdf	0.10 kW	0.45 kW	0.6 kW	0.23 kW	0.45 kW	0.8 kW	1.2 kW
50 % cdf[1]		0.60 kW	1.1 kW	0.31 kW	0.60 kW	1.4 kW	2.2 kW
25 % cdf		0.83 kW	1.9 kW	0.42 kW	0.83 kW	2.6 kW	3.8 kW
12 % cdf		1.11 kW	3.5 kW	0.58 kW	1.11 kW	4.7 kW	6.7 kW
6 % cdf		2.00 kW	5.7 kW	1.00 kW	2.00 kW	7.6 kW	10 kW[2]
3 % cdf **1 % cdf**	Note the **regenerative power limit** of the inverter! (= 150 % of the recommended motor power → Technical Data)						
Resistance value R_{BW}	90 Ω ±35 %	100 Ω ±10 %		72 Ω ±10 %		68 Ω ±10 %	
Trip current (of F16) I_F	-	0.8 A_{RMS}	1.8 A_{RMS}	0.6 A_{RMS}	1.0 A_{RMS}	2.5 A_{RMS}	3.4 A_{RMS}
Type	PTC	Flat type	Wire resistor on ceramic core	Flat type		Wire resistor on ceramic core	
Terminals	Cables	Cables	Ceramic terminals 2.5 mm^2 (AWG12)	Cables		Ceramic terminals 2.5 mm^2 (AWG12)	
Enclosure	IP20	IP54	IP20 (when mounted)	IP54		IP20 (when mounted)	
Ambient temperature ϑ_U	–20 ... +45 °C						
Type of cooling	KS = Self-cooling						
for MOVIDRIVE®	0005 ... 0014	0005 ... 0022	0015 ... 0040	0005 ... 0014		0015 ... 0040	

1) cdf = Cyclic duration factor of the braking resistor in relation to a cycle duration $T_D \leq 120$ s.

2) Physical power limit due to the DC link voltage and the resistance value.

6% cdf $\triangleq$ 7.2 s $\Rightarrow$ 7.2 s $\geq$ 0.2 s.

Requirement

- Peak braking power $P_{Br\_peak} \leq$ Braking power resistor 6 % cdf.
- Average braking power $P_{BR} \leq$ Load capacity of the resistor with reference to the cycle time of the application.

Selection of options and accessories

You have to select the option card for MOVIDRIVE® MDX61B with the corresponding encoder interface according to the motor encoder:

- DEH11B for Hiperface® encoder
- DER11B for resolver.

Other option cards might also be required (e.g. fieldbus card) depending on the application. For more information on available option cards and accessories (e. g. keypads, etc.), refer to the "MOVIDRIVE® MDX60B/61B" system manual.

For information on prefabricated motor and encoder cables, refer to the MOVIDRIVE® system manual, and to chapter 11 in this catalog.