EN

C

CDA3000

Engineering Guide

Inverter drive system
to 90 kW

With drive engineering
formula bank

The easy route
to your drive solution

LUST

LUST

Overview of documentation

Before purchase	**CDA3000 Catalogue** Selecting and ordering a drive system	**Engineering Guide CDA3000** C Dimensioning a drive system	
With shipment (depending on supply pakkage)	**CDA3000 Operation Manual** D Quick and easy initial commissioning	**User Manual DRIVEMANAGER and KEYPAD** E Operation via DRIVEMANAGER and KEYPAD	**Application Manual Traction and lifting drives, Rotational drives** F1 Adaptation of the drive system to the application
	CANLust Communication Module Manual G1 Project planning, installation and commissioning of the CDA3000 on the field bus	**CANopen Communication Module Manual** G2 Project planning, installation and commissioning of the CDA3000 on the field bus	**PROFIBUS-DP Communication Module Manual** G3 Project planning, installation and commissioning of the CDA3000 on the field bus

C

Engineering Guide CDA3000

ID no.: 0840.25B.1-00 Sheets for Engineering Guide
Date: December 1999

About this manual

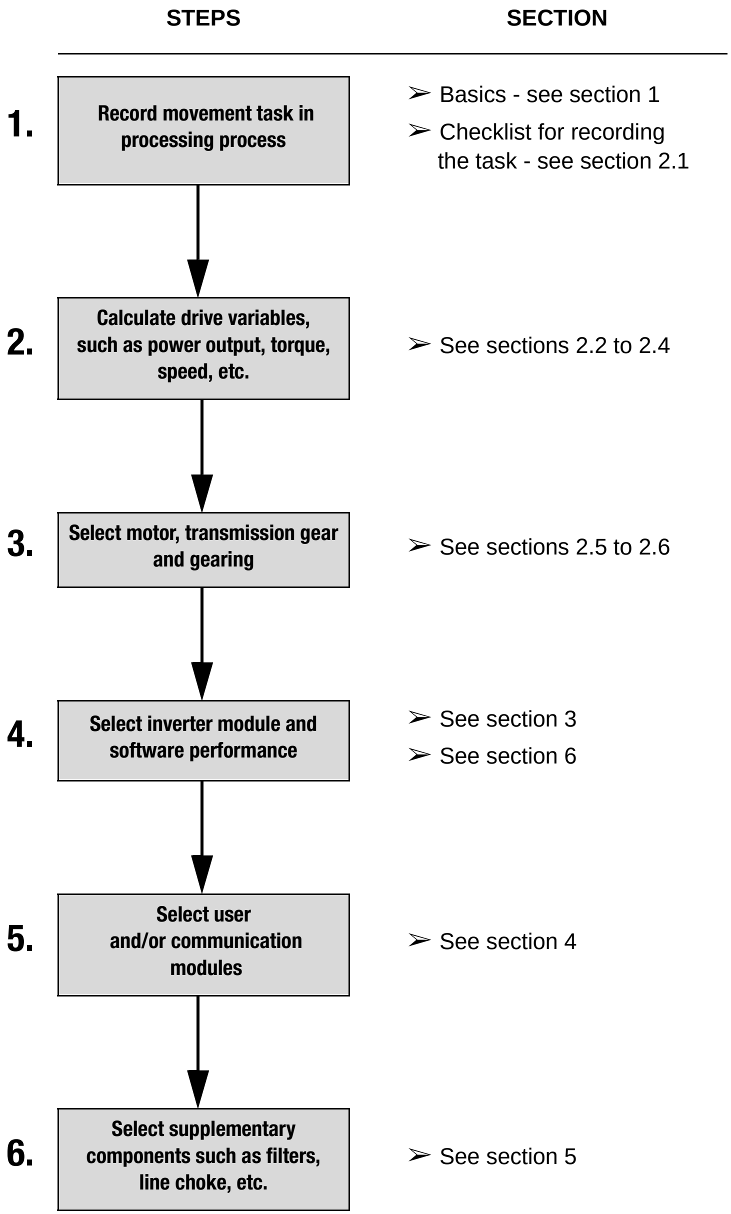
This guide is intended for users looking for background information relating to the engineering of inverter drives.

The term “engineering” (or “project planning”) in this context covers the design and configuration of complex technical systems through to receipt of the order to implement. General project planning tasks including:

- ➢ Analysis of the task
- ➢ Concept design of the system
- ➢ Design of the system components
- ➢ Selection of the best solution to be implemented.

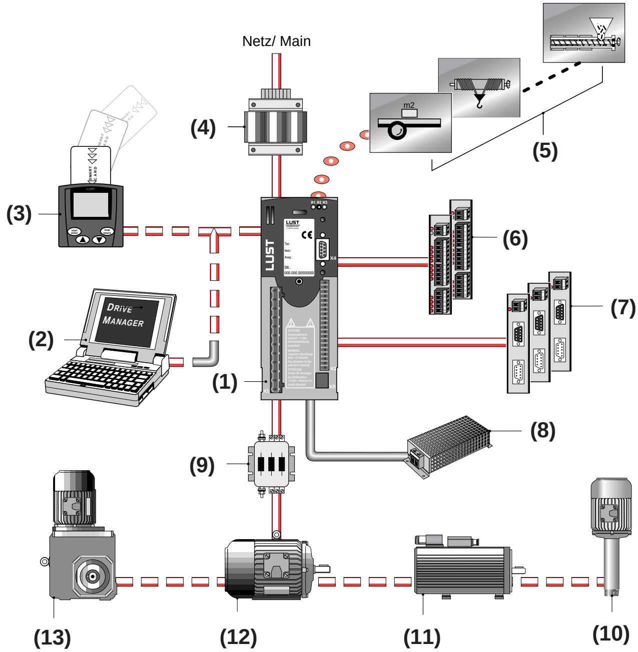
How to use this manual

Project planning flowchart



	STEPS	SECTION
1.	Record movement task in processing process	➢ Basics - see section 1 ➢ Checklist for recording the task - see section 2.1
2.	Calculate drive variables, such as power output, torque, speed, etc.	➢ See sections 2.2 to 2.4
3.	Select motor, transmission gear and gearing	➢ See sections 2.5 to 2.6
4.	Select inverter module and software performance	➢ See section 3 ➢ See section 6
5.	Select user and/or communication modules	➢ See section 4
6.	Select supplementary components such as filters, line choke, etc.	➢ See section 5

Drive system layout



System modules		Section
(1)	Inverter module	See section 3
(2)	DRIVEMANAGER PC user software	See section 4.1.4
(3)	KEYPAD control unit	See section 4.1.3
(4)	Line choke	See section 6.1
(5)	Software performance - Preset solutions	See section 4.2
(6)	I/O terminal expansion	See section 4
(7)	CAN$_{Lust}$, CAN$_{open}$, Profibus-DP bus interface	See section 5.3
(8)	Braking resistor	See section 6.3
(9)	Motor chokes	See section 6.2
(10)	HF spindle	See section 2.5.5
(11)	Asynchronous servomotor	See section 2.5.2
(12)	IEC standard motor	See section 2.5.1
(13)	Geared motor	See section 2.5

1 Analysis of task

2 Drive definition

3 Selection of inverter module

4 Software functions

5 Communication and user modules

6 Selection of supplementary components

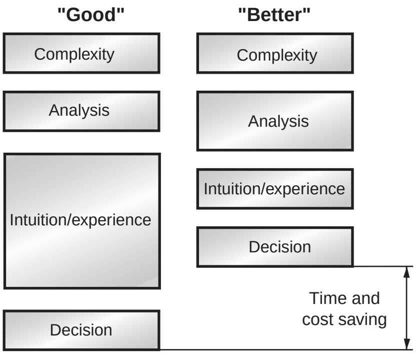
7 System installation

A Formula bank

1 Analysis of task

Take your time, especially at the beginning

Please note: The more complex the task, the more important is the analysis. A “better” analysis can identify impending failures in good time.



1.1 Systematic thinking

Before beginning your project planning you should read through this section - it will help you identify how to attain the new solutions you need.

What can we learn from system analysis? The term "system" in this context means:

Thinking differently
[leads to]
Belief
[in turn resulting in]
Acting differently

- ➢ a unified whole, distinct from its surroundings
- ➢ comprising individual elements
- ➢ between which fixed relationships exist
- ➢ and which perform specific functions.

The starting point for any system analysis is to record, understand and order the existing inter-relationships within a system. To this end, the system is split down into its subsidiary areas (components) such that all the individual components are distinct from each other and the relations between them become visible.

1.1.1 Inverter system

An inverter system comprises the following individual components and modules:

- Inverter module
- Operator module
- User module
- Communication module
- Software modules
- Line choke
- Mains filter
- Motor choke
- Braking resistor
- Cable
- Motors
- Gearing
- etc.

The chain is only as strong as its weakest link

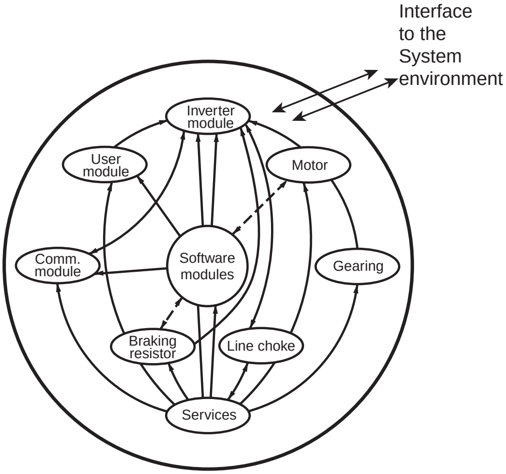


Figure 1.1 Inverter system

In summary: **An inverter system is a combination of standalone products and services which create new usable drive system properties with added value.**

1.1.2 System environment

Analysis of the system environment of inverter drives reveals four interfaces which outline that environment:

1. Interface to the processing process
2. Interface to the automation process
3. Interface to the surrounding environment and installation conditions
4. Interface to the requirements arising from standards, regulations and safety concerns

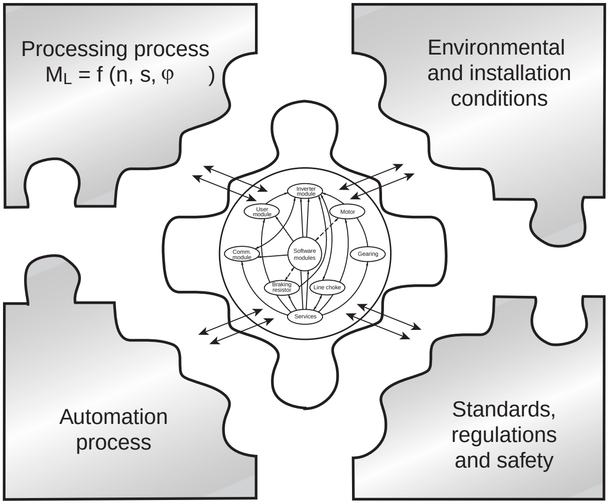


Figure 1.2 System environment

This section deals with the interface to the “processing process”. The other interfaces are dealt with in the subsequent sections of the guide.

1.2 Process analysis

First find out what processing process[1] the drive solution is to be used for. Apply the principles of process analysis, because process analysis will provide you with a non-solution-specific view of the task at hand.

Do not perform a functional analysis at the beginning of an analysis, because the functions used always describe the specific solution.

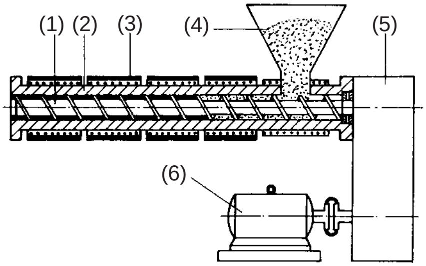
The functional analysis is derived from the value analysis. Its main role is to eliminate dual functions and to cut the cost per function.[2]

1.2.1 Example of a process analysis in comparison with functional analysis

Standard screw-type extruder

- ➢ An extruder is a machine which takes in solid to liquid (synthetic) molding compounds and presses them out of an opening, for the most part continuously.
  It compresses, mixes, plasticizes and homogenizes the compound in the process.

The screw-type extruder shown (see Figure 1.3) principally comprises a drive unit and a plasticizer unit. The plasticizer unit consists of a screw cylinder, a screw, a material funnel, and heating and cooling zones.



(1)	Screw	(4)	Funnel
(2)	Cylinder	(5)	Gearing
(3)	Heater	(6)	Motor

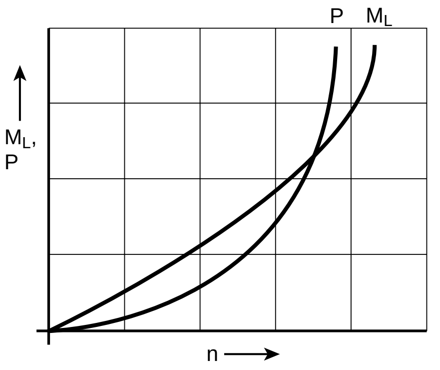
Figure 1.3 Schematic of an extruder

---

[1] Processing process: Process in the course of which energy, information and/or material is transformed and conveyed

[2] The value analysis method was developed in 1948 by the Purchasing department of General Electric. Literature: DIN 69910 and VDI 2801.

The drive unit is formed by a regulated DC drive, gearing and the screw return thrust bearing, which absorbs the forces occurring during conveying and plasticizing.

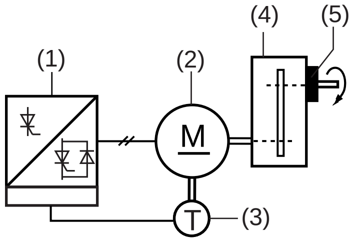


M_L = f (n)
P = f (n)

Figure 1.4 Load characteristic of the plastics extruder

Task for a new drive unit

In order to provider a higher degree of machine availability, the drive is to be switched from DC to three-phase AC. The DC drive used to date has a speed manipulating range of 1:1000 and an overload capacity to 200%.



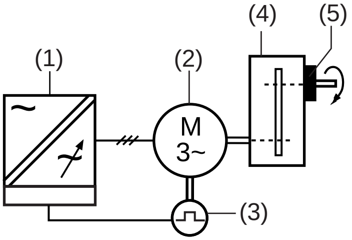
(1) DC controller
(2) DC motor
(3) Tacho
(4) Gearing
(5) Screw return thrust bearing

Figure 1.5 Old solution with DC drive

Functional analysis

In a functional analysis each component which performs a function must merely be replaced by another one. In this case this means:

- the DC motor is replaced by an AC motor
- the tacho is replaced by a digital encoder and
- the DC controller is replaced by an inverter with field-oriented regulation.



(1) Inverter with field-oriented regulation
(2) AC motor
(3) Encoder
(4) Gearing
(5) Screw return thrust bearing

Figure 1.6 Solution from functional analysis

The functional analysis produces a solution with speed feedback - See Table 1.1.

DC drive	Three-phase AC drive
1 DC controller	1 Inverter with field-oriented regulation
2 DC motor	2 AC motor
3 Tacho	3 Encoder
4 Gearing	4 Gearing
5 Screw return thrust bearing	5 Screw return thrust bearing
Old solution	**Functional analysis (NEW 1)**

Table 1.1 Comparison between old solution and solution from functional analysis

Process analysis

A process analysis establishes what demands the processing process places on the drive.

Questions to be answered:

1. What is the movement requirement for processing?
2. Moment of inertia of the processing machine, referred to the motor shaft?
3. What manipulating range is required for the processing process?
4. What load torque needs to be overcome?

Answer the questions in this example:

1. Continuous material flow.
2. Is of no significance in applications with continuous material flow.
3. Speed manipulating range of 1:10.
4. No overload necessary, because the screw of the extruder would otherwise be damaged. When the screw has become clogged, it is drawn forward out of the extruder for cleaning.

The answers supplied in the process analysis deliver a solution with a standard inverter without speed feedback. This means a substantial cost reduction.

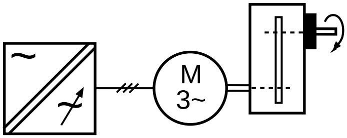


Figure 1.7 Solution from process analysis

Comparison of solutions: "Functional analysis / Process analysis"

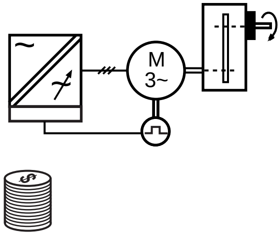
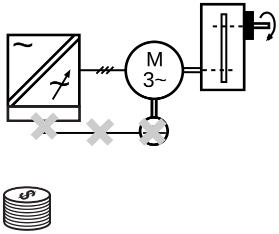
Solution from functional analysis	Solution from process analysis
	
NEW 1 **Inverter with field-oriented regulation**	**NEW 2** **Inverter with VFC**

Figure 1.8 Comparison of solutions

In summary: Always analyze the processing process! Because just because something is *known* does not necessarily mean it is *recognized*!

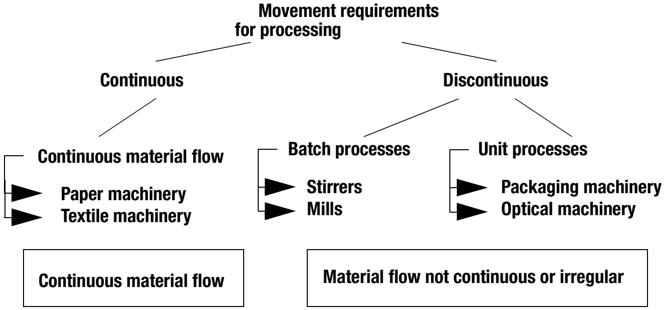
1.3 Characteristic values of machinery

You do not usually need to take account of the detailed structure of the machinery for drive project planning. It can be adequately described by:

1. the movement requirement for processing
2. the moment of inertia of the processing machine, referred to the motor shaft
3. the manipulating range and accuracy of the torque, speed and position
4. the characteristic over time of the load torque

1.3.1 Movement requirement

The movement requirement for processing is roughly divided into three groups.



Traction and mechanical function

The movement solution in the processing process in most cases involves a traction function and a mechanical function. The mechanical function usually generates a non-linear movement. The processing process counteracts this movement with a specific load torque.

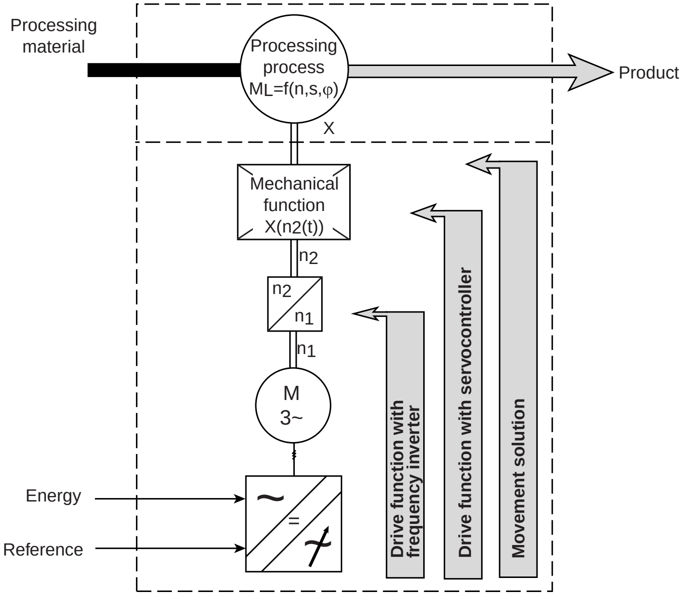


Figure 1.9 Movement solution in the processing process

Example of a movement solution

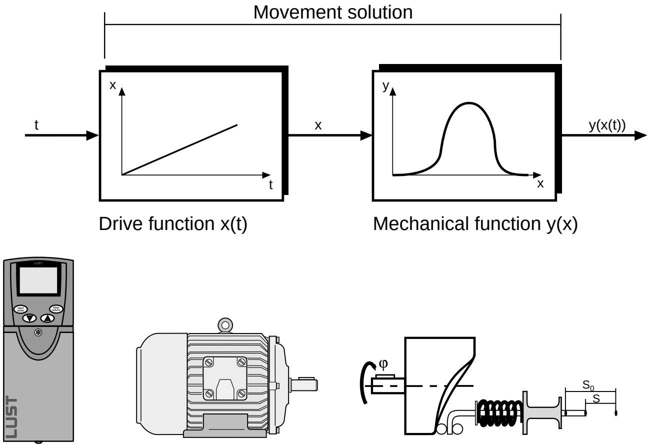


Figure 1.10 Movement solution split into traction and mechanical function

v/t diagram

The processing cycle of a machine or plant is typically described by the velocity/time profile, also termed the v/t diagram. From that diagram the acceleration/deceleration time and the startup and shutdown frequency can be determined. This repetition rate of the startup and shutdown process determines the

- ➢ motor rating

$$M_{eff} = \sqrt{\frac{M_1{}^2 \cdot t_1 + M_2{}^2 \cdot t_2 + M_n{}^2 \cdot t_n}{T}}$$

- ➢ current load of the inverter module

$$I_{eff} = \sqrt{\frac{I_1{}^2 \cdot t_1 + I_2{}^2 \cdot t_2 + I_n{}^2 \cdot t_n}{T}}$$

- ➢ and the braking chopper design

$$P_{eff} = \sqrt{\frac{P_1{}^2 \cdot t_1 + P_2{}^2 \cdot t_2 + P_n{}^2 \cdot t_n}{T}}$$

For more information on the subject of the v/t diagram refer to the formula bank in See Appendix A.2.9.

1.3.2 Moment of inertia

The moment of inertia of a machine or a machining process is kept as low as possible. However, the room for maneuver in terms of dimensioning is very low as a result of the pressure for technological optimization.

The moment of inertia of motors is of great significance for the overall drive design in cases of frequent and rapid changes of speed, while in rotational drives, such as a sugar centrifuge or a continuous winding drive, a reduction in the moment of inertia of the motor has little or no effect on the overall drive design.

For more information on this subject refer to the formula bank in section A.2.8 and section 2.

1.3.3 Manipulating range and accuracy

The desired torque rise time, the speed manipulating range and the positioning accuracy are likewise determined by the technological processing process.

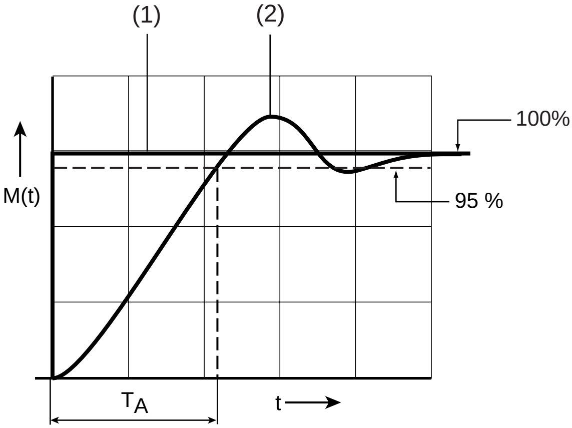
In the following some terms are defined more closely, in order to avoid misunderstandings between you - the customer - and the drive manufacturer.

Definition of terms

Torque rise time

The torque rise time is the time which elapses after a reference step from 0 to MN until the actual value of the torque in the motor has reached 95% of the nominal value.

The torque rise time is dependent on the control methods applied and on the electrical parameters of the motor used. As the speed increases the voltage reserve for injection of a current falls, causing the torque rise time to increase.



T_A= Torque rise time
(1) Reference
(2) Actual

Figure 1.11 Torque rise time

Speed manipulating range

The speed manipulating range is the range in which the motor can always deliver nominal torque.

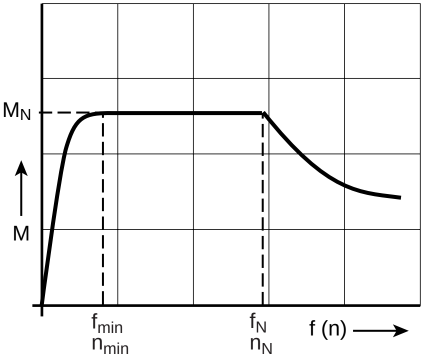


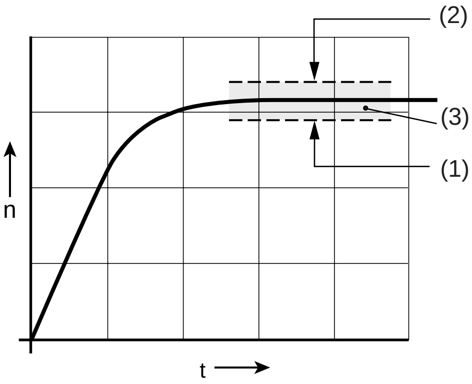
Figure 1.12 Speed manipulating range

$$\text{Manipulating range} = \frac{f_N}{f_{min}} = \frac{n_N}{n_{min}}$$

f_N	Rated frequency in Hz
f_{min}	Minimum frequency in Hz
n_N	Nominal speed in rpm
n_{min}	Minimum speed in rpm

Static speed accuracy

The static speed accuracy refers to the speed deviation in the steady (static) state after completion of startup.



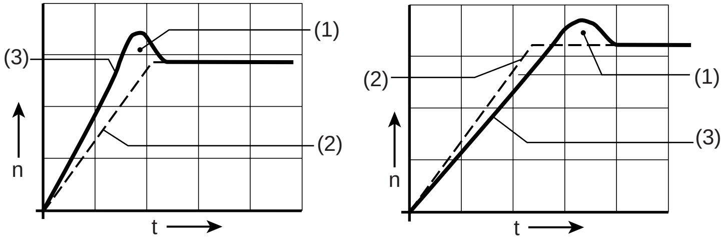
(1) Lower limit
(2) Upper limit
(3) Variation range

Figure 1.13 Static speed accuracy

In operation with speed control a high-frequency ripple is superimposed on the actual speed. The frequency of the ripple depends on the sampling rate of the speed controller. The amplitude of the said ripple is dependent on the encoder system used and on the mass inertia system (application and motor).

Dynamic speed accuracy

The dynamic speed accuracy refers to the speed deviation during the startup or braking process of a speed change. The greatest deviation very often occurs in the transient response in settling to the desired speed.



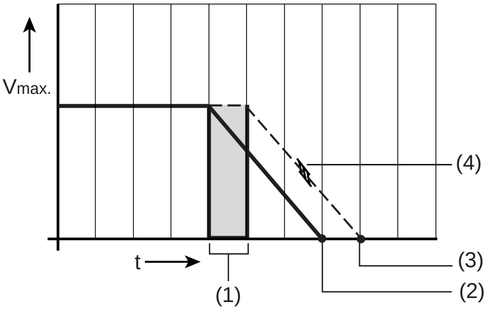
(1) Dynamic variation
(2) Reference
(3) Actual

(1) Dynamic variation
(2) Reference
(3) Actual

Figure 1.14 Dynamic speed accuracy

Positioning accuracy without position control (Start/Stop mode)

The term positioning accuracy refers to the position deviation at standstill. The degree of deviation is decisively influenced by the response times of the control and the drive controller.



$S_F = V_{max} \cdot t_{RF}$

S_F = Positioning error in mm

V_{max} = Velocity in mm/s

t_{RF} = Response error (terminal scan cycle) in s

(1)	Scan cycle of control terminals on inverter (t_{RF}=response error)	
(2)	Destination position 1	(stop signal comes together with read-in of control signals on inverter)
(3)	Destination position 2	(Stop signal comes directly after read-in of control signals on inverter)
(4)	Slip range	(depending on control mode the braking ramp is slipdependent)

Figure 1.15 Start/stop positioning

The positioning and repeat accuracy is of course also dependent on other factors such as:

- Implementation of the mechanical function
- Mechanical system of the pickup
- Gearing used
- Constant response time of the control
- Measurement resolution from position transducer
- etc.

A precise analysis is only possible in specific cases.

Positioning accuracy with position control

In the case of a positioning operation with position control in the controller, the positioning accuracy is dependent on the encoder system and the quality of the position control (with or without pre-control, sampling time, etc.).

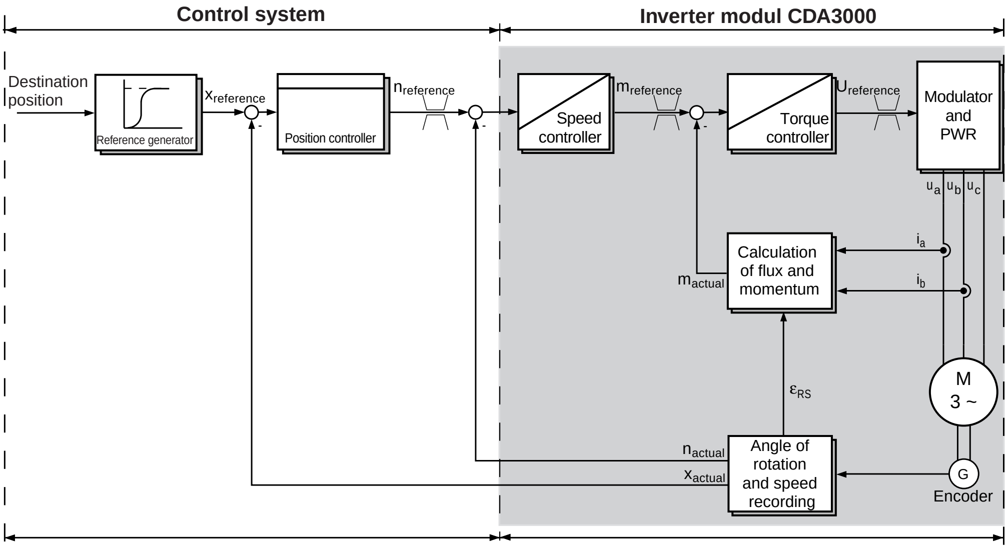


Figure 1.16 Positioning with reference generator and position control in the controller

Reference generator

The reference generator generates the characteristic over time of the reference position.

Position controller

The position controller ensures that the reference position is maintained as closely as possible.

Speed controller

The speed controller in turn ensures that the reference speed of the motor is maintained.

- The speed reference can be specified via +10 V to -10 V or via CAN or PROFIBUS

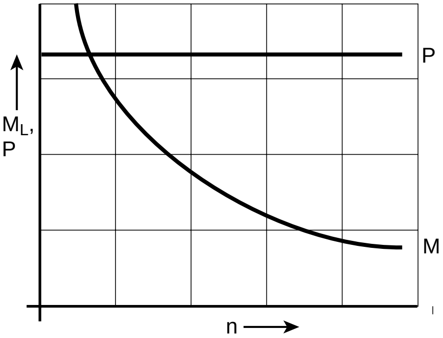
In summary: The positioning accuracy is dependent on the measurement system and on the position control sampling. It is also of course dependent on the sources of error of the machine (temperature, rigidity, vibration, etc.).

1.3.4 Load torque

All machinery counteracts the drive with a specific torque. This torque is composed of a static torque which is defined by the technological process and the acceleration or deceleration torque determined by the change of speed and the inert mass.

The static torque is generally termed "load torque", and in most cases acts opposing the direction of motion. In exceptional cases, such as on lifting gear during lowering, the load torque also acts in the direction of motion.

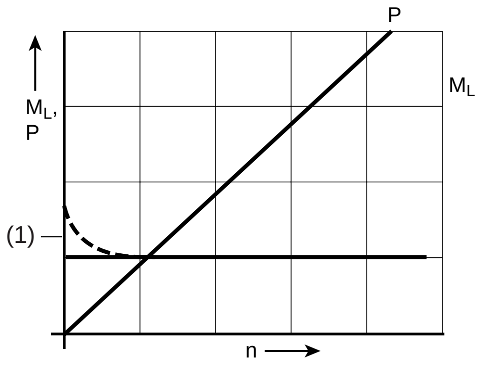
Winders, coilers, lathes



$M_L \sim 1/n$
P = constant

Figure 1.17 Load characteristic: Winders, coilers, lathes

Lifting gear, conveyor systems, piston compressors, rolling mills

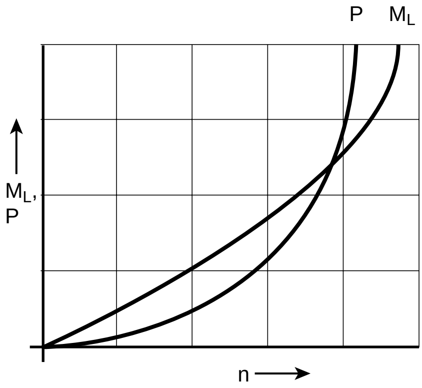


M_L = constant
P ~ n

(1) Break-away torque

Figure 1.18 Load characteristic: Lifting gear, conveyor systems, piston compressors, rolling mills

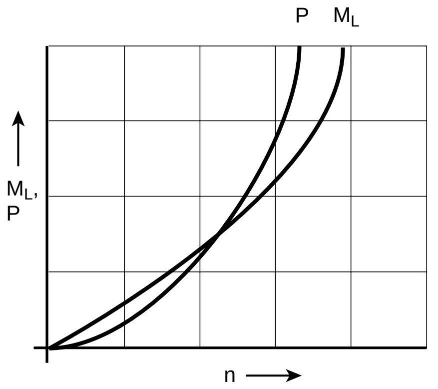
Extruders



M_L = f (n)
P = f (n)

Figure 1.19 Load characteristic: Extruders

Blowers, fans, centrifugal pumps

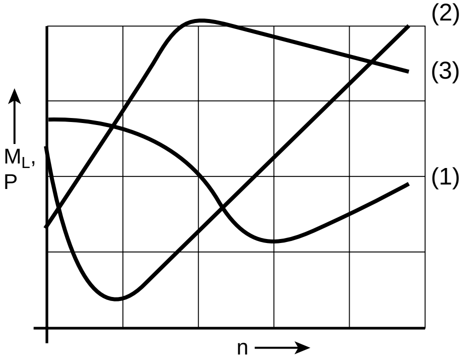


$M_L \sim n^2$
$P \sim n^3$

Figure 1.20 Load characteristic: Blowers, fans, centrifugal pumps

Mills

$M_L = f(n)$



(1) Hammer mill
(2) Centrifugal mill
(3) Ball mill

Figure 1.21 Load characteristics: Mills

Conveyors such as inclined lifts

$M_L = f(s)$

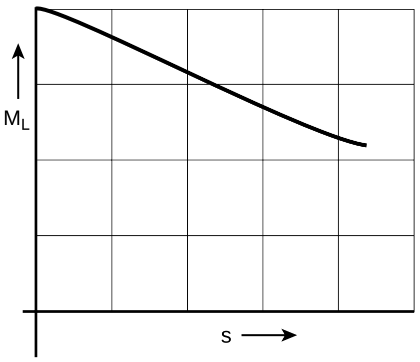


Figure 1.22 Load characteristic: Conveyors

Piston machines, eccentric presses, metal cutters

$M_L = f(\alpha)$

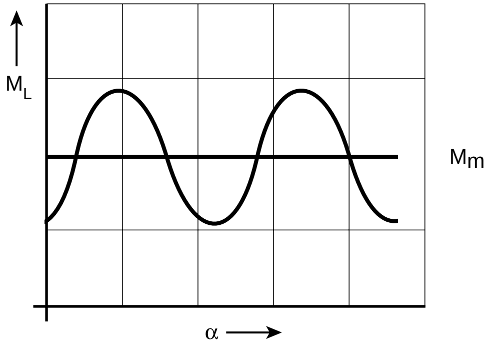


Figure 1.23 Load characteristic: Piston machines, eccentric presses, metal cutters

Machine tools

$M_L = f(t)$

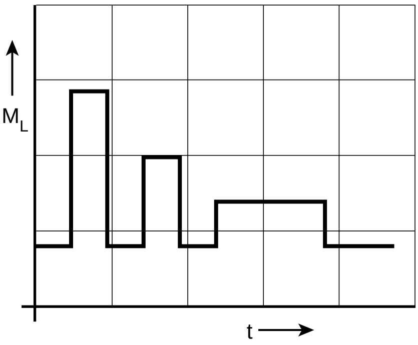


Figure 1.24 Load characteristic: Machine tools

2 Drive definition

2.1 Recording of movement task

This process involves the description of the movement task in the processing process. For information on the basics of this subject See section 1.

The procedure proposed in the following does not claim to be generally applicable to all movement tasks. It is merely intended to illustrate a possible procedure which can be applied with little labor commitment.

Recording of movement task

Project name:: Name of project

Company: Address

Name/Function:
Smith / Client
Jones / Project Engineer

Industry/Application: Packaging machine / Seal jaw drive

The goal must be realistic

Goal: What is to be changed (content; scope; timeframe)?

Key limits must be known

Special background conditions: 1. Standards, regulations, safety
2. Max. base data from processing process (load surge)
3. Ambient condition/installation (50°C ambient temperature)

Comments:

Author: Date: Sheet 1 of 4

You will find the copy template in the appendix under "Practical working aids for the project engineer".

Movement requirement

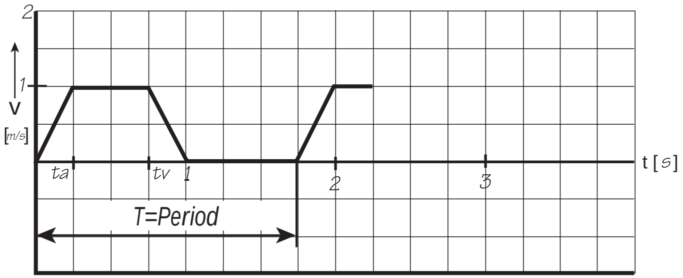
Movement requirement for processing

Project name: ____________________

☐ Continuous material flow

☐ Discontinuous batch process

☒ Discontinuous unit process



☐ Rotational movement [n=f(t)]

☒ Translational movement [v=f(t)]

Radius of drive shaft by which the movement is generated: 65 mm

Comments: A positioning accuracy of ± 0.5 mm is to be attained.
For reasons of time slow jog mode must not be run.

Author: ____________ Date: ____________ Sheet 2 of 4

For definitions of terms in this context See section 1.3.

You will find the copy template in the appendix under "Practical working aids for the project engineer".

Movement requirement

Movement requirement for processing

Project name: ____________

Moment of inertia: ______ [kgm²]

or

Mass: 200 [kg]

Mode of movement: Translational (conveyor belt); see section 7.2.9

Speed manipulating range: /

Static speed accuracy: / [rpm]

Dynamic speed accuracy: / [rpm]

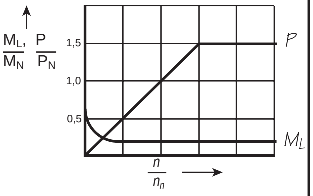
Torque rise time: / [ms]

Positioning accuracy: ± 0,5 [ms]

Comments: Transmission gear; see drawing in Appendix

Load torque of processing process

- ☐ M_L~ 1/n, P=constant
- ☒ M_L=constant, P~n
- ☐ M_L=f(n), P=f(n)
- ☐ M_L~n², P~n³
- ☐ M_L=f(n)
- ☐ M_L=f(s)
- ☐ M_L=f(α)
- ☐ M_L=f(t)



Author: ____________ Date: ____________ Sheet 3 of 4

For definitions of terms in this context see section 1.3.

You will find the copy template in the appendix under "Practical working aids for the project engineer".

System interface

- ➢ Automate
- ➢ Environment
- ➢ Standards

Additional environmental data

Project name:

Automation process: *Interface to Simatic S7 via Profibus-DP with protocol to EN 50170*

Environmental and installation conditions: *Switch cabinet installation, but ambient temperature of 50°C*

Standards, regulations and safety: *CE, EMC, otherwise no other regulations*

Author: ________ Date: ________ Sheet *4* of *4*

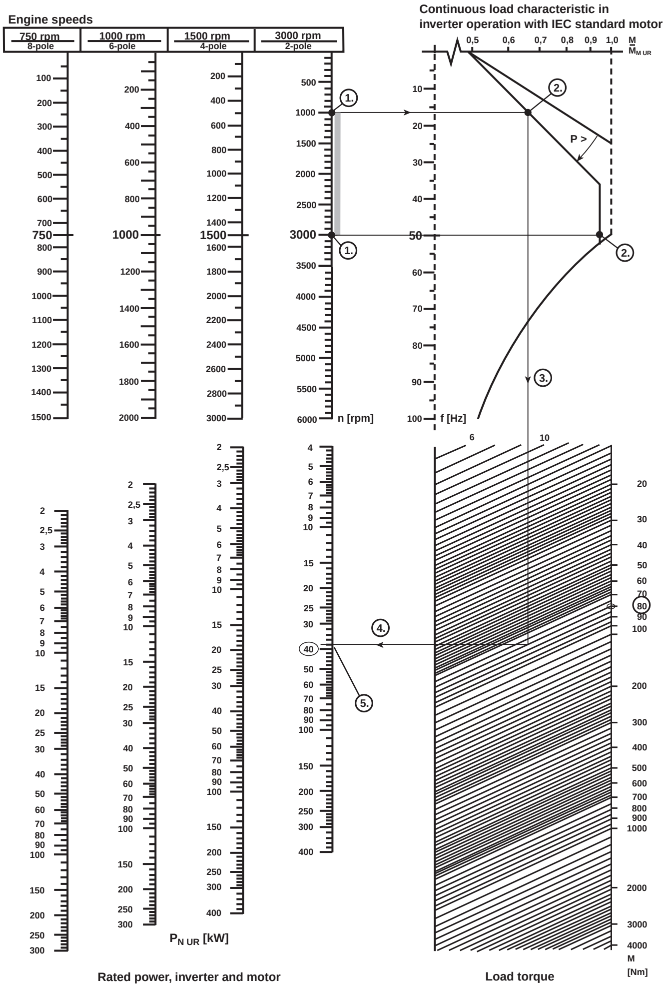
You will find the copy template in the appendix under "Practical working aids for the project engineer".

2.2 Drive definition via normogram

The normogram provides user-friendly graphical power ratings for applications with IEC standard motor. It is primarily used to define the power outputs of rotational drives such as winders, mills, extruders, centrifuges, mixers, etc. Any break-away torques or load surges occurring must be calculated separately.

Using the normogram:

1. Plot the speed vertices for the relevant motor.
2. Draw two straight lines to the continuous load characteristic.
3. Connect the lowest point on the continuous load characteristic to the load torque by a straight line.
4. Connect the load torque to the rated power by a straight line.
5. Select your product based on the performance rating data.



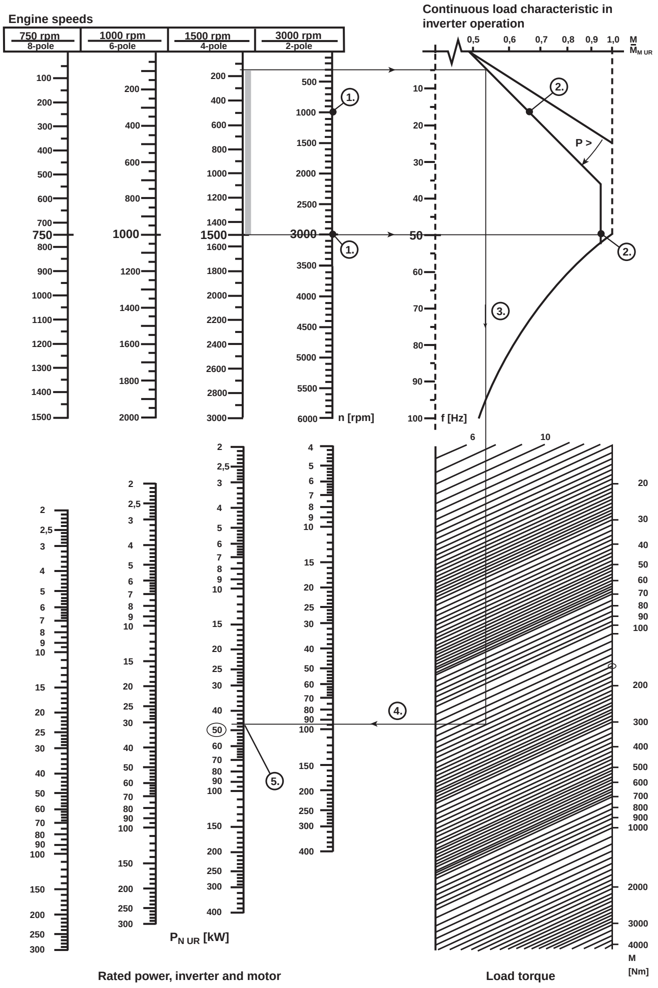
You will find the copy template in the appendix under "Practical working aids for the project engineer". Continuous load characteristic - See section 2.5.1.

2.2.1 Example of solution with four-pole motor

Requirement:

n_1 = 150 rpm
n_2 = 1500 rpm
$M_1 = M_2$ = 150 Nm

External ventilation not permitted.



Solution:
The rated power of the motor (four-pole) and the inverter is 50 kW.

2.2.2 Example of solution with six-pole motor

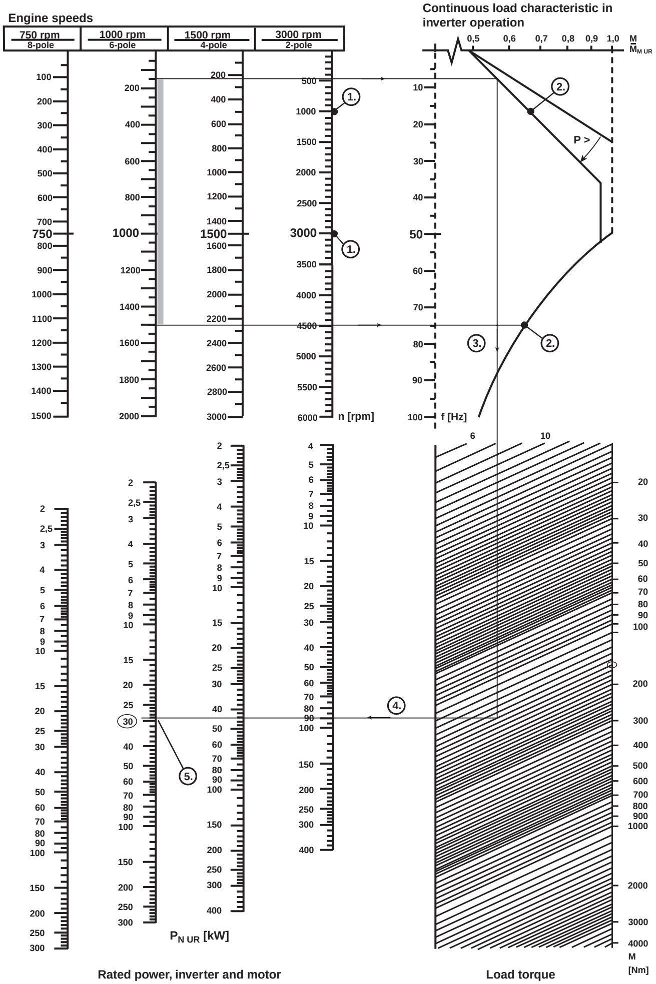
Requirement:

n_1 = 150 rpm

n_2 = 1500 rpm

M_1 = M_2 = 150 Nm

External ventilation not permitted.



Solution:
The rated power of the motor (six-pole) and the inverter is 30 kW.

2.3 Drive definition via power rating

The method of power rating is principally used in three areas of application:

1. Metalworking machinery (milling, drilling, grinding, etc.)
2. Process engineering (pumps/fans, extruder, etc.)
3. General engineering (packaging and special machinery, manipulators and conveyor systems, etc.)

The equations relating to areas of application 1 and 2 and their application are described in Appendix A.2.2.

The following deals with **area of application 3** and thus with the design of traction and lifting drives.

Packaging machinery	Manipulators	Conveyor systems	General engineering
• Discharge drive (cladding removal, vacuum packing sheet feed) • Metering drive (volume metering, screw-type metering) • Traction/lifting axis (packers, palletizers) • Belt drive (bucket conveyor, product loading belt) • Labeling machine (X/Y drive) • etc.	• Traveling axis, X/Z-axis • Lifting axis, Y-axis • Indexing table drive • Gripper drive • etc.	• Trolley drive with 1, 2 and 4 motors • Crane lifting gear, trolley and running gear • Conveyor belt • Door drive • Shelf conveyor • Parquet flooring conveyor belt • Roller and chain drive • etc.	• Metalworking machinery • Cross-cutters • All kinds of special machinery • etc.

Table 2.1 Typical examples of power rating from area of application 3

2.3.1 Example 1: Traction drive

Example: Z-axis of a manipulator

$m = 51.5$ kg
$a = 3$ m/s^2
$v = 1.5$ m/s
$\eta = 0.88$
ta = 0.5
$\mu = 0.01$

1. Determine power requirement to move the application

$$P_a = \frac{m \cdot a \cdot v}{\eta} = \frac{51,5\mathrm{kg} \cdot 3\mathrm{m}/\mathrm{s}^2 \cdot 1,5\mathrm{m}/\mathrm{s}}{0,88} = 264\mathrm{W}$$

$$P_F = \frac{m \cdot g \cdot \mu \cdot v}{\eta} = \frac{51,5\mathrm{kg} \cdot 9,8\mathrm{m}/\mathrm{s}^{s} \cdot 0,01 \cdot 1,5\mathrm{m}/\mathrm{s}}{0,88} = 9\mathrm{W}$$

$$P_{Fahr} = P_a + P_F = 273\mathrm{W}$$

2. Select motor

The selected motor must have a power rating higher than P_{Drive}. Select the motor from the list.

Selected motor: Type 71L/4, 370W, $J_M = 0.00073$ kgm
The motor is to be run at max. 2000 rpm
(70 Hz characteristic).

$$P_{aR} = \frac{J_M \cdot n_M^2}{91,2 \cdot t_a} = \frac{0,00073\mathrm{kgm}^2 \cdot 2000^2\mathrm{min}^{-1}}{91,2 \cdot 0,5} = 65\mathrm{W}$$

3. Calculate gross output

$P_{Gross} = P_a + P_F + P_{aR} = 264\mathrm{W} + 9\mathrm{W} + 65\mathrm{W} = 338\mathrm{W}$

For more details on “Selection of inverter modules” refer to sections 3.3 to 3.6.

Abbreviations used

P_a	Power to accelerate the load	[W]
P_{aR}	Power to accelerate the rotor	[W]
P_F	Power to overcome the tractive resistance/friction	[W]
P_H	Power to lift the load	[W]
m	Total mass	[kg]
a	Acceleration	[m/s^2]
v	Velocity	[ms]
µ	Tractive resistance/Coefficient of friction	
η	Efficiency of the drive solution	
g	Acceleration due to gravity	[9.8m/s^2]
J_M	Moment of inertia of the selected motor	[kgm^2]
n_M	Max. speed of the selected motor	[rpm]
t_a	Acceleration time	[s]

For a list of standard three-phase AC motors See section A.2.11 Motor list.
Asynchronous motors See section 2.5.2.

2.3.2 Example 2: Lifting drive

Example: Z-axis of a manipulator

$m = 2.5$ kg

$\eta = 0.88$

$a = 10$ m/s^2

ta = 0.15

$v = 1.5$ m/s

$\mu = 0.01$

1. Determine power requirement to move the application

$$P_a = \frac{m \cdot a \cdot v}{\eta} = \frac{2,5kg \cdot 10m/s^2 \cdot 1,5m/s}{0,88} = 43W$$

$$P_F = \frac{m \cdot g \cdot \mu \cdot v}{\eta} = \frac{2,5kg \cdot 9,8m/s^s \cdot 0,01 \cdot 1,5m/s}{0,88} = 1W$$

$$P_H = \frac{m \cdot g \cdot v}{\eta} = \frac{2,5kg \cdot 9,8m/s^s \cdot 1,5m/s}{0,88} = 42W$$

$$P_{Lift} = P_a + P_F + P_H = 86W$$

2. Select motor

The selected motor must have a power rating higher than P_{Lift}. Select the motor from the list.

Selected motor:

Type 71S/4, 250W, $I_M = 0.00056$ kgm^2
The motor is to be run at max. 2000 rpm
(70 Hz characteristic).

$$P_{aR} = \frac{J_M \cdot n_M^2}{91,2 \cdot t_a} = \frac{0,00056kgm^2 \cdot 2000^2 min^{-1}}{91,2 \cdot 0,15} = 164W$$

3. Calculate gross output

$P_{Gross} = P_a + P_F + P_H + P_{aR} = 43W + 1W + 42W + 164W = 250W$

For more details on “Selection of inverter modules” refer to sections 3.3 to 3.6.

2.4 Drive definition via LuDrive PC program

The LuDrive drive calculation program meets the wishes of many users for quick and easy calculation of the various drive solutions. The drive program is divided into two sections.

The first section contains a formula bank with 38 formulae for calculation of:

- Moments of inertia of various bodies
- Moments of inertia of applications
- v/t diagrams
- Tractive resistances and friction moments
- Effective torque loads
- Various drive capacities
- Drive torques

With the aid of the second section complete drive units can be configured. The drive data are entered in a practice-oriented sequence. This second section supports the design of:

- Horizontal traction drives
- Traction drives with rise for upward movement
- Traction drives with rise for downward movement
- Lifting drives without counterweight (lifting)
- Lifting drives without counterweight (lowering)
- Indexing tables with ball rim
- Indexing tables with shaft through the center point
- Spindle drives
- Rotational drives

After calculating the drive LuDrive displays a graph on the PC. The graph shows the characteristic of the mean torque, the speed and the moment over time. Based on this graph, the behavior of the drive solutions in practical applications can be assessed. Of course, all influencing factors such as the rotor moment of inertia of the motor, the field weakening range, the nominal winding point of the motor etc. are analyzed and/or calculated and translated onto the graph.

In addition to the functions described, the LuDrive program also supports ancillary functions such as Help, Print, Save and Load.

Note: The LuDrive drive program is based on the theoretical principles of the book entitled “Das 1x1 der Antriebsauslegung” (“The ABC of drive design”) - see "Bibliography and source reference".

Where can you get LuDrive?

You can download the LuDrive drive design program for MS-DOS™ version 1.6 (viable under Windows® 95) free of charge from our website: http://www.lust-tec.de/produkte.

The program is easily controlled from the keyboard. The DOS user interface provides access to calculation formulae which have been tried and proven over decades of practical application.

Please note that the software LuDrive is only available in german language.

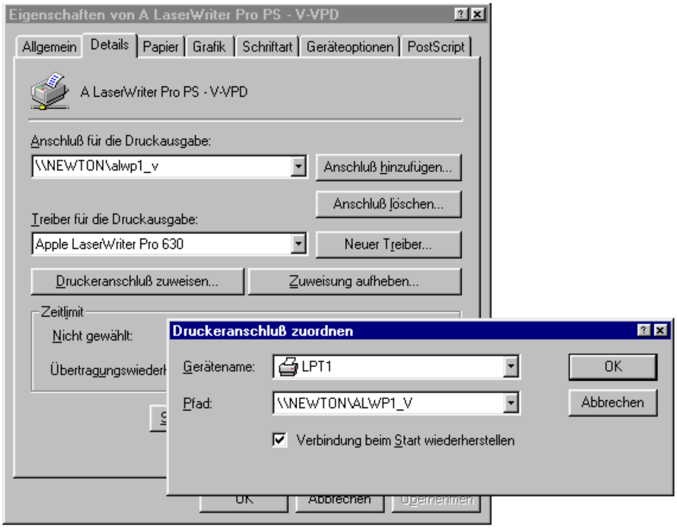
Network printing

When printing from DOS applications under Windows® 95 in network mode, the printer must be assigned to the parallel port LTP1.

From the "Start menu choose Settings > Printers", select the printer you want to use and click with the right mouse button to open the "Properties" dialog box.

On the "Details" tab click on the "Capture Printer Port" button.

Make sure that data to be printed to LTP1 are diverted to the network printer - See Figure 2.1.



Anschluß für die Druckausgabe: \\NEWTON\alwp1_v

Treiber für die Druckausgabe: Apple LaserWriter Pro 630

Gerätename: LPT1

Pfad: \\NEWTON\ALWP1_V

☑ Verbindung beim Start wiederherstellen

Figure 2.1 The network printer must be assigned to the parallel port LTP1

2.4.1 Example 1: Trolley drive for gantry crane

Because of the narrow track width the trolley has a central drive powering a running wheel on each side. The running wheels are coupled together by a shaft. The drive system is a four-pole helical gearbox motor with brake.

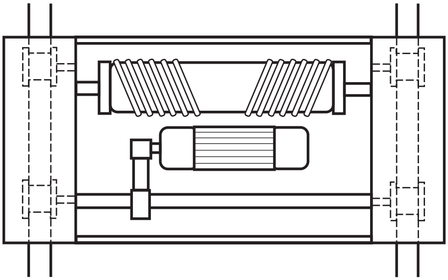


Figure 2.2 Standard trolley drive with geared motor

Known data:

Intrinsic weight of the trolley	5 t
Lifting weight	10 t
Running speed	30 m/min.
Two wheels are driven	
Wheel diameter	315 mm
Journal diameter	80 mm
Friction pairing (rail/wheel)Steel/steel	
Transmission gear	z1=18
	z2=34
Efficiency of the drive	80%
Mass moment of inertia of the running wheels and the shaft	0.85 kgm^2
Acceleration and braking time	1.5 s
Max. factor for starting torque	1.25

Steps in drive design

1. Calculate acceleration and deceleration by means of “v/t diagram” program section.

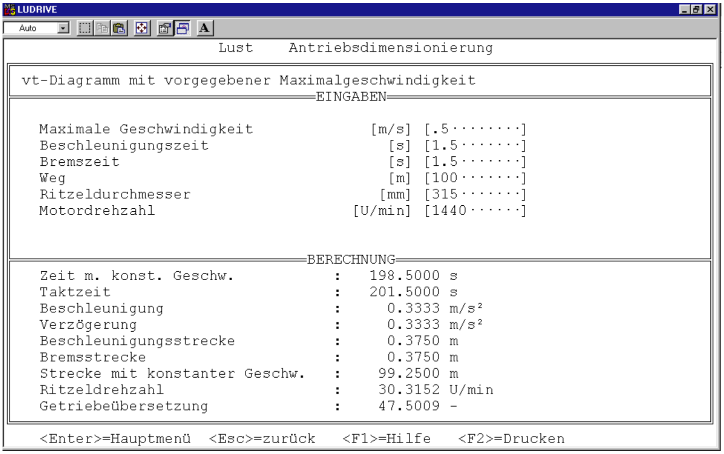
2. Calculate longitudinal coefficient of friction between rail and wheel by means of “Tractive resistance/Friction moment” program section.

3. Calculate drive capacity by means of “Drive calculation/Traction drive” program section.

   a) for max. motor speed 1440 rpm

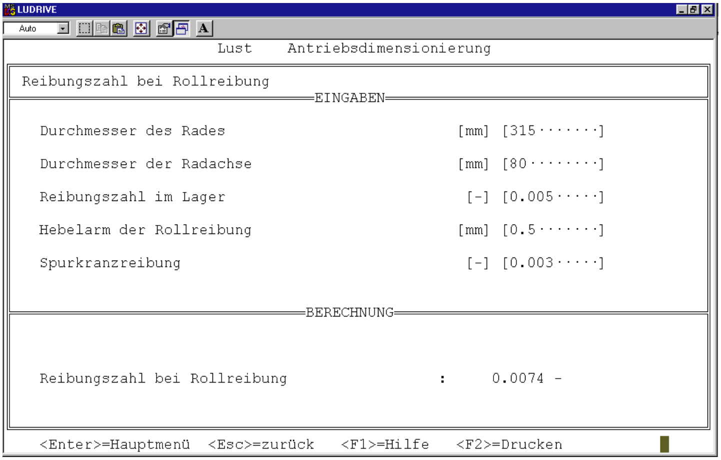
   b) for max. motor speed 2000 rpm

1.



```
                          Lust    Antriebsdimensionierung

 vt-Diagramm mit vorgegebener Maximalgeschwindigkeit
                                  EINGABEN

   Maximale Geschwindigkeit                 [m/s]  [.5········]
   Beschleunigungszeit                        [s]  [1.5·······]
   Bremszeit                                  [s]  [1.5·······]
   Weg                                        [m]  [100·······]
   Ritzeldurchmesser                         [mm]  [315·······]
   Motordrehzahl                          [U/min]  [1440······]

                                 BERECHNUNG
   Zeit m. konst. Geschw.              :    198.5000 s
   Taktzeit                            :    201.5000 s
   Beschleunigung                      :      0.3333 m/s²
   Verzögerung                         :      0.3333 m/s²
   Beschleunigungsstrecke              :      0.3750 m
   Bremsstrecke                        :      0.3750 m
   Strecke mit konstanter Geschw.      :     99.2500 m
   Ritzeldrehzahl                      :     30.3152 U/min
   Getriebeübersetzung                 :     47.5009 -

   <Enter>=Hauptmenü  <Esc>=zurück   <F1>=Hilfe   <F2>=Drucken
```

Figure 2.3 Drive design with LuDrive

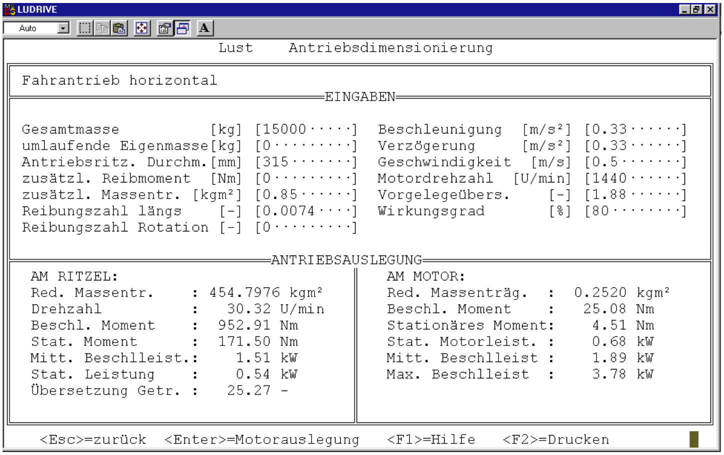


```
                    Lust     Antriebsdimensionierung

 Reibungszahl bei Rollreibung
                                   EINGABEN

   Durchmesser des Rades                              [mm]  [315·······]

   Durchmesser der Radachse                           [mm]  [80········]

   Reibungszahl im Lager                               [-]  [0.005·····]

   Hebelarm der Rollreibung                           [mm]  [0.5·······]

   Spurkranzreibung                                    [-]  [0.003·····]

                                  BERECHNUNG


   Reibungszahl bei Rollreibung                   :      0.0074 -


   <Enter>=Hauptmenü  <Esc>=zurück   <F1>=Hilfe   <F2>=Drucken
```

Figure 2.4 Tractive/frictional resistance

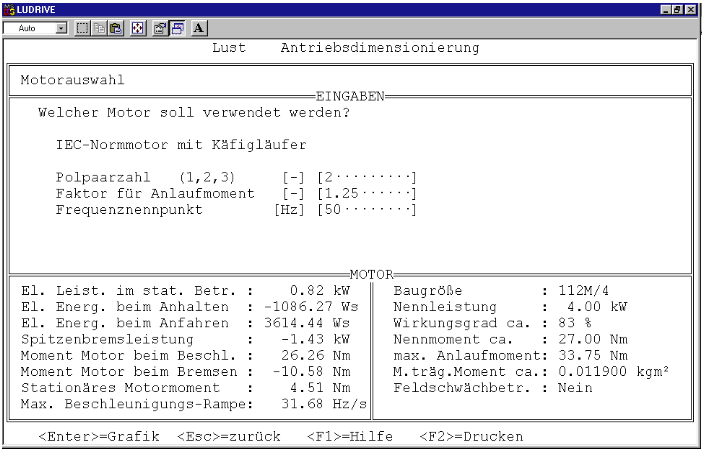
1
2
3
4
5
6
7
A
DE
EN

Max. motor speed 1440 rpm



```
                    Lust    Antriebsdimensionierung

Fahrantrieb horizontal
                                   EINGABEN

Gesamtmasse           [kg] [15000·····]  Beschleunigung   [m/s²] [0.33······]
umlaufende Eigenmasse[kg] [0·········]  Verzögerung      [m/s²] [0.33······]
Antriebsritz. Durchm.[mm] [315·······]  Geschwindigkeit   [m/s] [0.5·······]
zusätzl. Reibmoment   [Nm] [0·········]  Motordrehzahl   [U/min] [1440······]
zusätzl. Massentr. [kgm²] [0.85······]  Vorgelegeübers.     [-] [1.88······]
Reibungszahl längs    [-] [0.0074····]  Wirkungsgrad        [%] [80········]
Reibungszahl Rotation [-] [0·········]

                              ANTRIEBSAUSLEGUNG
 AM RITZEL:                              AM MOTOR:
 Red. Massentr.    : 454.7976 kgm²       Red. Massenträg.  :  0.2520 kgm²
 Drehzahl          :   30.32 U/min       Beschl. Moment    :   25.08 Nm
 Beschl. Moment    :  952.91 Nm          Stationäres Moment:    4.51 Nm
 Stat. Moment      :  171.50 Nm          Stat. Motorleist. :    0.68 kW
 Mitt. Beschlleist.:    1.51 kW          Mitt. Beschlleist :    1.89 kW
 Stat. Leistung    :    0.54 kW          Max. Beschlleist  :    3.78 kW
 Übersetzung Getr. :   25.27 -

   <Esc>=zurück  <Enter>=Motorauslegung   <F1>=Hilfe   <F2>=Drucken
```

Figure 2.5 Drive capacity

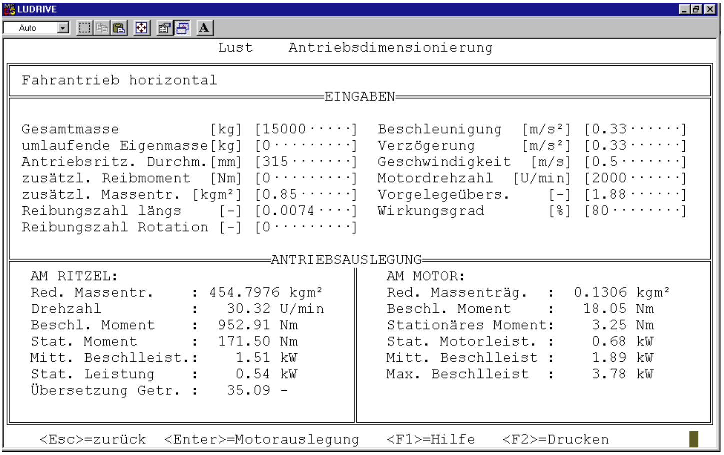


```
                    Lust    Antriebsdimensionierung

Motorauswahl
                                   EINGABEN
   Welcher Motor soll verwendet werden?

     IEC-Normmotor mit Käfigläufer

     Polpaarzahl   (1,2,3)      [-]  [2·········]
     Faktor für Anlaufmoment    [-]  [1.25······]
     Frequenznennpunkt         [Hz]  [50········]

                                      MOTOR
El. Leist. im stat. Betr. :    0.82 kW  Baugröße         : 112M/4
El. Energ. beim Anhalten  : -1086.27 Ws Nennleistung     :  4.00 kW
El. Energ. beim Anfahren  : 3614.44 Ws  Wirkungsgrad ca. : 83 %
Spitzenbremsleistung      :   -1.43 kW  Nennmoment ca.   : 27.00 Nm
Moment Motor beim Beschl. :   26.26 Nm  max. Anlaufmoment: 33.75 Nm
Moment Motor beim Bremsen :  -10.58 Nm  M.träg.Moment ca.: 0.011900 kgm²
Stationäres Motormoment   :    4.51 Nm  Feldschwächbetr. : Nein
Max. Beschleunigungs-Rampe:   31.68 Hz/s

   <Enter>=Grafik  <Esc>=zurück   <F1>=Hilfe   <F2>=Drucken
```

Figure 2.6 Motor selection

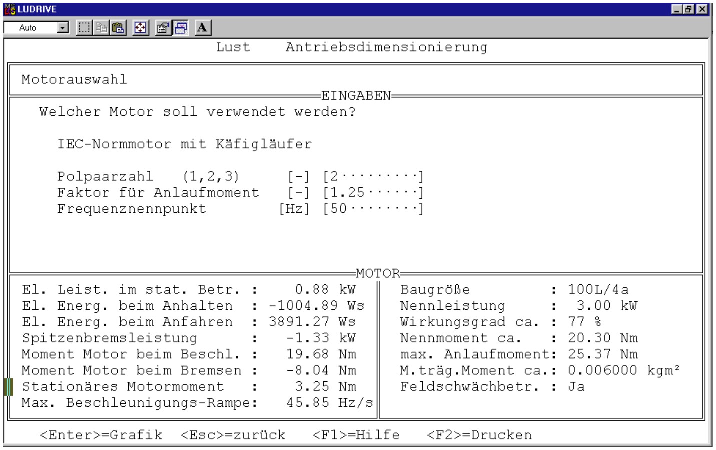
3.

Max. motor speed 2000 rpm



```
                 Lust    Antriebsdimensionierung

 Fahrantrieb horizontal
                          ═EINGABEN═

 Gesamtmasse          [kg] [15000·····]  Beschleunigung  [m/s²] [0.33······]
 umlaufende Eigenmasse[kg] [0·········]  Verzögerung     [m/s²] [0.33······]
 Antriebsritz. Durchm.[mm] [315·······]  Geschwindigkeit  [m/s] [0.5·······]
 zusätzl. Reibmoment  [Nm] [0·········]  Motordrehzahl  [U/min] [2000······]
 zusätzl. Massentr. [kgm²] [0.85······]  Vorgelegeübers.    [-] [1.88······]
 Reibungszahl längs    [-] [0.0074····]  Wirkungsgrad       [%] [80········]
 Reibungszahl Rotation [-] [0·········]

                      ═ANTRIEBSAUSLEGUNG═
  AM RITZEL:                          AM MOTOR:
  Red. Massentr.     : 454.7976 kgm²  Red. Massenträg.   :  0.1306 kgm²
  Drehzahl           :    30.32 U/min Beschl. Moment     :   18.05 Nm
  Beschl. Moment     :   952.91 Nm    Stationäres Moment:    3.25 Nm
  Stat. Moment       :   171.50 Nm    Stat. Motorleist. :    0.68 kW
  Mitt. Beschlleist.:      1.51 kW    Mitt. Beschlleist :    1.89 kW
  Stat. Leistung     :     0.54 kW    Max. Beschlleist  :    3.78 kW
  Übersetzung Getr. :     35.09 -

    <Esc>=zurück  <Enter>=Motorauslegung   <F1>=Hilfe   <F2>=Drucken
```

Figure 2.7 Drive capacity



```
                 Lust    Antriebsdimensionierung

 Motorauswahl
                          ═EINGABEN═
   Welcher Motor soll verwendet werden?

     IEC-Normmotor mit Käfigläufer

     Polpaarzahl   (1,2,3)     [-] [2·········]
     Faktor für Anlaufmoment   [-] [1.25······]
     Frequenznennpunkt        [Hz] [50········]


                              ═MOTOR═
 El. Leist. im stat. Betr. :    0.88 kW    Baugröße          : 100L/4a
 El. Energ. beim Anhalten  : -1004.89 Ws   Nennleistung      :  3.00 kW
 El. Energ. beim Anfahren  : 3891.27 Ws    Wirkungsgrad ca. : 77 %
 Spitzenbremsleistung      :   -1.33 kW    Nennmoment ca.    : 20.30 Nm
 Moment Motor beim Beschl. :   19.68 Nm    max. Anlaufmoment: 25.37 Nm
 Moment Motor beim Bremsen :   -8.04 Nm    M.träg.Moment ca.: 0.006000 kgm²
 Stationäres Motormoment   :    3.25 Nm    Feldschwächbetr. : Ja
 Max. Beschleunigungs-Rampe:   45.85 Hz/s

   <Enter>=Grafik  <Esc>=zurück   <F1>=Hilfe   <F2>=Drucken
```

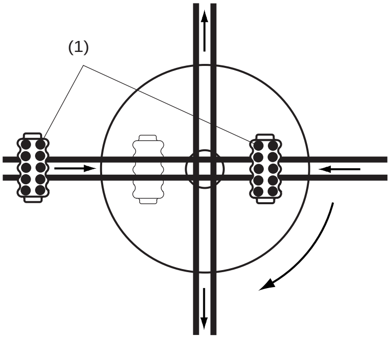
Figure 2.8 Motor selection

2.4.2 Example 2: Belt turning station for truck engine distribution

The indexing table for the belt turning station is designed to distribute the truck engines across two different conveyor belts. The indexing table is incremented in steps of 90°.

The rotating upper section is supported by a slewing ring. Slewing rings permit a highly compact design combined with a low center of gravity (only one bearing to absorb all forces and moments).

The size of the bearing support means that correspondingly very high radial and axial forces and moments are absorbed.



(1) Truck engines

Figure 2.9 Belt turning station

Known data:

Mass of indexing table with slewing ring etc.	130 kg
Indexing table diameter	1600 mm
Mass of truck engine	500 kg
Distance of truck from pivot point	600 mm
Max. cycle time for 90°	1.4 s
Acceleration/deceleration time	0.2 s
Ball rim	z1=29 z2=180
Efficiency	90%
Motor nominal speed	1440 rpm

Positioning accuracy need only be approx. ± 2 mm, because mechanical indices are used.

Steps in drive design

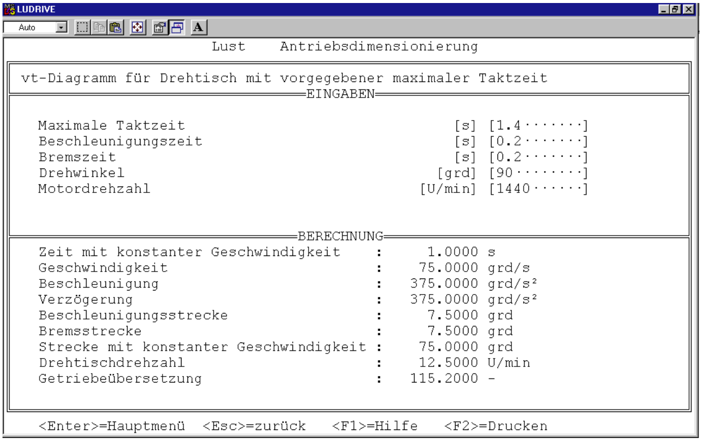
1. Calculate rotational velocity, rotational acceleration and rotational deceleration by means of “v/ t diagram for indexing table” program section.

2. Calculate drive capacity by means of “Drive calculation / Indexing table with slewing ring” program section.

   a. Startup factor 1.25 typical values with Voltage Frequency Control (VFC)

   b. Startup factor 2 typical values with Sensorless Flux Control (SFC)

1.



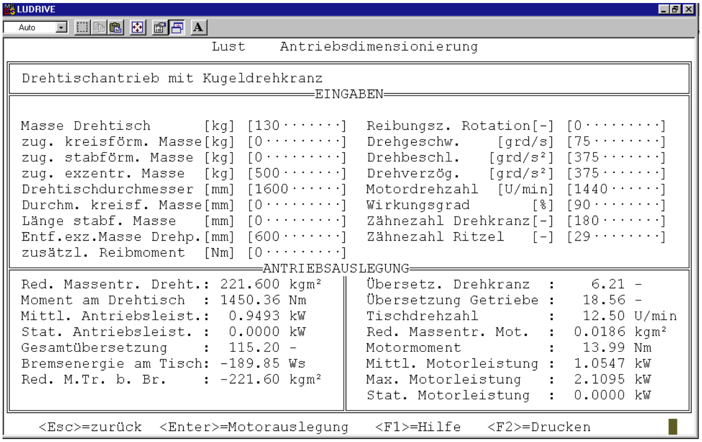
```
                        Lust    Antriebsdimensionierung

 vt-Diagramm für Drehtisch mit vorgegebener maximaler Taktzeit
                                EINGABEN

   Maximale Taktzeit                                    [s]  [1.4·······]
   Beschleunigungszeit                                  [s]  [0.2·······]
   Bremszeit                                            [s]  [0.2·······]
   Drehwinkel                                         [grd]  [90········]
   Motordrehzahl                                    [U/min]  [1440······]

                               BERECHNUNG
   Zeit mit konstanter Geschwindigkeit    :      1.0000 s
   Geschwindigkeit                        :     75.0000 grd/s
   Beschleunigung                         :    375.0000 grd/s²
   Verzögerung                            :    375.0000 grd/s²
   Beschleunigungsstrecke                 :      7.5000 grd
   Bremsstrecke                           :      7.5000 grd
   Strecke mit konstanter Geschwindigkeit :     75.0000 grd
   Drehtischdrehzahl                      :     12.5000 U/min
   Getriebeübersetzung                    :    115.2000 -

   <Enter>=Hauptmenü  <Esc>=zurück   <F1>=Hilfe   <F2>=Drucken
```

Figure 2.10 v/t diagrams

25% motor overload with VFC

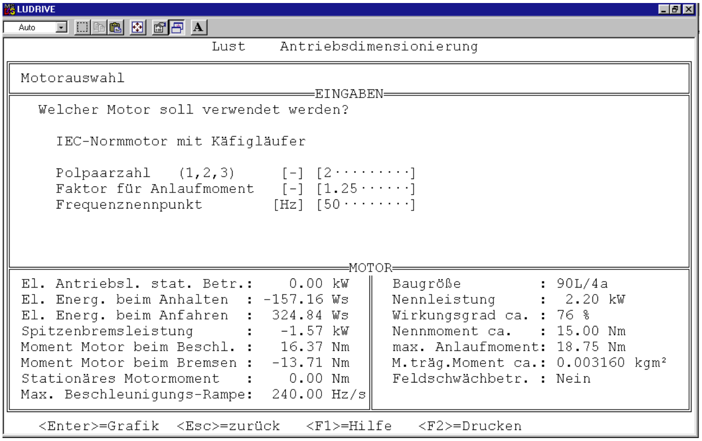
Factor for starting torque = 1.25

($1.25 \cdot M_N$)



```
                        Lust    Antriebsdimensionierung

 Drehtischantrieb mit Kugeldrehkranz
 ══════════════════════════════EINGABEN══════════════════════════════

 Masse Drehtisch      [kg] [130·······]  Reibungsz. Rotation[-]  [0·········]
 zug. kreisförm. Masse[kg] [0·········]  Drehgeschw.     [grd/s] [75········]
 zug. stabförm. Masse [kg] [0·········]  Drehbeschl.    [grd/s²] [375·······]
 zug. exzentr. Masse  [kg] [500·······]  Drehverzög.    [grd/s²] [375·······]
 Drehtischdurchmesser [mm] [1600······]  Motordrehzahl   [U/min] [1440······]
 Durchm. kreisf. Masse[mm] [0·········]  Wirkungsgrad        [%] [90········]
 Länge stabf. Masse   [mm] [0·········]  Zähnezahl Drehkranz[-]  [180·······]
 Entf.exz.Masse Drehp.[mm] [600·······]  Zähnezahl Ritzel   [-]  [29········]
 zusätzl. Reibmoment  [Nm] [0·········]
 ═══════════════════════════ANTRIEBSAUSLEGUNG═══════════════════════════
 Red. Massentr. Dreht.: 221.600 kgm²  Übersetz. Drehkranz   :    6.21 -
 Moment am Drehtisch  : 1450.36 Nm    Übersetzung Getriebe  :   18.56 -
 Mittl. Antriebsleist.:  0.9493 kW    Tischdrehzahl         :   12.50 U/min
 Stat. Antriebsleist. :  0.0000 kW    Red. Massentr. Mot.   :  0.0186 kgm²
 Gesamtübersetzung    :  115.20 -     Motormoment           :   13.99 Nm
 Bremsenergie am Tisch: -189.85 Ws    Mittl. Motorleistung  :  1.0547 kW
 Red. M.Tr. b. Br.    : -221.60 kgm²  Max. Motorleistung    :  2.1095 kW
                                      Stat. Motorleistung   :  0.0000 kW

    <Esc>=zurück  <Enter>=Motorauslegung   <F1>=Hilfe   <F2>=Drucken
```

Figure 2.11 Calculation

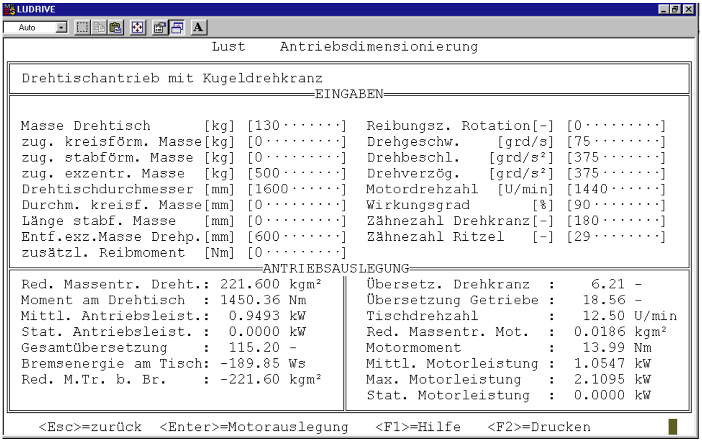


```
                        Lust    Antriebsdimensionierung

 Motorauswahl
 ══════════════════════════════EINGABEN══════════════════════════════
   Welcher Motor soll verwendet werden?

     IEC-Normmotor mit Käfigläufer

     Polpaarzahl   (1,2,3)      [-]  [2·········]
     Faktor für Anlaufmoment    [-]  [1.25······]
     Frequenznennpunkt         [Hz]  [50········]


 ════════════════════════════════MOTOR═══════════════════════════════
 El. Antriebsl. stat. Betr.:    0.00 kW    Baugröße          : 90L/4a
 El. Energ. beim Anhalten  : -157.16 Ws    Nennleistung      :  2.20 kW
 El. Energ. beim Anfahren  :  324.84 Ws    Wirkungsgrad ca.  : 76 %
 Spitzenbremsleistung      :   -1.57 kW    Nennmoment ca.    : 15.00 Nm
 Moment Motor beim Beschl. :   16.37 Nm    max. Anlaufmoment: 18.75 Nm
 Moment Motor beim Bremsen :  -13.71 Nm    M.träg.Moment ca.: 0.003160 kgm²
 Stationäres Motormoment   :    0.00 Nm    Feldschwächbetr.  : Nein
 Max. Beschleunigungs-Rampe:  240.00 Hz/s

    <Enter>=Grafik  <Esc>=zurück   <F1>=Hilfe   <F2>=Drucken
```

Figure 2.12 Motor selection

3.

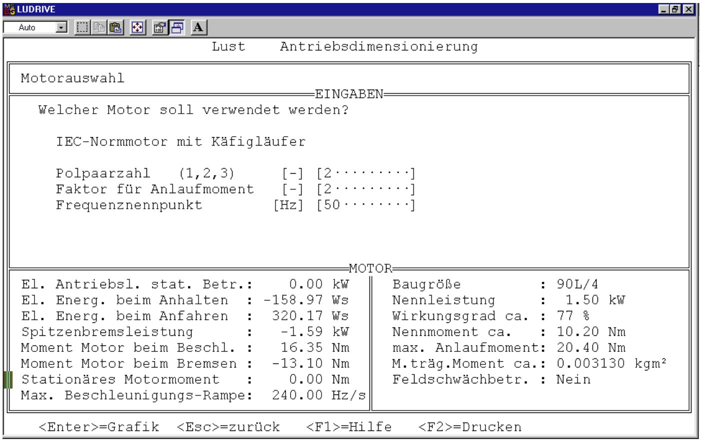
100% motor overload with “SFC”



```
                  Lust    Antriebsdimensionierung

 Drehtischantrieb mit Kugeldrehkranz
                                 EINGABEN

 Masse Drehtisch      [kg] [130·······]  Reibungsz. Rotation[-] [0·········]
 zug. kreisförm. Masse[kg] [0·········]  Drehgeschw.    [grd/s] [75········]
 zug. stabförm. Masse [kg] [0·········]  Drehbeschl.   [grd/s²] [375·······]
 zug. exzentr. Masse  [kg] [500·······]  Drehverzög.   [grd/s²] [375·······]
 Drehtischdurchmesser [mm] [1600······]  Motordrehzahl  [U/min] [1440······]
 Durchm. kreisf. Masse[mm] [0·········]  Wirkungsgrad       [%] [90········]
 Länge stabf. Masse   [mm] [0·········]  Zähnezahl Drehkranz[-] [180·······]
 Entf.exz.Masse Drehp.[mm] [600·······]  Zähnezahl Ritzel   [-] [29········]
 zusätzl. Reibmoment  [Nm] [0·········]
                          ANTRIEBSAUSLEGUNG
 Red. Massentr. Dreht.: 221.600 kgm²   Übersetz. Drehkranz  :    6.21 -
 Moment am Drehtisch  : 1450.36 Nm     Übersetzung Getriebe :   18.56 -
 Mittl. Antriebsleist.:  0.9493 kW     Tischdrehzahl        :   12.50 U/min
 Stat. Antriebsleist. :  0.0000 kW     Red. Massentr. Mot.  :  0.0186 kgm²
 Gesamtübersetzung    :  115.20 -      Motormoment          :   13.99 Nm
 Bremsenergie am Tisch: -189.85 Ws     Mittl. Motorleistung :  1.0547 kW
 Red. M.Tr. b. Br.    : -221.60 kgm²   Max. Motorleistung   :  2.1095 kW
                                       Stat. Motorleistung  :  0.0000 kW

   <Esc>=zurück  <Enter>=Motorauslegung   <F1>=Hilfe   <F2>=Drucken
```

Figure 2.13   Calculation

Factor for starting torque = 2 (2 $\cdot$ M_N)



```
                  Lust    Antriebsdimensionierung

 Motorauswahl
                                 EINGABEN
   Welcher Motor soll verwendet werden?

     IEC-Normmotor mit Käfigläufer

     Polpaarzahl   (1,2,3)      [-] [2·········]
     Faktor für Anlaufmoment    [-] [2·········]
     Frequenznennpunkt         [Hz] [50········]


                                     MOTOR
 El. Antriebsl. stat. Betr.:    0.00 kW   Baugröße         : 90L/4
 El. Energ. beim Anhalten  : -158.97 Ws   Nennleistung     :  1.50 kW
 El. Energ. beim Anfahren  :  320.17 Ws   Wirkungsgrad ca. : 77 %
 Spitzenbremsleistung      :   -1.59 kW   Nennmoment ca.   : 10.20 Nm
 Moment Motor beim Beschl. :   16.35 Nm   max. Anlaufmoment: 20.40 Nm
 Moment Motor beim Bremsen :  -13.10 Nm   M.träg.Moment ca.: 0.003130 kgm²
 Stationäres Motormoment   :    0.00 Nm   Feldschwächbetr. : Nein
 Max. Beschleunigungs-Rampe:  240.00 Hz/s

   <Enter>=Grafik  <Esc>=zurück   <F1>=Hilfe   <F2>=Drucken
```

Figure 2.14   Motor selection

2.5 Selection of motor

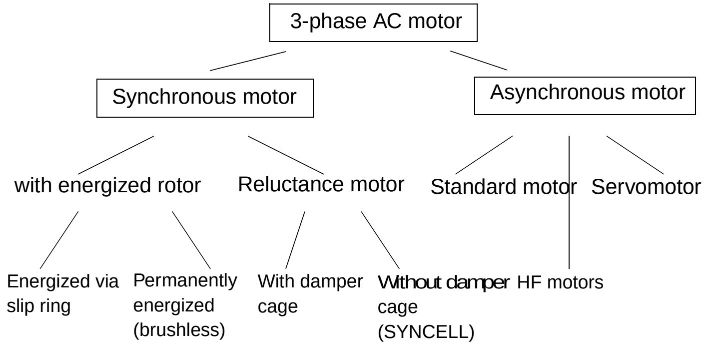
A wide variety of three-phase AC motors can be run on the CDA3000 inverter system. Three-phase AC motors are manufactured in synchronous and asynchronous design versions. The stator winding is designed such that, when in service in a three-phase AC system, a rotating field is created in the motor which drives the rotor. The rotation speed is determined by the following variables:

$$n_s = \frac{f \cdot 60}{P}$$

n_s = synchronous speed
P = number of pole pairs
f = stator frequency

The motor type is determined by the rotor introduced into the rotating field.

Overview of three-phase AC motors



Typical areas of application of three-phase AC motors

Motor type	Working principle	Application
Standard three-phase AC motor	asynchronous	In all industrial sectors. Around 10-15% of all motors are speed-adjustable by way of inverters.
Synchronous motor	synchronous	In the textile industry for: Spoolers, viscose pumps, galette drives, roller drives etc. Further areas of application are in the glass and paper industry as winding drives, etc.
Reluctance motor	asynchronous/ synchronous	In the textile industry for: Spoolers, viscose pumps, galette or roller motors, etc. Further areas of application are in drafting equipment and for synchronous running of two axles.
High-frequency motor	asynchronous	In the timber processing industry as the main drive. Further areas of application are grinding and milling spindles, centrifuges, vacuum pumps and winders.
Asynchronous servomotor	asynchronous	In the packaging and food industries as a clock and positioning drive. Further applications as the main drive for machine tools.
Displacement-type armature motor	asynchronous with motor brake	In conveyor systems as a traction and lifting motor.

Table 2.2 Areas of application for three-phase AC motors

Use of the following sections

The following sections 2.5.1 to 2.5.5 summarize the typical characteristic values. They provide an overview of the performance capabilities of the various motor types. Selection of the motors, dependent on application, is presented in sections 3.3 to 3.6.

2.5.1 Characteristic values of standard three-phase AC motors

Startup characteristic in mains operation

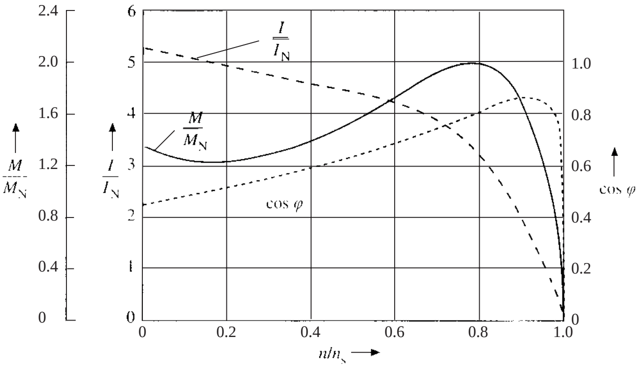


Figure 2.15 Typical startup characteristic of a standard three-phase AC motor in mains operation

Operating characteristic

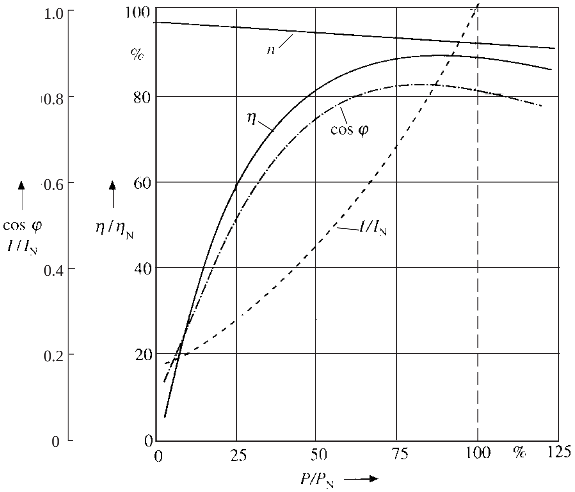
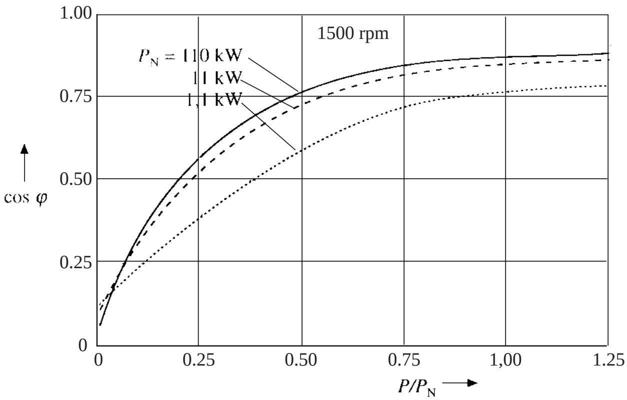


Figure 2.16 Typical operating characteristic of a standard three-phase AC motor

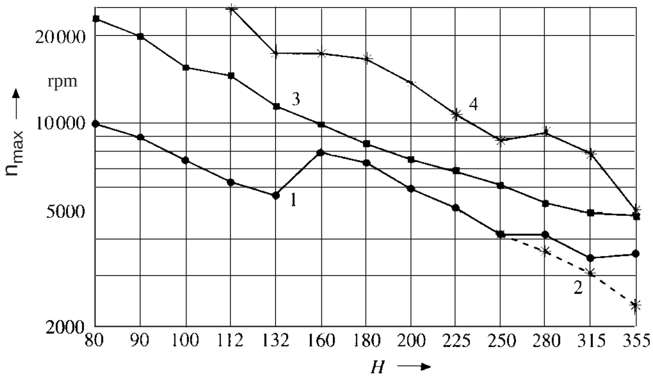
Power factor



P/PN Loading on the shaft

Figure 2.17 Power factor cos φ of a four-pole standard three-phase AC motor

Limit speed



n_{max} Limit speed
H Axle height
1 Greased groove ball bearings in two-pole motors
2 Greased groove ball bearings in four-pole motors and higher
3 Strength of the short-circuiting rings of the rotor cage
4 Bend-critical speed

Figure 2.18 Typical limit speed of a standard three-phase AC motor

For more information on rotating electric machines, rating and operating behavior, refer to standard DIN VDE 0530 or
EN 60034-1.

Tolerances of standard three-phase AC motor to DIN 57 530/IEC 34

Property	Tolerance
Efficiency [η]	$P_N \leq$ 50 kW - 0.15 $(1-\eta)$ $P_N >$ 50 kW - 0.1 $(1-\eta)$
Power factor [φ]	$-\frac{1-\cos\varphi}{6}$ min. 0.02; max. 0.07
Slip [s]	± 20%
Break-away starting current [I_A]	+ 20%
Break-away torque [M_A]	-15% to +20%
Breakdown torque [M_K]	-10%
Noise [L_A]	+3 dB(A)
Voltage deviation [u]	±5% at rated load and 45ºC ambient temperature

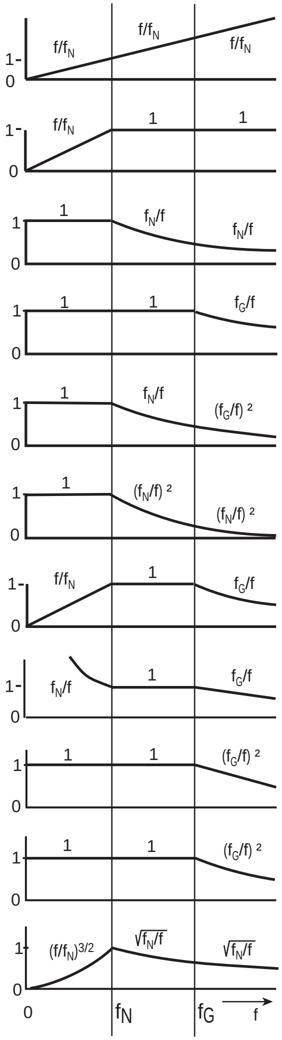
Table 2.3 Tolerances to DIN 57530 and IEC 34

Notes:

Limit frequency in inverter operation

$$\boxed{f_G \approx f_N \cdot \left(\frac{M_K}{M_N}\right) \cdot 0,7}$$

Dependencies of the motor variables in inverter operation



Variable	Referenced variable	Characteristic of referenced variable		
		Constant flux	Field weakening	
		M=const.	P_2= const.	$P_2 \sim \frac{1}{n}$
Speed [n]	$\frac{n}{n_N}$	f/f_N	f/f_N	f/f_N
Voltage [U]	$\frac{U}{U_N}$	f/f_N	1	1
Flux [Φ]	$\frac{\Phi}{\Phi_N}$	1	f_N/f	f_N/f
Current [I]	$\frac{I}{I_N}$	1	1	f_G/f
Torque [M]	$\frac{M}{M_N}$	1	f_N/f	$(f_G/f)^2$
Breakdown torque [M_k]	$\frac{M_k}{M_{kN}}$	1	$(f_N/f)^2$	$(f_N/f)^2$
Mechanical output [P_2]	$\frac{P_2}{P_N}$	f/f_N	1	f_G/f
Slip [s]	$\frac{s}{s_N}$	f_N/f	1	f_G/f
Stator copper loss [P_{cu1}]	$\frac{P_{cu1}}{P_{cu1N}}$	1	1	$(f_G/f)^2$
Rotor copper loss [P_{cu2}]	$\frac{P_{cu2}}{P_{cu2N}}$	1	1	$(f_G/f)^2$
Core loss [P_{Fe}]	$\frac{P_{Fe}}{P_{FeN}}$	$(f/f_N)^{3/2}$	$\sqrt{f_N/f}$	$\sqrt{f_N/f}$

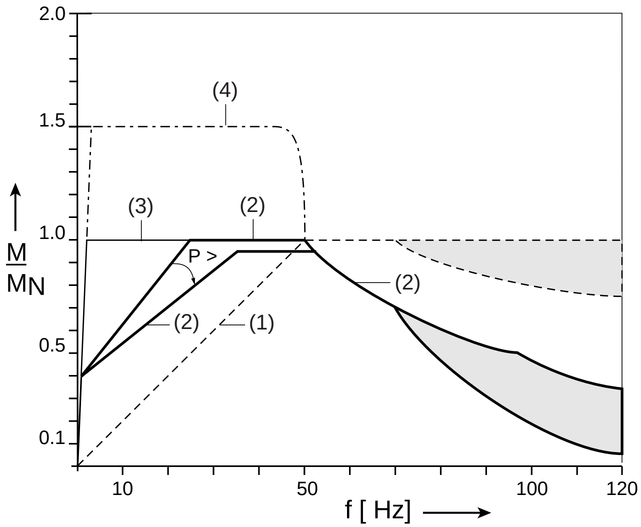
Table 2.4 Dependencies of the motor variables

Abbreviations used in Table 2.4

f	Frequency
f_N	Rated frequency
f_G	Limit frequency in inverter operation
I	Current, effective value
I_N	Rated current
M	Torque
M_k	Breakdown torque
M_{kN}	Nominal breakdown torque
M_N	Nominal torque
n	Speed
n_N	Nominal speed
P_{cu1}	Stator copper loss
P_{cu2}	Rotor copper loss
$P_{cu1, N}$	Nominal stator copper loss of fundamental
$P_{cu2, N}$	Nominal rotor copper loss of fundamental
P_{Fe}	Core loss
P_N	Rated power
P_2	Mechanical output
s	Slip
U	Voltage, effective value
Φ	Magnetic flux

Achtung: Safe inverter operation can only be guaranteed when the max. output frequency is not higher than the limit frequency (f6).

Typical torque characteristic of a standard three-phase AC motor in standard inverter operation



(1) Delivered power output of a 3-phase AC motor with inverter
(2) Permissible torque characteristic of an internally cooled 3-phase AC motor
(3) Permissible torque characteristic of an adequately externally cooled 3-phase AC motor
(4) Maximum permissible torque for 120 s to DIN VDE 0530 Part 1

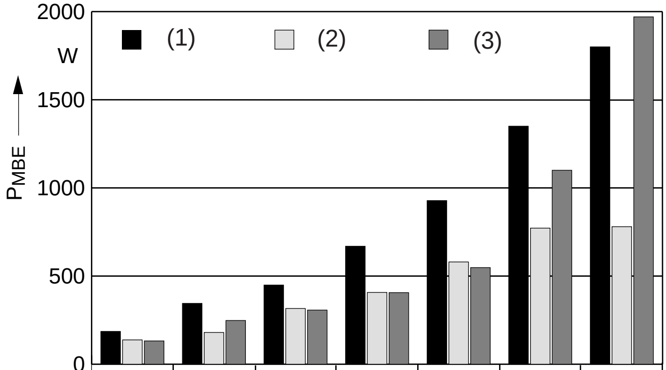
Figure 2.19 Torque characteristic of a standard three-phase AC motor in inverter operation

Typical acceleration behavior of standard three-phase AC motors

$$P_{MBE} = \frac{J_M \cdot n^2}{91,2 \cdot t_{BE}}$$

JM	Moment of inertia of the motor (rotor) in [kgm²]
tBE	Acceleration time in [s]
PMBE	Motor acceleration time in [W]

Acceleration from 0 rpm to nominal speed in 100 ms



	250 W	370 W	550 W	750 W	1.1 kW	1.5 kW	2.2 kW
(1)	186	345	449	669	928	1350	1800
(2)	138	180	316	407	580	772	780
(3)	132	248	307	406	548	1100	1970

(1) 1 pole pair
(2) 2 pole pairs
(3) 3 pole pairs

Figure 2.20 Acceleration behavior as a function of of number of pole pairs of standard three-phase AC motor

Motors with one pole pair are unsuitable for dynamic drive tasks.

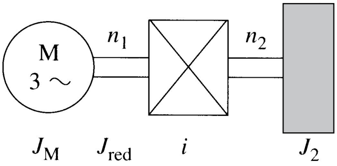
In summary: As the diagram shows, standard three-phase AC motors with two pole pairs (four-pole) are particularly well suited to dynamic drive tasks.

Typical max. acceleration times of four-pole standard three-phase AC motors

Size	Power P in W	Idle acceleration time in ms [I_{red}=0]	Acceleration time with moment of inertia adaptation in ms [I_{red}=IM]
63L/4	250	55	110
71L/4	375	49	98
80/S/4	550	57	114
80L/4	750	54	108
90S/4	1100	52	104
90L/4	1500	52	104
90L/4a	2200	35	70
100L/4	2200	50	100
100L/4a	3000	50	100
112M/4	4000	123	246

Table 2.5 Max. acceleration times of four-pole standard three-phase AC motors

Example: Equations for reduction via a gearbox

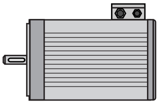


$$J_{red} = \frac{J_2}{(i)^2} = \frac{J_2}{(n_1 / n_2)^2}$$

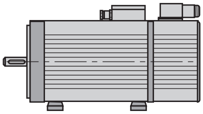
$$J_{tot} = J_M + J_{red}$$

For further calculations of mass moments of inertia See Appendix A.2.8.

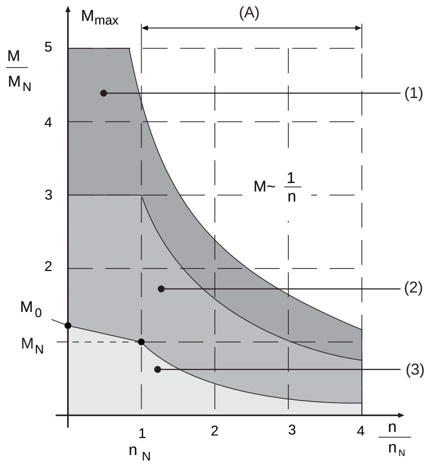
2.5.2 Characteristic values of asynchronous servomotors ASx



Without incremental encoder



With incremental encoder



(1) Pulse mode (2) Intermittent (3) Continuous

Figure 2.21 M-n characteristic for asynchronous motors

Abbreviations used

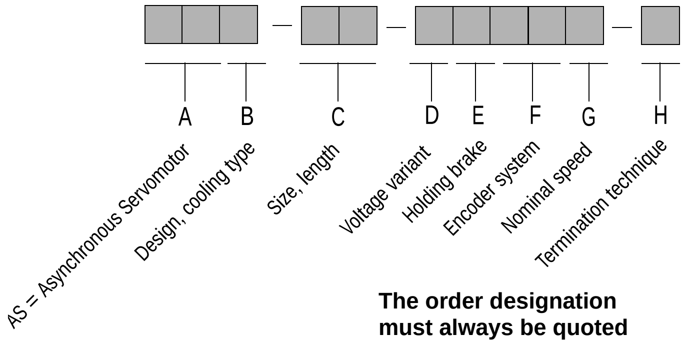
Term	Explanation
M_0 Standstill torque	Thermal limit torque of the motor at standstill. The motor can deliver this torque for an unlimited length of time.
I_0 Standstill current	Effective value of the motor phase current required to generate the standstill torque.
M_N Nominal torque	Thermal limit torque of the motor at nominal speed n_N.
I_N Rated current	Effective value of the motor phase current required to generate the nominal torque.
P_N Rated power	Full-load power of the motor at the nominal working point (M_N, n_N) at rated current IN and rated voltage U_N.
M_{max}, I_{max} Limit curve	A maximum of five times the rated current may be applied to the motors.

Standards and regulations

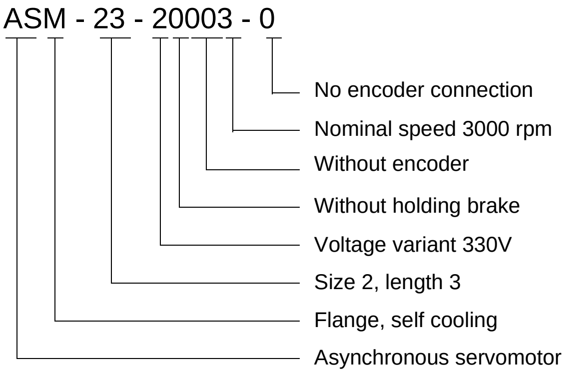
Property	Asynchronous servomotors ASx
Machine type	Asynchronous servomotor
Design (DIN 42948)	IM B35, IM B5, BV1, V3
Protection (DIN 40050)	IP65, shaft seal IP64 (option IP65)
Insulating material class	Insulating material class F to VDE0530 winding overtemperature $\Delta\tau = 105$, coolant temperature tu=+40°C
Cooling	Self cooling (IC 0041) IP65 forced cooling (IC 0641) IP44,54
Coating	RAL 9005 (black)
Shaft end on the A (D) side	Cylindrical shaft end DIN 748, featherkey and featherkey way DIN 6885, tolerance band k6
Flange dimension	DIN 42948 and IEC 72
Smooth running, coaxiality and concentricity to DIN 42955	Tolerance N (normal) R (reduced) on request
Vibration severity to ISO 2373	Stage N, optionally R
Therm. motor monitoring	PTC thermistor in stator winding
Torque load	To prevent thermal overloading of the motors, the effective load torque must not be greater than the nominal torque of the servomotor. $M_{eff} = \sqrt{\frac{\Sigma M_n^2 \times t_n}{}} \qquad M_{eff} \leq M_N$
Maximum pulse torque	Typically 2 to 5 times nominal torque, depending on controller assignment. 3 to 5 times nominal torque is permissible for max. 0.2 s.
Bearing service life	The average service life under nominal conditions (Mmax. ≤ MN) is 20,000 h.

Table 2.6 General technical data

Type code for asynchronous servomotor ASX



The order designation must always be quoted in full in the specified order.



Technical data of the asynchronous servomotors with self cooling

Self cooling	M_0 [Nm]	MN [Nm]	PN [kW]	I_0 [A]	I_N [A]	nN [rpm]	JL [kgcm²]	m [kg]	nmax [rpm]
ASM (H)-11 -2xxx3	1.5	1.3	0.41	1.6	1.4	3000	2.8	6.5	12000
ASM (H)-12 -2xxx3	2	1.7	0.54	2.1	1.8	3000	3.7	7.5	12000
ASM (H)-13 -2xxx3	2.7	2.3	0.72	2.74	2.3	3000	4.7	8.5	12000
ASM (H)-14 -2xxx3	4.2	3.5	1.1	4	3.3	3000	6.5	10.2	12000
ASM (H)-15 -2xxx3	5.2	4.7	1.5	5.4	4.5	3000	8.9	12.8	12000
ASM (H)-21 -2xxx3	4.2	3.5	1.1	3.6	3	3000	10.9	10.8	12000
ASM (H)-22 -2xxx3	5.6	4.7	1.5	4.7	3.9	3000	14.4	13.2	12000
ASM (H)-23 -2xxx3	8.4	7	2.2	6.7	5.6	3000	21.5	16.2	10000
ASM (H)-24 -2xxx2	12	10	2.1	6.4	5.3	2000	29.8	20.3	10000
ASM (H)-25 -2xxx2	15	13	2.7	7.7	6.6	2000	38.4	24	8000
ASM (H)-31 -2xxx1	15.5	13	2.1	6.2	5.2	1500	70	29.8	8000
ASM (H)-32 -2xxx1	20	17	2.7	8.2	6.8	1500	90	33	8000
ASM (H)-33 -2xxx1	27.5	23	3.6	10.3	8.7	1500	130	41.5	8000
ASM (H)-34 -2xxx1	42	35	5.5	15.1	12.6	1500	209	56.6	8000
ASH-41-2xxx1	47	40	6.3	21	17.9	1500	450	87	8000
ASH-42-2xxx1	70	60	9.4	30	25.5	1500	740	113	8000
ASH-43-2xxx1	85	70	11	37	30.4	1500	960	135	8000

Table 2.7 Technical data, self cooling

Abbreviations used

Term	Explanation
M_0 Standstill torque	Thermal limit torque of the motor at standstill. The motor can deliver this torque for an unlimited length of time.
I_0 Standstill current	Effective value of the motor phase current required to generate the standstill torque.
M_N Nominal torque	Thermal limit torque of the motor at nominal speed n_N.
I_N Rated current	Effective value of the motor phase current required to generate the nominal torque.
P_N Rated power	Full-load power of the motor at the nominal working point (M_N, n_N) at rated current I_N and rated voltage U_N.
M_{max}, I_{max} Limit curve	A maximum of five times the rated current may be applied to the motors.

Technical data of the asynchronous servomotors with forced cooling

Forced cooling	M_0 [Nm]	MN [Nm]	PN [kW]	I_0 [A]	I_N [A]	nN [rpm]	JL [kgcm²]	m [kg]	nmax [rpm]
ASF (V)-11 -2xxx3	2	1.7	0.54	2.1	1.8	3000	2.8	7.5	12000
ASF (V)-12 -2xxx3	2.7	2.3	0.72	2.8	2.4	3000	3.7	8.6	12000
ASF (V)-13 -2xxx3	3.6	3	0.94	3.54	2.9	3000	4.7	9.7	12000
ASF (V)-14 -2xxx3	5.6	4.7	1.5	5.1	4.3	3000	6.5	12.5	12000
ASF (V)-15 -2xxx3	7.7	6.5	2	7.3	6.2	3000	8.9	14,2	12000
ASF (V)-21 -2xxx3	5.6	4.7	1.5	4.6	3.9	3000	10.9	13.8	12000
ASF (V)-22 -2xxx3	8.4	6.5	2	6.5	5	3000	14.4	16.2	12000
ASF (V)-23 -2xxx3	12	10	3.1	8.9	7.4	3000	21.5	19,2	10000
ASF (V)-24 -2xxx2	15.5	13	2.7	8	6.7	2000	29.8	23.3	10000
ASF (V)-25 -2xxx2	19.7	16.5	3.4	9.8	8.2	2000	38.4	27	8000
ASF (V)-31 -2xxx1	21.5	18	2.8	8.4	7	1500	70	33.8	8000
ASF (V)-32 -2xxx1	27.5	23	3.6	10.6	8.9	1500	90	37.5	8000
ASF (V)-33 -2xxx1	38	32	5	13.8	11.6	1500	130	46.5	8000
ASF (V)-34 -2xxx1	56	47	7.4	18.4	15.4	1500	209	62.1	8000
ASV-41-2xxx1	83	70	11	33	27.5	1500	450	95	8000
ASV-42-2xx1	140	118	18.5	50	42	1500	740	121	8000
ASV-43-2xxx1	170	143	22.5	61	51	1500	960	145	8000

Table 2.8 Technical data, forced cooling

Abbreviations used

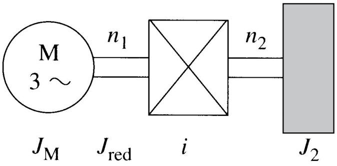
Term	Explanation
M_0 Standstill torque	Thermal limit torque of the motor at standstill. The motor can deliver this torque for an unlimited length of time.
I_0 Standstill current	Effective value of the motor phase current required to generate the standstill torque.
M_N Nominal torque	Thermal limit torque of the motor at nominal speed n_N.
I_N Rated current	Effective value of the motor phase current required to generate the nominal torque.
P_N Rated power	Full-load power of the motor at the nominal working point (M_N, n_N) at rated current I_N and rated voltage U_N.
M_{max}, I_{max} Limit curve	A maximum of five times the rated current may be applied to the motors.

Typical max. acceleration times of asynchronous servomotors

ASx Size Length	Installation window [mm]	Accelera-tion torque [Nm]	Power class [kW]	Idle accele-ration time [ms] $I_{red}=0$	Acceleration time [ms] $I_{red}=IM$
11 to 15	110x110	3,25 to 11.75	0.4 to 1.5	14 to 12	28 to 24
21 to 25	140x140	8.75 to 32.5	1.1 to 2.7	20 to 19	40 to 38
31 to 34	190x190	32.5 to 87.5	2.1 to 5.5	34 to 38	68 to 76
41 to 43	260x260	100 to 175	6.3 to 11	71 to 87	142 to 174
Precondition:	Acceleration from 0 to 1500 rpm at 2.5 times nominal torque and idle ($I_{red}=0$)				

Table 2.9 Idle acceleration time

Example: Equations for reduction via a gearbox



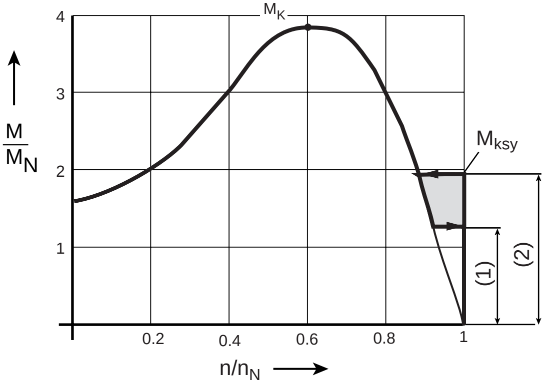
$$J_{red} = \frac{J_2}{(i)^2} = \frac{J_2}{(n_1 / n_2)^2}$$

$$J_{tot} = J_M + J_{red}$$

Calculation of mass moments of inertia - See section A.2.8.

2.5.3 Characteristic values of reluctance motors

Typical torque characteristic



(1)	Pull-in to synchronism	$M_{sy} \approx 1,2 \cdot M_N$
(2)	Pull-out of synchronism	$M_{ksy} \approx 1,6bis1,8 \cdot M_N$

$$M_K \approx 3,5 \cdot M_N$$

Figure 2.22 Typical torque characteristic of a reluctance motor in mains operation

---

Note: The motor may only be run to accelerate in asynchronous mode. If asynchronous mode is run for longer the motor will be destroyed.

Torque as a function of load angle

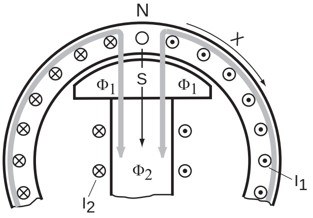
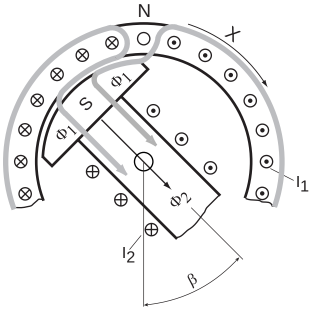
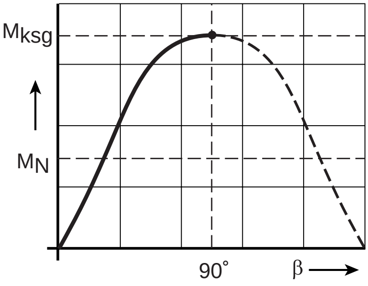
Idling of the reluctance/ synchronous motor	Loading of the reluctance/ synchronous motor
	
The stator field Φ1 with the field system of the rotor Φ2 represents a fixed magnetic adhesion.	As the load on the shaft increases, the rotor displacement angle/load angle increases steadily. The speed remains synchronous.
X Direction of rotation β Load angle	

Table 2.10 Torque as a function of rotor displacement angle β (load angle)



β referred to the motor shaft		
Pole pairs	**β_{MN} typical**	**β_{Mksg}**
1	20°	45°
2	10°	22.5°
3	6.75°	15°
4	5°	11,25°

Table 2.11 Internal torque as a function of load angle

Internal torque (M_i) $M_i = k \cdot \Phi \cdot i \cdot \sin\beta$

Project planning notes

A 3-phase AC reluctance motor is a special motor which must be tested anew prior to every production deployment. Depending on the situation, smooth running, heat, noise or vibration problems may occur. The following table presents a listing of key points which may need to be considered.

Detailed information can only be provided by the manufacturer of the reluctance motor, however.

Subject	Project planning notes
Motor design	See manufacturer’s data sheet Tips: • Winding always in star configuration (high inductance) • Inquiries for motors for S3 to S6 operation must usually be submitted separately • Motor protection only possible via PTC or Klixon • High tendency to vibrate, especially < 25Hz
Inverter design	In static operation • I-Inverter $\approx$ 1,2 I_N Motor In dynamic operation • I-Inverter ≈ 1.8 I_N Motor • Shut down the slip compensation, load compensation and V/F characteristic adaptation software functions • V/F characteristic with at least 3-6 fully programmable interpolation points • At frequencies > 150 Hz an additional filter must very often be inserted in the motor cable • The max. output frequency must not be higher than F_N (frequency nominal point). • When motors are connected up a very high short-circuit current flows (typically up to 30-40 times I_N)

Table 2.12 Project planning notes for drive system with reluctance motors

2.5.4 Characteristic values of synchronous motors

Synchronous motor with salient-pole rotor

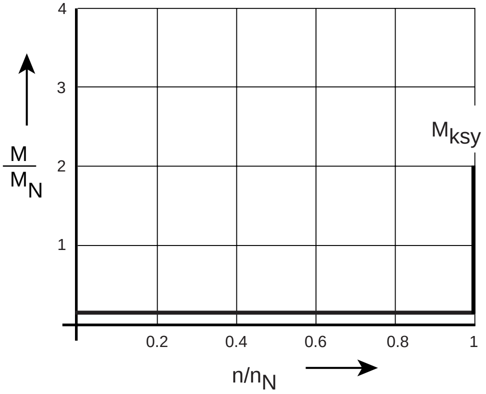
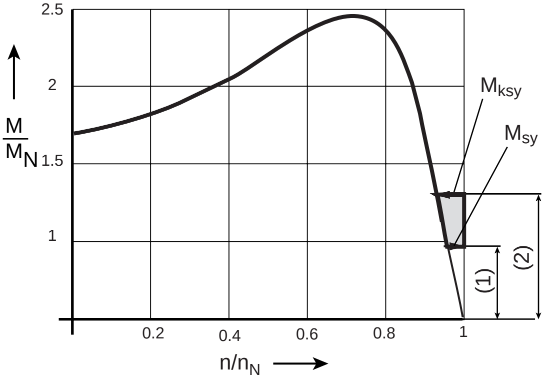


Figure 2.23 Typical torque characteristic of a synchronous motor with salient-pole rotor

Synchronous motor with cage winding and permanent magnets



(1) Pull-in to synchronism $M_{sy} \approx 0, 9 \cdot M_N$

(2) Pull-out of synchronism $M_{ksy} \approx 1, 35 \cdot M_N$ (corresponding to VDE 0530)

Figure 2.24 Typical synchronous motor of a synchronous motor with cage winding and permanent magnets

Torque as a function of load angle

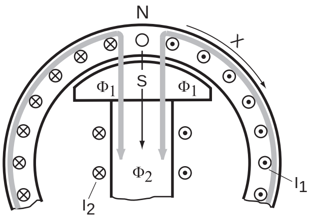
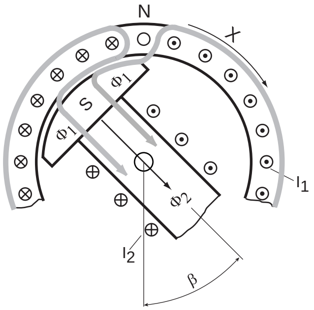
Idling of the reluctance/ synchronous motor	Loading of the reluctance/ synchronous motor
	
The stator field Φ1 with the field system of the rotor Φ2 represents a fixed magnetic adhesion.	As the load on the shaft increases, the rotor displacement angle/load angle increases steadily. The speed remains synchronous.
X Direction of rotation β Load angle	

Table 2.13 Torque as a function of rotor displacement angle β (load angle)

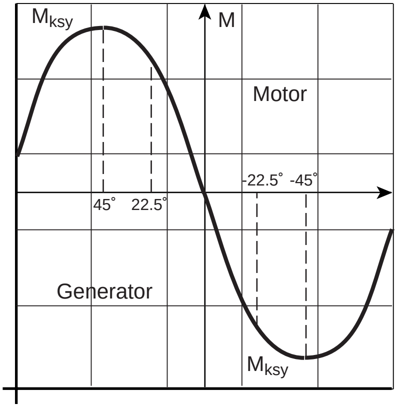


Figure 2.25 Torque as a function of load angle in the synchronous machine with salient-pole rotor

Project planning notes

A synchronous motor, too, is a special motor which must be tested anew prior to every production deployment. Depending on the situation, smooth running, heat, noise or vibration problems may occur. The following table presents a listing of key points which may need to be considered.

Subject	Project planning notes
Motor design	For precise data refer to the manufacturer's data specification booklet Tips: • Synchronous motors with cage winding can be run on the mains and on the inverter. • The synchronous breakdown torque M_{Ksy} is approx. 1.35 x M_N. If a higher breakdown torque is required (e.g. 1.6 times), a higher-powered motor must be chosen. • The external moment of inertia specified by the manufacturer must not be exceeded, otherwise the motor will not be able to generate the acceleration torque required for synchronization. • At low frequencies the no-load current may be higher than the load current. • Motor protection only possible via PTC • High tendency to vibrate
Inverter design	In static operation with manipulating range $\leq$ 1:5 (20-100 Hz) • I-Inverter ~ I_N Motor In static operation with manipulating range $\leq$ 1:5 (5-100 Hz) • I-Inverter ~ 1.2 x I_N Motor With group drive • Refer to the "Multi-motor operation" project planning notes, section 3.3. The startup currents for connection of the motor to max. frequency may be 30 times the motor rated current. • V/F characteristic with at least three programmable interpolation points • Shut down the slip compensation, load compensation and V/F characteristic adaptation software functions For rapid synchronization the motor should be run in the frequency range to 50 Hz with current injection. In individual applications it will be necessary to stop the acceleration process for 10 s at 5 Hz to allow the motor time to switch to synchronous mode.

Table 2.14 Project planning notes for permanent magnet excited synchronous motors with cage winding for asynchronous self-starting.

Detailed information can only be provided by the manufacturer of the synchronous motor, however.

2.5.5 Characteristic values of high-frequency motors

Not available at time of going to press.

At frequencies > 1000 Hz special project planning directives must be followed.

1
2
3
4
5
6
7
A
DE
EN

2.6 Selection of gearing

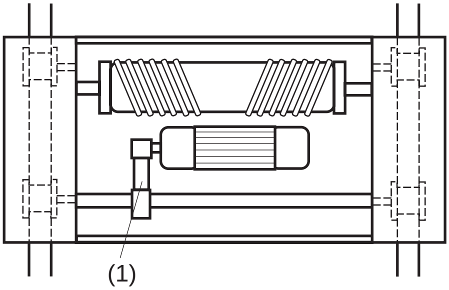
This section presents the key gearing data in table form. For precise data regarding design, magnetic flux direction, transmission, play etc. refer to the various manufacturers' catalogues.

What points need to be considered in designing the gearing?

- Fitting location conditions (room conditions, temperature, position)
- Max. drive speed
- Max. output torque
- Service factor (the standard gears are designed for uniform load)
- Transversal forces, axial forces
- Circumferential backlash
- Torsional rigidity

2.6.1 Transmission gear

Insertion of a transmission gear stage between the geared motor and the output shaft results in different gear output speeds and torques.



(1) Transmission gear with chain wheels

Figure 2.26 Transmission gear

Practical tip

➢ In practice the transmission gear is usually implemented by way of toothed belts
$i_{max} \approx 4$, $i_{typical} = 2$ to 3

➢ $i_{tot} = i_v \cdot i_G$

i_v Transmission gear reduction
i_G Gear reduction

2.6.2 Characteristic values of standard gears

Characteristics	Spur gear	Flat spur gear	Worm gear	Bevel gear
Magnetic flux	straight	straight	rectangular	rectangular
Max. torque [Nm]	approx. 15,000	approx. 6,000	approx. 4000	approx. 40,000
2nd shaft end	not possible	possible	possible	possible
Hollow output shaft	not possible	possible	possible	possible
Reduction range (without compound transmission)	approx. 3.5 to 230	approx. 6 to 270	approx. 6 to 290	approx. 6 to 165
Efficiency	0.93 to 0.98	0.93 to 0.98	0.3 to 0.85	0.9 to 0.96
Circumferential backlash in[1] angle minutes	approx. 30 to 40	approx. 30 to 40	approx. 30 to 40	approx. 25 to 40
Reduction mathematically[2] precise? (rating plate)	no	no	no	no
Cost DM/Nm	low	low	medium	relatively high

[1] For explanation See section 2.6.3

[2] The cogs of the cogwheel pairing have common dividers so that different cogs always engage with each other.
Example: i = Z2/Z1 = 96/16 = 5.9375 ⇒ Catalogue specification 5.94

Table 2.15 Characteristic values of standard gears

2.6.3 Characteristic values of planetary gears

Characteristics	Standard gear	Planetary gear	Bevel gear
Gear stages	1/2/3	1/2	1/2
Efficiency (without worm gear)	very good	very good	very good
Circumferential backlash in angle minutes	approx. 25 to 40	1 to 10	6 - 15
Impulse torques	poor	very good	poor
Torsional rigidity	medium	very good	medium
Dynamics	medium	very good	medium
Power density	poor	very good	poor
Transmission math. precise? (rating plate)	no	yes	yes
Cost DM/Nm	low	relatively high	medium

Table 2.16 Characteristic values of planetary gears

Circumferential backlash

The circumferential backlash of a gear is the angular tolerance between the output and the drive, referred to the output shaft with the drive blocked and a torque of approx. 3 to 5% of the nominal torque of the gear.

- ➢ Figures are always absolute values and in angle minutes.
- ➢ Figure is obtained with drive shaft stopped.
- ➢ Figure relates to the output and is obtained by means of an alternating load of approx. 3 to 5% M_{max}.

Torsional rigidity

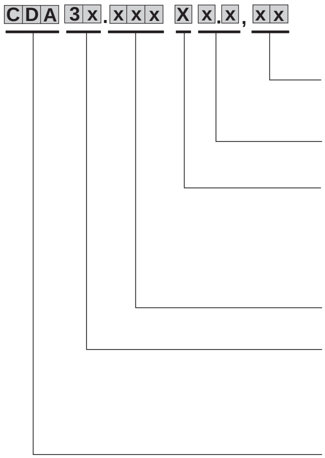
Torsional rigidity is the torsion of a gear relative to the loading.

- ➢ Figure always in Nm per angle minute.
- ➢ Figure is obtained with drive shaft stopped.
- ➢ Figure relates to the output and is obtained by means of an alternating load of approx. 0 to 100% M_{max}.

3 Selection of inverter module

3.1 Technical data

Type codes of inverter modules



Design code*)

Hardware default configuration

Cooling method:
C = Cold plate
W= Wall mounting
D = Push-through heat sink

Continuous output current

Mains voltage:
2 = 1 x 230 V -20% +15%
4 = 3 x 460 V -25% +10%

Inverter module series

*) The design code is separated by a comma. A maximum of 5 designs can be suffixed.

Single-phase inverter modules

Inverter module	Rec. 4-pole standard motor	Rated current	Peak current[1]	Power loss	Device output
CDA32.003,Cx.x	0.375 kW	2.4 A	4.3 A	25 W	0.95 kVA
CDA32.004,Cx.x	0.75 kW	4.0 A	7.2 A	45 W	1.5 kVA
CDA32.006,Cx.x	1.1 kW	5.5 A	9.9 A	75 W	2.1 kVA
CDA32.008,Cx.x	1.5 kW	7.1 A	12.8 A	95 W	2.7 kVA
1) 1.8 x I_N for 30 s	Mains voltage 1 x 230 V -20 % +15 % Mains frequency 50/60 Hz ±10 % Cooling air temperature (1000 m above MSL) 45 °C at 4 kHz			Power stage switching frequency 4, **8**, 16 kHz Output frequency 0 ... 1600 Hz	

Table 3.1 Overview of inverter modules for 230 V systems

Three-phase inverter modules

Inverter module	Rec. 4-pole standard motor	Rated current	Peak current	Power loss at 4 kHz	Device output
CDA34.003,Cx.x	0.75 kW	2,2 A	4.0 A1)	45 W	1.5 kVA
CDA34.005,Cx.x	1.5 kW	4.1 A	7.4 A1)	80 W	2.8 kVA
CDA34.006,Cx.x	2.2 kW	5.7 A	10.3 A1)	100 W	3.9 kVA
CDA34.008,Wx.x	3.0 kW	7.8 A	14 A1)	140 W	5.4 kVA
CDA34.010,Wx.x	4.0 kW	10 A	18 A1)	180 W	6.9 kVA
CDA34.014,Wx.x	5.5 kW	14 A	25 A1)	210 W	9.7 kVA
CDA34.017,Wx.x	7.5 kW	17 A	31 A1)	270 W	11.7 kVA
CDA34.024,Wx.x	11 kW	24 A	43 A1)	390 W	16.6 kVA
CDA34.032,Wx.x	15 kW	32 A	58 A1)	480 W	22.1 kVA
CDA34.045,Wx.x	22 kW	45 A	81 A2)	600 W	31 kVA
CDA34.060,Wx.x	30 kW	60 A	90 A2)	720 W	42 kVA
CDA34.072,Wx.x	37 kW	72 A	108 A2)	840 W	52 kVA
CDA34.090,Wx.x	45 kW	90 A	135 A2)	1080 W	62 kVA
CDA34.110,Wx.x	55 kW	110 A	165 A2)	1300 W	80 kVA
CDA34.143,Wx.x	75 kW	143 A	214 A2)	1680 W	104 kVA
CDA34.170,Wx.x	90 kW	170 A	255 A2)	2040 W	125 kVA

1) 1.8 x I_N for 30 s

2) 1.5 x I_N for 60s

Mains voltage 3 x 460 V -25 % +10 %
Mains frequency 50/60 Hz ±10 %
Cooling air temperature
(1000 m above MSL) 45 °C at 4 kHz

Power stage switching frequency 4, **8**, 16 kHz
Output frequency 0 ... 1600 Hz to 15 kW
0 ... 400 Hz 22 kW to 90 kW

Table 3.2 Overview of inverter modules for 460 V systems

3.1.1 Acceptance tests

Acceptance tests / Standards / Directives	Characteristic data
CE	The inverter modules conform to the requirements for installation in a machine or system under the terms of the Low Voltage Directive.
Approvals	$_c U_L$ (in preparation)
Conformance to standards	• Fitting-out of power installations with electronic equipment E50178 • EMC1) interference immunity IEC 1000-4-2 / EN 61000-4-2 IEC 1000-4-3 / EN 61000-4-3 IEC 1000-4-4 / EN 61000-4-4 IEC 1000-4-5 / EN 61000-4-5 • EMC, line-borne and radiated interference emission EN 50081-1 and EN 50081-2 IEC 55011 integrated radio interference suppression level A2)/**B**2) for inverter modules to 7.5 kW. For inverter modules 11 to 90 kW a wide range of filters is available to ensure conformance to IEC 55011. • All devices conform to the product norm EN618000-3 for speed-adjustable electric drives.

1) EMC = Electromagnetic compatibility

2) Motor cable length - See section 6.4

Table 3.3 Acceptance tests/Standards

Explanation of the “Acceptance tests and standards” table

Standard	Test	Comments
EN 61000-4-2	• By touch Discharge 6 kV • In air Discharge 8 kV	Test of immunity to electrostatic discharge (ESD)
EN 61000-4-3	• 26-1000 MHz (10 V/m)	Test of the electromagnetic field
EN 61000-4-4	• at control terminals 2 kV • on mains and motor cable Impulse voltage 4 kV	Test of immunity to rapid transient electrical interference (burst)
EN 61000-4-5	• Conductor / conductor 1 kV • Conductor / ground 2 kV	Immunity to voltage surge

Table 3.4 Explanation of the “Acceptance tests and standards” table

Standard	Test	Comments
EN 50081-1	• Residential and business • Motor cable length - See section 6.4	Protection against emission of electrical, magnetic and electromagnetic interference and against conducted interference
EN 50081-2	• Industrial • Motor cable length - See section 6.4.2	Protection against emission of electrical, magnetic and electromagnetic interference and against line-borne interference
EN 55011	• Industrial Class A • Residential and business Class B • Motor cable length - See section 6.4	Protection against line-borne interference

Table 3.4 Explanation of the "Acceptance tests and standards" table

3.1.2 Ambient conditions

Feature		Characteristic data
Temperature range	in operation	-10 ... 45 °C with derating to 55 °C (BG1 ... BG5) 0 ... 40 °C (BG6 ... BG8)
	in storage	-25 ... +55 °C
	in transit	-25 ... +70 °C
Relative air humidity		15 ... 85 %, condensation not permitted
Mechanical strength to IEC 68-2-6	in stationary operation	Vibration: 0.075 mm in frequency range 10 ... 58 Hz Shock: 9.8 m/s^2 in frequency range >58 ... 500 Hz
	in transit	Vibration: 3.5 mm in frequency range 5 ... 9 Hz Shock: 9.8 m/s^2 in frequency range >9 ... 500 Hz
Protection	Device menu	IP20 (NEMA 1)
	Cooling method	Cold plate IP20 Push-through heat sink IP54 (3...15kW) Push-through heat sink IP20 (22...37kW)
Touch protection		VBG 4
Power reduction		See section 3.2.x

Table 3.5 Ambient conditions

3.1.3 Installation and cooling methods

The CDA3000 inverter module offers three different methods of installation and cooling:

- ➢ Cold plate
- ➢ Wall mounting with heat sink
- ➢ Push-through heat sink

General project planning notes

Subject	Project planning notes
Side clearance	• Inverter modules 0.37 to 15 kW can be mounted next to each other with no gap. • Above 22 kW a side clearance of 50 mm must additionally be maintained.
Clearance above and below	• There must be a clearance of 100 mm above and below.
⚠	• Polluted cooling air (dust, fluff, oil, aggressive gases) may impair the functioning of the inverter modules. - Take adequate precautions; cold plate; separate ventilation; installation of filters; regular cleaning etc. • Do not exceed the permissible range of the operational cooling temperature (see sections 3.1.2 and 3.2.14). • Observe other ambient conditions (see section 3.1.2). • Mounting orientation: Vertical on the rear of the switch cabinet or other mounting surface. • With “cold plate and push-through heat sink” cooling, comply with the special conditions for discharge of power loss.

Table 3.6 Project planning notes

Overview of the permissible cooling methods referred to size and power output

Size	Power output	Inverter module	Power loss1)	Cold plate	Wall mounting	Push-through heat sink
BG1	0.375 kW 0.75 kW	CDA32.00 3 CDA32.00 4	25 W 45 W	YES	YES2)	NO
BG2	1.1 kW 1.5 kW 0.75 kW 1.5 kW	CDA32.00 6 CDA32.00 8 CDA34.00 3 CDA34.00 5	75 W 95 W 45 W 80 W	YES	YES2)	NO
BG2	2.2 kW	CDA34.00 6	100 W	YES	YES	NO
BG3	3.0 kW 4.0 kW	CDA34.00 8 CDA34.01 0	120 W 150 W	YES	YES	YES3)
BG4	5.5 kW 7.5 kW	CDA34.01 4 CDA34.01 7	180 W 225 W	YES	YES	YES3)
BG5	11 kW 15 kW	CDA34.02 4 CDA34.03 2	330 W 400 W	YES	YES	YES3)
BG6	22 kW 30 kW 37 kW	CDA34.04 5 CDA34.06 0 CDA34.07 2	500 W 600 W 700 W	NO	YES	YES4)
BG7	45 kW 55 kW	CDA34.09 0 CDA34.11 0	900 W 1100 W	NO	YES	NO
BG8	75 kW 90 kW	CDA34.14 3 CDA34.17 0	1400 W 1700 W	NO	YES	NO

1) With a power stage clock frequency of 4 kHz
2) See current curves in section 3.2.14
3) The push-through heat sink has IP54 protection
4) The push-through heat sink has IP20 protection

Table 3.7 Overview of inverter modules and possible cooling methods

At 8 kHz power stage clock frequency the power losses increase by 40%.

“Cold plate” cooling method based on the example of size 3 (3 and 4 kW)

CDA3..., Cx.x	
Installation	Vertical on mounting plate (heat-conducting) or cooling profile,) cold plate principle
Protection	IP20
Cooling air temperature	45 °C (at 4 kHz switching frequency of power stage)
Weight	2.8 Kg
H (height)	303 mm
W (width)	100 mm
D (depth)	182.5 mm

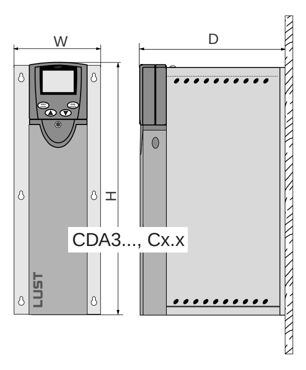
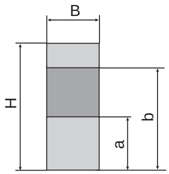


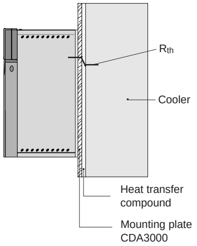
Table 3.8 Cold plate installation and cooling method

Project planning notes, “Cold plate”

<table>
<tr><th>Subject</th><th>Project planning notes</th></tr>
<tr><td>Thermal connection to cooler</td><td>

- Evenness of contact surface of 0.05 mm
RZR 6.3 = maximum roughness of contact surface
- Coat area between inverter module (“cold plate” backing plate) and cooler with heat transfer compound (coat thickness 30-70µ).
- The temperature in the middle of the inverter module backing plate must not exceed 85 °C.

</td></tr>
<tr><td>Distribution of power loss</td><td>
<table>
<tr><th>Size</th><th>Power output</th><th>Heat sink</th><th>Housing</th></tr>
<tr><td>BG 1/2</td><td>0.37 to 2.2 kW</td><td>approx. 65%</td><td>approx. 35%</td></tr>
<tr><td>BG 3</td><td>3 to 4 kW</td><td>approx. 70%</td><td>approx. 30%</td></tr>
<tr><td>BG 4</td><td>5.5 to 7.5 kW</td><td>approx. 75%</td><td>approx. 25%</td></tr>
<tr><td>BG 5</td><td>11 to 15 kW</td><td>approx. 80%</td><td>approx. 20%</td></tr>
</table>
</td></tr>
<tr><td>Active cooling area


</td><td>
<table>
<tr><th rowspan="2">Size</th><th rowspan="2">Power output [kW]</th><th colspan="2">Device basic area [mm]</th><th colspan="2">Active cooling area [mm]</th></tr>
<tr><th>B</th><th>H</th><th>a</th><th>b</th></tr>
<tr><td>BG 1</td><td>0.37 to 0.75 kW</td><td>70</td><td>193</td><td>50</td><td>165</td></tr>
<tr><td>BG 2</td><td>1.1 to 2.2 kW</td><td>70</td><td>218</td><td>90</td><td>200</td></tr>
<tr><td>BG 3</td><td>3 to 4 kW</td><td>100</td><td>303</td><td>120</td><td>260</td></tr>
<tr><td>BG 4</td><td>5.5 to 7.5 kW</td><td>150</td><td>303</td><td>65</td><td>215</td></tr>
<tr><td>BG 5</td><td>11 to 15 kW</td><td>200</td><td>303</td><td>80</td><td>300</td></tr>
</table>
</td></tr>
<tr><td>Thermal resistance


</td><td>
<table>
<tr><th>Size</th><th>Power output [kW]</th><th>Temperature lag between active cooling area and cooler R_{th} [K/W]</th></tr>
<tr><td>BG 1</td><td>0.37 to 0.75 kW</td><td>0.05</td></tr>
<tr><td>BG 2</td><td>1.1 to 2.2 kW</td><td>0.05</td></tr>
<tr><td>BG 3</td><td>3 to 4 kW</td><td>0.03</td></tr>
<tr><td>BG 4</td><td>5.5 to 7.5 kW</td><td>0.02</td></tr>
<tr><td>BG 5</td><td>11 to 15 kW</td><td>0.015</td></tr>
</table>
</td></tr>
</table>

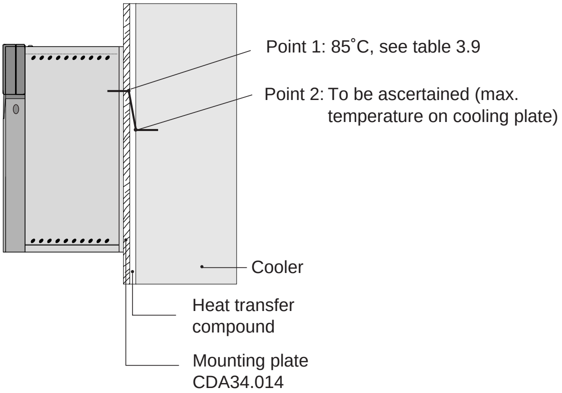
Table 3.9 Project planning notes, “Cold plate”

The inverter module has a temperature evaluation facility as standard.

The current temperature at point 1 of the heat sink is displayed by way of parameter 427-KTEMP in subject area _VAL (actual values).

Example: Heat transfer via a cooler

- Inverter module CDA34.014
- Power stage clock frequency 4 kHz



1. Power loss discharged by way of the mounting plate of the inverter module.

The CDA34.014 has a power loss of 180 W (table 3.2).
75% of the power loss is discharged via the mounting plate (active cooling area) and 25% as radiated heat via the housing (table 3.9)
$P_{\text{Mountingplate}} = 180\text{ W} \times 0.75 = 135\text{ W}$

2. Calculate temperature difference between mounting plate and cooling plate.

$\Delta\vartheta = P_{\text{Mounting plate}}\ \text{x}\ R_{th}{}^{1)} = 135\text{ W x } 0.02\text{ K/W} = 2.7\text{ K}$

$^{1)}$ See table 3.9

3. Maximum temperature at point 2 and on the cooler

$\vartheta_{\text{Point 2}} = \vartheta_{\text{Point 1}} \text{-DJ} = 85\text{ °C} - 2.7\text{ °C} = 82.3\text{ °C}$

4. Calculation of the cooler:

- At point 2 the max. temperature of 82.3 °C must not be exceeded.
- 135 W of power loss must be discharged by way of the cooler.
- The exact solution depends on the cooler used, e.g. heat sink to air or water, heat exchanger etc.

“Wall mounting” cooling method based on the example of size 3 (3 and 4 kW)

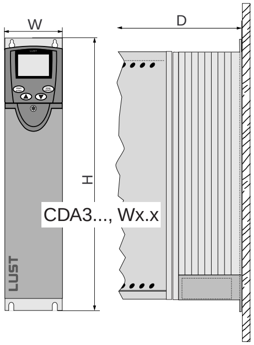
CDA3..., Wx.x		
Installation	Vertical wall mounting with heat sink	
Protection	IP20	
Cooling air temperature	45 °C (at 4 kHz switching frequency of power stage)	
Weight	3.7 Kg	
H (height)	330 mm	
W (width)	70 mm355 mm	
D (depth)	250.5 mm	

Table 3.10 Wall mounting installation and cooling method

With this cooling method the inverter module can even be mounted on non-heat-conducting surfaces.

“Push-through heat sink” cooling method based on the example of size 3 (3 and 4 kW)

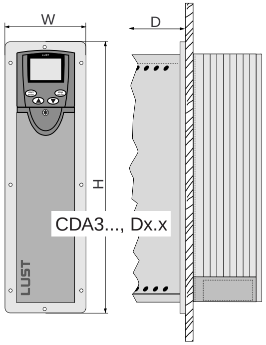
CDA3..., Dx.x		
Installation	Vertical mounting with push-through heat sink	
Protection	IP20 units, IP54 heat sink side	
Cooling air temperature	45 °C (at 4 kHz switching frequency of power stage)	
Weight	3.9 Kg	
H (height)	340 mm	
W (width)	110 mm	
D (depth)	170.5 mm	

Table 3.11 Push-through heat sink installation and cooling method

When the “push-through heat sink” cooling method is used, the heat sink of the inverter module can be mounted outside the switch cabinet, or mounting space, in order to reduce the heat generated. The power loss split is dependent on size, and is shown in the following table.

Size	Power output	To the outside	To the inside
BG 3	3 to 4 kW	70%	30%
BG 4	5.5 to 7.5 kW	75%	25%
BG 5	11 to 15 kW	80%	20%
BG 6	22 to 37 kW	85%	15%

Table 3.12 Distribution of power loss with the “push-through heat sink” cooling method

Size of inverter modules dependent on cooling method

Size	Power output [kW]	Cold plate1) W x H x D	Wall mounting1) W x H x D	Push-through heat sink1) W x H x D	Clearance above/ below2) [mm]
BG 1	0.37 to 0.75	70x193x153	70x193x228	no	100 / 100
BG 2	1.1 to 2,2	70x218x178	70x218x253	no	100 / 100
BG 3	3 to 4	100x303x183	70x330x251	110x340x171	100 / 100
BG 4	5.5 to 7.5	150x303x183	120x330x251	160x340x171	100 / 100
BG 5	11 to 15	200x303x183	170x330x251	210x340x171	100 / 100
BG 6	22 to 37	no	250x375x325	250x411x248	100 / 100
BG 7	45 to 55	no	300x600x305	no	100 / 100
BG 8	75 to 90	no	412x540x370	no	100 / 100

1) Max. outer dimensions to be maintained

2) The bending radii of the cables must be taken into account for the mounting clearance below

Note: The modules can be mounted side-by-side. As from size 6 an additional side clearance of 50 mm is required.

Table 3.13 Size of inverter modules dependent on on cooling method

3.2 Extreme operating conditions

Safety instructions

While in operation, inverter surfaces can be conductive, uninsulated, sometimes also moving or rotating, and hot, according to their type of protection. This means that a frequency inverter drive can endanger human life.

To prevent serious physical injury or considerable material damage, only qualified persons familiar with electrical drive equipment may work on the equipment. Only those persons who are familiar with mounting, installing, commissioning and operating inverters and have appropriate professional qualifications shall be regarded as qualified. Those persons must read the Operation Manual carefully before installation and commissioning, and follow the safety instructions.

In this context the standards IEC 364 and CENELEC HD 384 or DIN VDE 0100 and IEC-Report 664 or VDE 0110 and national accident prevention regulations or VBG 4 must be observed.

Repairs to the device may only be carried out by the manufacturer or by a repair workshop approved by the manufacturer. Unauthorized opening and unprofessional intervention could lead to physical injury or material damage.

Intended use

Inverters are components that are intended for installation in electrical systems or machines.

The inverter may not be commissioned (i.e. it may not be put to its intended use) until it has been established that the machine complies with the provisions of EC Directive 89/392/EEC (Machinery Directive); EN60204 is to be observed.

In addition to the Low Voltage Directive 73/23/EEC the harmonized standards of the prEN 50178/DIN VDE 0160 series in conjunction with EN 60439-1/DIN VDE 0660 Part 500 and EN 60146/DIN VDE 0558 are to be applied with regard to the inverters.

The technical data and the instructions concerning connection conditions are given on the name plate and in the documentation, and are to be observed under all circumstances.

The inverters are to be protected against unauthorized stress. In particular, components may not be bent, nor may insulation distances be altered during transport and use.
Inverters contain components that are vulnerable to electrostatic accumulation and can therefore easily be damaged if incorrectly handled. Ensure that electrical components are not mechanically damaged or destroyed.

When work is being carried out on live inverters, the applicable national accident prevention regulations (e.g. VBG 4) are to be observed.
Electrical installation is to be carried out in accordance with the relevant regulations (e.g. cable cross section, fuses, grounding lead connection). Other details are contained in the documentation.

Electronic devices are fundamentally not fail-safe. Users are themselves responsible for ensuring that the drive is rendered safe if the device fails.

If the inverter is used for special applications (e.g. subject to explosion hazards), the required standards and regulations (e.g. EN50014 and EN50018) must be observed.

3.2.1 Mains side/system condition

DIN VDE 0100-300: 1996-01 distinguishes between three different mains power systems. It is made especially clear how the IT system differs from the TT and TN systems based on the means of ground connection.

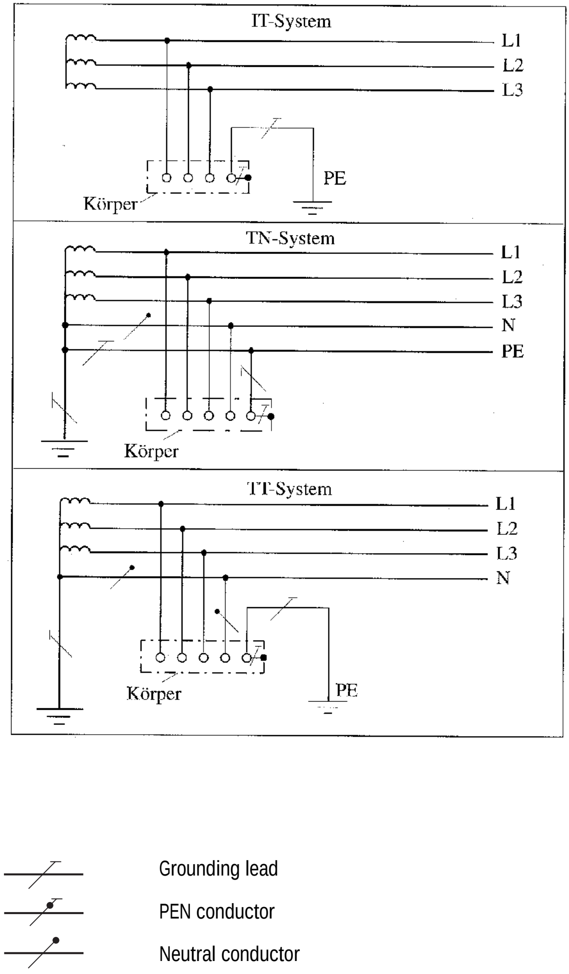


Figure 3.1 IT, TN and TT systems

First letter - Link from the supply system to the ground:

T	Direct connection of a point to the ground
I	Either all active parts isolated from ground or one point connected to ground via an impedance.

Second letter - Link from the bodies of the electrical system to ground:

T	Body grounded directly, regardless of any grounding of a point of the supply system
N	Body grounded directly with the grounded point of the supply system (in AC systems the grounded point is generally the center point or, if there is no center point, an outer conductor).

Voltage conditions in the IT system

In an IT system the voltages of the outer conductors are adjusted against ground according to the voltage distribution by the discharge impedances. These impedances comprise the capacitors of the conductors and those of the equipment against ground, and the parallel switched insulation resistors. If the said discharge impedances are equally large for every conductor, all outer conductors likewise conduct the same voltage against ground. High-resistance voltmeters connected between the outer conductor and ground display the same value. In three-phase AC systems this is the star voltage; in AC systems half the conductor voltage is displayed. Insulation monitors should therefore be connected symmetrically. If a ground fault occurs on a conductor, its voltage to ground collapses. However, because the voltage between the conductors is maintained the healthy conductors are raised to the conductor voltage against ground.

It should be considered that in the event of a ground fault on a conductor in ungrounded systems the center point of the transformer takes on phase voltage and the non-faulty outer conductors are raised to the outer conductor voltage against ground.

This increased voltage load may result in puncture at a point with low electrical insulation resistance, and this cause a double short circuit to frame.

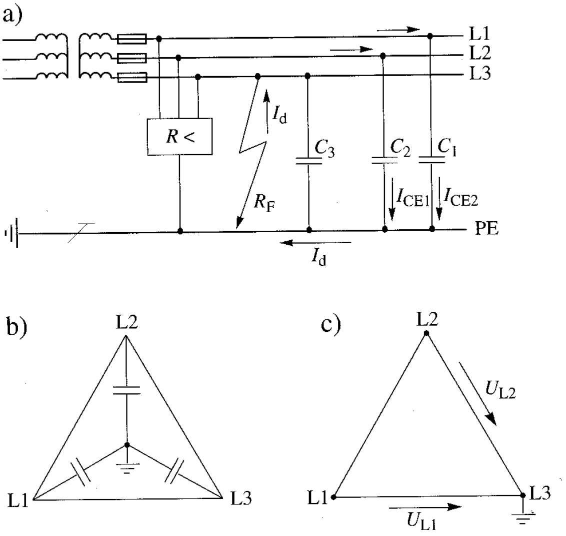


Figure 3.2 Voltage and current conditions in the IT system

a) IT system with ground fault on conductor L3. The ground fault current I_d flows via the capacitors of the healthy conductors.
b) Conductor voltage against ground with symmetrical conductor capacity. All conductors conduct the star voltage against ground.
c) Conductor voltage against ground in the system. System with a ground fault on conductor L3. The healthy conductors conduct the conductor voltage against ground. It determines the amount of the ground fault current by way of the conductor capacitors.

System conditions for the CDA3000 inverter drive system

For operation of the CDA3000 drive controllers on the various mains power systems the following conditions must be met.

Power system	Operation with Inverter CDA3000	Comments
TN and TT	Permitted without restriction	• Pay attention to connection data • Best system form in terms of EMC
	Operation of several CDA32.xxx (1x230V) in the 3AC/N/PE system	• Split symmetrically across the three outer conductors • Pay attention to the loading of the common zero conductor, increase the cross-section as necessary.
IT with insulated center point	Operation of inverter modules in this system type is not permitted.	• Radio interference suppression filters (internal/external) may be destroyed in the event of “ ground fault”. • In the event of a “ground fault” the voltage load is increased (to around twice as much), as a result of which the creepages and clearances are not maintained and so the system no longer conforms to the Low Voltage Directive EN50178 (safety-low voltage).

Table 3.14 System conditions

Additional comments on the IT system

For devices, machines and plant which need to be run in an IT system, an isolating transformer must be fitted. The secondary side of the power transformer must be configured as a TN system (TN-S with isolated grounding lead).

Radio interference suppression filters must not be inserted/operated in the IT system. The IEC1800-3 standard stipulates that the filters cannot be used in this type of system because correct operation of the insulation monitoring cannot then be guaranteed.

3.2.2 Loading on the supply system

All inverter systems draw a non-sinusoidal current from the system. This is because of the 1/3-phase input rectifier in the inverter input. This non-sinusoidal current consumption results in voltage distortions (THD=Total Harmonic Distortion) in the system.

Depending on local conditions, line chokes may need to be inserted to reduce the voltage distortions. A line choke reduces the voltage distortion in the system by approx. 67%.

System load

	Without line choke	With line choke	Change
	4 kW inverter, line impedance 0.6 mH	4 kW inverter, line impedance 0.6 mH	**Without line choke to with line choke**
Voltage distortion (THD)	99 %	33 %	-67 %
Mains current amplitude	18.9 A	9.7 A	-48 %
Mains current effective	8.5 A	6,23 A	-27 %
Commutation notches referred to the mains voltage	28 V	8 V	-70 %
Life of the DC-link capacitors	Nominal life	2 to 3 times nominal life	+200 to 300 %

Table 3.15 Change in system load resulting from insertion of a line choke with 4 % short-circuit voltage based on the example of a 4 kW inverter CDA34.010

For more information on “System load” and “Line chokes” refer to section 6.1.

If you want to know more about “harmonics and input rectifiers” we can recommend the book entitled “Oberwellen” ("Harmonics" - German) by Albert Kloss - see the bibliography and source reference.

3.2.3 General points on the mains connection

The minimum cross-section of the mains power cable is based on the local provisions (to VDE 0100 Part 523, VDE 0298 Part 4), the ambient temperature and the specified rated current of the inverter.

Current load capacity of multi-wire cables and assignment of protective devices to VDE 0100 Part 523

Nominal cross-section in mm	Multi-wire cable (e.g. non-metallic sheathed cables or moveable cables)	
	Rated current of cable (Cu) in A	Protective device rated current in A
0.75	12	6
1.0	15	10
1.5	18	10 1)
2.5	26	20
4	34	25
6	44	35
10	61	50
16	82	63
25	108	80
35	135	100
50	168	125
70	207	160
95	250	200
120	292	250
150	335	250
185	382	315
240	453	400
300	504	400

1) For cables with only two wires under load a 16 A protective device can continue to be selected until the final specification is made.

Table 3.16 Current load capacity of multi-wire cables

Current load capacity of multi-wire cables dependent on ambient temperature to VDE 0298 Part 4

Insulating material*)	NR/SR	PVC	EPR
Permissible operating temperature	60 °C	70 °C	80 °C
Ambient temperature °C	Conversion factors		
10	1,29	1.22	1.18
15	1.22	1.17	1.14
20	1.15	1.12	1.10
25	1.08	1.06	1.05
30	1.00	1.00	1.00
35	0.91	0.94	0.95
40	0.82	0.87	0.89
45	0.71	0.79	0.84
50	0.58	0.71	0.77
55	0.41	0.61	0.71
60	-	0.50	0.63
65	-	-	0.55
70	-	-	0.45
*) At higher ambient temperatures based on manufacturer's specifications			

Table 3.17 Current load capacity of multi-wire cables dependent on ambient temperature

For more information on “current load capacity and protection of cables with PVC insulation” refer to VDE 0100 Part 430 supplement sheet 1 (11/91).

Protection of the mains power cable

Normal time-lag fuses (see Table 3.16) can be used to protect the mains power cable.[1]

The fuses must be designed in conformance with local safety standards, the matching mains voltage and the corresponding rated input current of the inverter.

If standard commercially available miniature circuit-breakers are used for protection purposes, the tripping characteristic “C” must be configured.

---

[1] The fuse does not protect the input rectifier bridge of the inverter module, it merely protects the cable.

Please note that the mains power cable and fuses used must conform to the specified listings (such as cUL).

Minimum cross-section of the grounding lead to VDE 0100 Part 540

Cross-section	PE mains connection
Mains power cable < 10 mm^2	Grounding lead (PE) cross section of at least 10 mm **or** lay a second electrical conductor parallel to the existing grounding lead, because the operational leakage current is > 3.5 mA.
Mains power cable >10 mm^2	PE conductor with cross-section of mains power cable - see VDE 0100 Part 540

Table 3.18 Minimum cross-section of the grounding lead

3.2.4 Operation of fault current breakers

In operation of the inverter, because of the internal suppression capacitors, the high clock frequencies, the parasitic capacitors, the power stage of the parasitic capacitors, the motor cable and the radio interference suppression filters the leakage current is > 3.5 mA. In individual cases it may be several hundred mA.

The inverter module must therefore always be thoroughly grounded (VDE 0100 Part 540, EN 50178) in order to conform to the provisions regarding increased leakage currents applicable above 3.5 mA.

Fault current breakers must be used in accordance with local regulations. It should however be noted that, due to the three-phase input rectifier, the leakage current contains a DC component and short-term pulse-shaped leakage currents occur on power-up.

Only all-current sensitive fault current breakers suitable for inverter operation may be used.

The fault current breaker must meet the following conditions:

- **Suitable for protection of devices with DC component in the leakage current (only with three-phase rectifier bridge)**
- **Suitable for short-term pulse-shaped leakage currents**
- **Suitable for high leakage currents**

3.2.5 Switching at the inverter input

The CDA3000 inverter modules must be connected to the mains power by way of an external mains isolator (e.g. power circuit-breaker, contactor (AC3), etc.).

The mains isolator must conform to EN 60204-1 or local safety standards.

The mains isolator must not be used to control the inverter module (in jog mode) - extensive control functions are provided for that purpose.

The inverter module may be connected to the mains every 60 seconds.
Frequent connection will not result in destruction of the input circuit on the inverter module. The inverter module protects itself by means of high-resistance through isolation inverter from the mains power. This is made possible by a special PTC precharge technique.

3.2.6 High-voltage test/Insulation test

Every shipped inverter module is tested by means of a high-voltage test for insulation resistance between the main circuit and the housing or chassis (1.9 k VDC for 1 s). It is therefore not necessary to monitor the insulation resistance of the modules.

If the insulation resistance is nonetheless to be tested, the procedure set out below should be followed:

1. **The high-voltage test must be performed prior to connection of the CDA3000 inverter.**
2. **The inputs and outputs U, V, W, +, -, RB, L1, L2 and L3 must be shorted.**
3. **The control inputs (X2, X3) and control outputs must be connected to PE.**
4. **The high-voltage test is performed by applying a maximum of 1.9 VDC for 1 second. The voltage is applied between the shorting jumper at point 2. and the shorting jumper at point 3.**

3.2.7 Forming of the DC-link capacitors

All Voltage inverters have an input current inverter (rectifier) by way of which the 50/60 Hz AC or three-phase voltage is rectified. The rectified voltage is stored in the so-called **DC-link capacitors**. The motor-side power inverter in the output circuit of the inverter reforms the DC link voltage into a new three-phase voltage system, with variable frequency (f) and voltage (u).

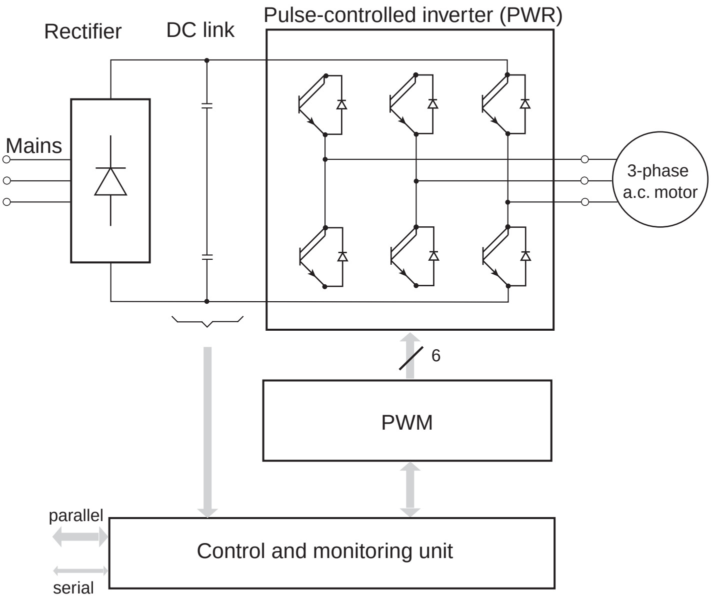


Figure 3.3 Block diagram of a voltage transformer

Forming of the DC-link capacitors

To form the DC-link capacitors the inverter modules must be connected to the mains power at 400/460 V (CDA34.xxx) approx. every 6 months for 1 hour. The time is dependent on the storage temperature: Inverter modules stored at approx. 45 °C only need be connected to the mains approx. every 8 months.

Figure 3.4 Inverter module rating plate with year and month identification

Attention: If the inverters have been left standing for more than 8 months after shipping (see rating plate) the DC-link capacitors must be reformed. This can be avoided if the inverters are connected to the mains for one hour approx. every 6 months.

Of course you can also arrange for our Service department to carry out the forming.

LUST Service Center
Gewerbestraße 7
35633 Lahnau

Tel. 06441 / 966-136
Fax 06441 / 966-211
e-mail: service@lust-tec.de

3.2.8 Direction of rotation and terminal designation

The direction of rotation is referred to the drive side.

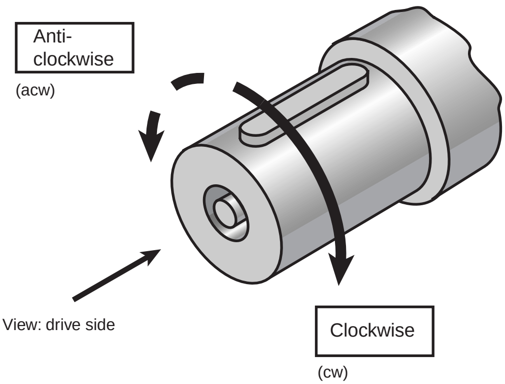


Figure 3.5 Direction of rotation

The terminals should be labeled such that the alphabetical order of the terminal designation (inverter U, V, W - motor U1, V1, W1) corresponds to the phase sequence over time of the mains voltage (L1, L2, L3) in clockwise running.

Clockwise[1]	**Terminals**		
Inverter CDA3000	U	V	W
Motor	U1	V1	W1
Anti-clockwise[2]	**Terminals**		
Inverter CDA3000	V	U	W
Motor	U1	V1	W1
1) Control signal “Clockwise 2) Control signal “Anti-clockwise”			

Table 3.19 Clockwise/anti-clockwise

3.2.9 Switching at the inverter output

The motor connected to the inverter may be isolated by means of a contactor or motor circuit-breaker. It is not possible to damage the CDA3000 inverter module by shutting down the motor.

When motor loads are shut off very high switching overvoltages occur, because the inductance of the motor does not permit stepped current changes. These switching overvoltage may also lead to fault shutdowns and/or error messages from the inverter, depending on the drive configuration. In such cases a motor choke must be inserted - see section 6.2.

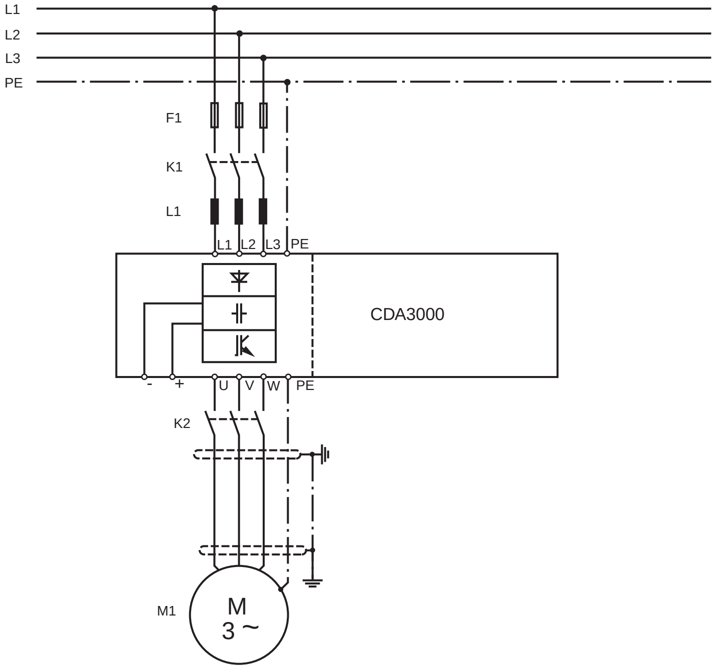


Figure 3.6 Circuitry example “Switching at the inverter output”

Multi-motor operation

Several motors can be run in parallel on one CDA3000 inverter module. In this application case motors not only need to be shut down, but also activated. For details of the operating conditions under which such cases apply refer to section 3.3.6.

Note on AC-3 contactors

Note: If contactors of usage category AC-3 are used (conforming to IEC 947-4-1, EN 60947 or VDE 0660 Part 102), the number of actuations must not exceed five per minute and 10 every 10 minutes. For higher actuating rates different switching elements should be selected accordingly.

Activation of energized motors or direct switching of the number of poles in variable-pole motors, and reversing the direction of the motor - such as by means of a reversing contactor - is not permitted during operation.

3.2.10 Short-circuit and ground fault proofing

The inverters of series CDA3000 are fitted with one current sensor per motor phase. In the event of a short-circuit or ground fault in the motor cable, the power stage is disabled and an appropriate error message is delivered.

The CDA3000 inverter modules are short-circuit and ground fault proof.

3.2.11 Motor cable length

The maximum motor cable length depends on a number of different factors (see following table).

Factor	Section
Standard EN 55011 A/B	Section 6.4
Clock frequency of power stage	Section 3.2.14
Voltage drop on the motor cable	See explanation below
Connection of a motor choke du/dt	Section 6.3

Table 3.20 Motor cable length

Voltage drop on the motor cable

In designing a drive solution it should be noted that the mains voltage can fall by 10% and the components used (line choke, inverter, motor cable, etc.) cause a voltage drop.

The system undervoltage (-10%) and the voltage drops mean that, in certain operating states, the full motor torque is not attained and the field weakening begins earlier.

Typical voltage drops

Component	Typical voltage drop referred to the respective mains voltage
Line choke with 4 % U_K	approx. 1%
Mains filter	<0.1%
Inverter module	≈3%
Motor choke	< 1%
Motor cable	$$\Delta U = \frac{1{,}6^{1)} \cdot \ell \cdot I}{56\ \frac{m}{\Omega \cdot mm2} \cdot A}$$ ℓ= Length of motor cable in [m] I = Current in [A] A = Cable cross-section in [mm^2] [1] Typical factor for inverter operation (1.73x0.9)

Table 3.21 Typical voltage drops

3.2.12 Voltage load on the motor winding

When a standard three-phase AC motor is operated on an inverter the winding insulation is subjected to higher stress than in a sinusoidal system. The reason lies in the periodic switching operations by the inverter which lead to high rates of rise of voltage (du/dt) and voltage peaks (Upeak) on the motor winding. This increased voltage load on the motor winding may shorten the service life of the motors - see the research report from the ZVEI in the "Bibliography and source reference" section.

Market practice

Technology	du/dt Typical	Problems with IEC standard motor1)	Special motors2)
Inverter technology with standard transistors (on the market for over 15 years)	3-6 kV/µs	Not known	Isolated cases known
Inverter technology with IGBTs	10-20 kV/µs	Isolated cases known	Isolated cases known
Inverter technology with IGBTs and du/dt limitation to around 6 kV/µs	3-6 kV/µs	Not known	Isolated cases known
Inverter technology with IGBTs and du/dt motor choke	< 1kV/µs	Not known	Not known

1) With vacuum-saturated winding insulation (without air bubbles) and insulated winding heads
2) Without vacuum-saturated winding insulation (with air bubbles) and without insulated winding heads

Table 3.22 Practical experience with du/dt voltage load

The rate of rise of voltage of the CDA3000 inverter modules is typically 3-6 kV/µs. For applications with special motors we provide a wide range of motor chokes (see 6.2).

Our experience shows that no problems arise in connection with IEC standard motors with vacuum-saturated windings and insulated winding heads. However, the decisive factor in each individual case is the specifications of the motor manufacturer!

3.2.13 Motor protection possibilities

The following chart presents a summary of frequently occurring overload types and the possibilities for protection offered by various devices (motor circuit-breakers, thermistor protective relays, inverter functions).

Motor protection possibilities

	A	B	C	D	C+D
Overload type	**Motor circuit-breaker (e.g. PKZM)**	**Thermistor protective relay**	**Motor-PTC monitoring of the CDA3000**	**Software function: motor protection of the CDA3000**	**Motor-PTC monitoring and motor protection of the CDA**
Overload in continuous operation 1)	●	●	●	●	●
Heavy starting 2)	●	◐ 3)	◐ 3)	●	●
Blocking 1)	●	●	●	●	●
Blocking 2)	●	◐ 3)	◐ 3)	●	●
Ambient temperature >50°C 1)	○	●	●	○	●
Impairment of cooling 1)	○	●	●	○	●
Inverter operation <50 Hz	○	●	●	◐ 4)	●

○ No protection ◐ Limited protection ● Full protection

1) The inverter and motor have the same power rating (1:1)
2) The inverter is at least four times larger than the motor (4:1)
3) Effective when motor warm, too long response time when motor cold
4) No full protection, because only the permissible current is applied as the basis

Table 3.23 Motor protection possibilities

Fuses are not included in this comparison because they only protect the cable and not the motor.

In summary: From the point of view of “motor protection” the use of additional motor circuit-breakers or thermistor protective relays is not required. All required safety functions are provided by the inverter module as standard.

3.2.14 Power reduction

The maximum permissible inverter rated current and the peak current are specified referred to 400 V mains voltage, a 10/25 m motor cable, a power stage clock frequency of 4 kHz and an ambient temperature of 45 °C.

If background conditions such as the mains voltage, motor cable length, power stage clock frequency or ambient temperature change, the max. permissible current load on the inverter modules also changes. For details of which current load on the power stage modules is permissible under which changed background conditions, refer to the following characteristic diagrams and tables.

Maximum output current as a function of mounting height

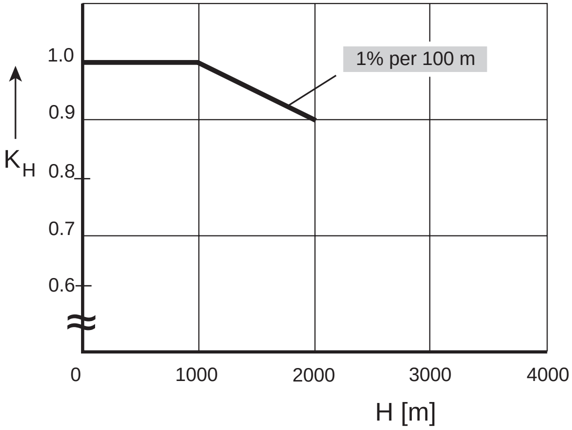


Figure 3.7 Current correction factor (KH) as a function of mounting height

Permissible rated current of the single-phase inverter modules 0.37 kW to 2.2 kW

	1 x 230 V mains voltage					
	45 °C ambient temperature 4 kHz clock frequency 10 m motor cable	**40 °C ambient temperature 8 kHz clock frequency 10 m motor cable**	**40 °C ambient temperature 16 kHz clock frequency 10 m motor cable**	**45 °C ambient temperature 4 kHz clock frequency 25 m motor cable**	**40 °C ambient temperature 8 kHz clock frequency 25 m motor cable**	**40 °C ambient temperature 16 kHz clock frequency 25 m motor cable**
Inverter modules	**Rated current [A]**	**Rated current [A]**	**Rated current [A]**	**Rated current[4)] [A]**	**Rated current[4)] [A]**	**Rated current[4)] [A]**
CDA32.003,Cx.x[1)]	2.40	2.40	2.40	2.25	2.15	2.00
CDA32.004,Cx.x[2)]	4.00	4.00	3.00	3.85	3.70	2.60
CDA32.006,Cx.x	5.60	5.40	4.00	5.45	5.25	3.85
CDA32.008,Cx.x[3)]	7.10	7.10	5.20	6.95	6.85	4.80

1) Mounted side-by-side, with no additional cooling area
2) Mounted side-by-side, with backplane (940 mm x 70 mm = 0.065 m²) as additional cooling area
3) inverter module With Heat sink “HS32.200”
4) The rated current with a 25 m motor cable is less than that with a 10 m motor cable by the amount of the current loss occurring on the motor cable (see table 3.2.7)

Table 3.24 Output current for inverter modules with 230 V power supply

Permissible rated current of three-phase inverter modules 0.75 kW to 90 kW

Inverter modules	3 x 400 V mains voltage					
	45 °C ambient temperature 4 kHz clock frequency 10 m motor cable	40 °C ambient temperature 8 kHz clock frequency 10 m motor cable	40 °C ambient temperature 16 kHz clock frequency 10 m motor cable	45 °C ambient temperature 4 kHz clock frequency 25 m motor cable	40 °C ambient temperature 8 kHz clock frequency 25 m motor cable	40 °C ambient temperature 16 kHz clock frequency 25 m motor cable
	Rated current [A]	Rated current [A]	Rated current [A]	Rated current [A]	Rated current [A]	Rated current [A]
CDA34.003,Cx.x1)	2.2	2.2	1.4	2.0	1.7	0.5
CDA34.005,Cx.x2)	4.1	4.2	2.3	3.9	3.6	1.4
CDA34.006,Wx.x	5.7	5.7	3.5	5.7	5.7	2.6
CDA34.008,Wx.x	7.8	7.8	*	7.8	*	*
CDA34.010,Wx.x	10	10	*	10	*	*
CDA34.014,Wx.x	14	14	*	14	*	*
CDA34.017,Wx.x	17	17	*	17	*	*
CDA34.024,Wx.x	24	24	*	24	*	*
CDA34.032,Wx.x	32	32	*	32	*	*
CDA34.045,Wx.x	45	45	*	45	*	*
CDA34.060,Wx.x	60	60	*	60	*	*
CDA34.072,Wx.x	72	72	*	72	*	*
CDA34.090,Wx.x	90	90	*	90	*	*
CDA34.110,Wx.x	110	110	*	110	*	*
CDA34.143,Wx.x	143	143	*	143	*	*
CDA34.170,Wx.x	170	170	*	170	*	*

* Not available at time of going to press

1) Mounted side-by-side, with no additional cooling area

2) Mounted side-by-side with heat sink “HS32.200” or with 0.3 m² backplane

Table 3.25 Output current for inverter modules with 400 V power supply

	3 x 460 V mains voltage					
Inverter modules	**45 °C ambient temperature 4 kHz clock frequency 10 m motor cable Rated current [A]**	**40 °C ambient temperature 8 kHz clock frequency 10 m motor cable Rated current [A]**	**40 °C ambient temperature 16 kHz clock frequency 10 m motor cable Rated current [A]**	**45 °C ambient temperature 4 kHz clock frequency 25 m motor cable Rated current [A]**	**40 °C ambient temperature 8 kHz clock frequency 25 m motor cable Rated current [A]**	**40 °C ambient temperature 16 kHz clock frequency 25 m motor cable Rated current [A]**
CDA34.003						
CDA34.005						
CDA34.006						
CDA34.008						
CDA34.010						
CDA34.014						
CDA34.017						
CDA34.024						
CDA34.032						
CDA34.045						
CDA34.060						
CDA34.072						
CDA34.090						
CDA34.110						
CDA34.143						
CDA34.170						

*Not available
at time of going to press.*

Table 3.26 Output current for inverter modules with 460 V power supply

Current characteristic, CDA32.003,Cx.x (0.37 kW)

Cooling method:	Cold plate without additional cooling area
Motor cable length:	10 m
Rated current:	2.4 A
Switching frequency of power stage:	4, 8, 16 kHz
Mounting type:	side-by-side
Mounting height:	1000 m

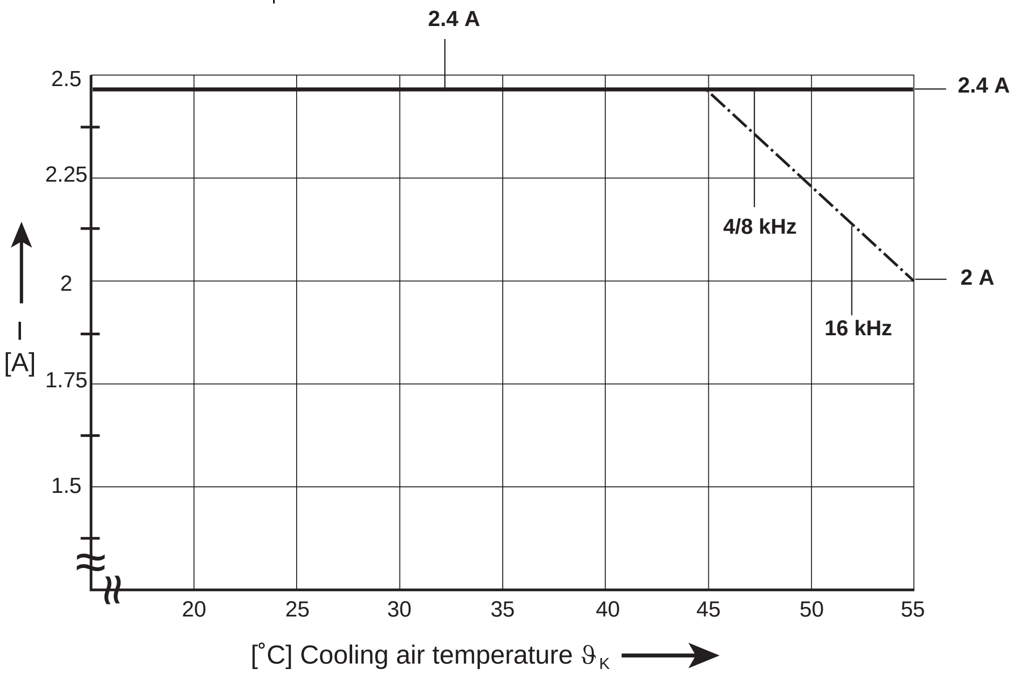


Figure 3.8 Max. current load of the CDA32.003,Cx.x / 0.37 kW / side-by-side / without additional cooling area

Current characteristic, CDA32.004,Cx.x (0.75 kW)

Cooling method:	Cold plate without additional cooling area
Motor cable length:	10 m
Rated current:	4 A
Switching frequency of power stage:	4, 8, 16 kHz
Mounting type:	side-by-side
Mounting height:	1000 m

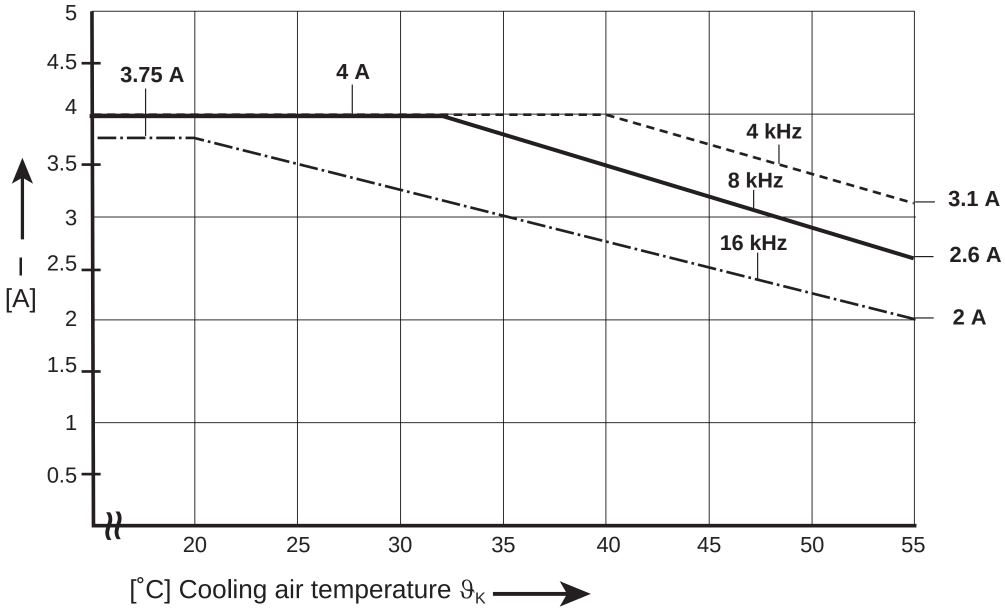


Figure 3.9 Max. current load of the CDA32.004,Cx.x / 0.75 kW / side-by-side / without additional cooling area

Current characteristic, CDA32.004,Cx.x (0.75 kW)

Cooling method:	Cold plate with backplane (0.065 m^2) as additional cooling area
Motor cable length:	10 m
Rated current:	4 A
Switching frequency of power stage:	4, 8, 16 kHz
Mounting type:	side-by-side
Mounting height:	1000 m

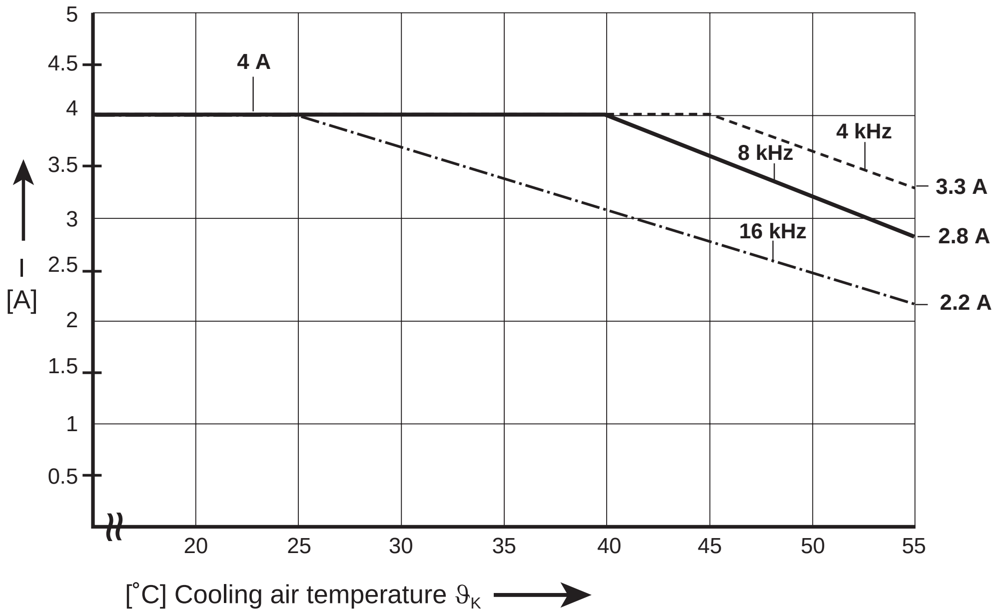


Figure 3.10 *Max. current load of the CDA32.004,Cx.x / 0.75 kW / side-by-side /* with backplane (0.065 m) as additional cooling area

Current characteristic, CDA32.008,Cxx (1.5 kW)

Cooling method:	Cold plate without additional cooling area
Motor cable length:	10 m
Rated current:	7.1 A
Switching frequency of power stage:	4, 8, 16 kHz
Mounting type:	side-by-side
Mounting height:	1000 m

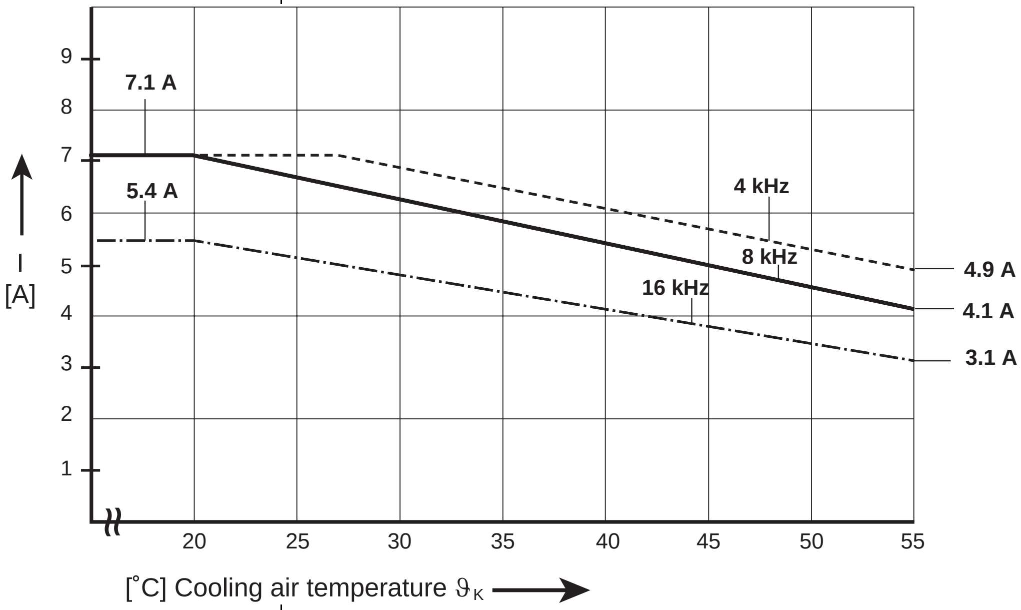


Figure 3.11 Max. current load of the CDA32.008,Cx.x / 1.5 kW / side-by-side / without additional cooling area

Current characteristic, CDA32.008,Cxx (1.5 kW)

Cooling method:	Cold plate with heat sink HS32.200
Motor cable length:	10 m
Rated current:	7.1 A
Switching frequency of power stage:	4, 8, 16 kHz
Mounting type:	side-by-side
Mounting height:	1000 m

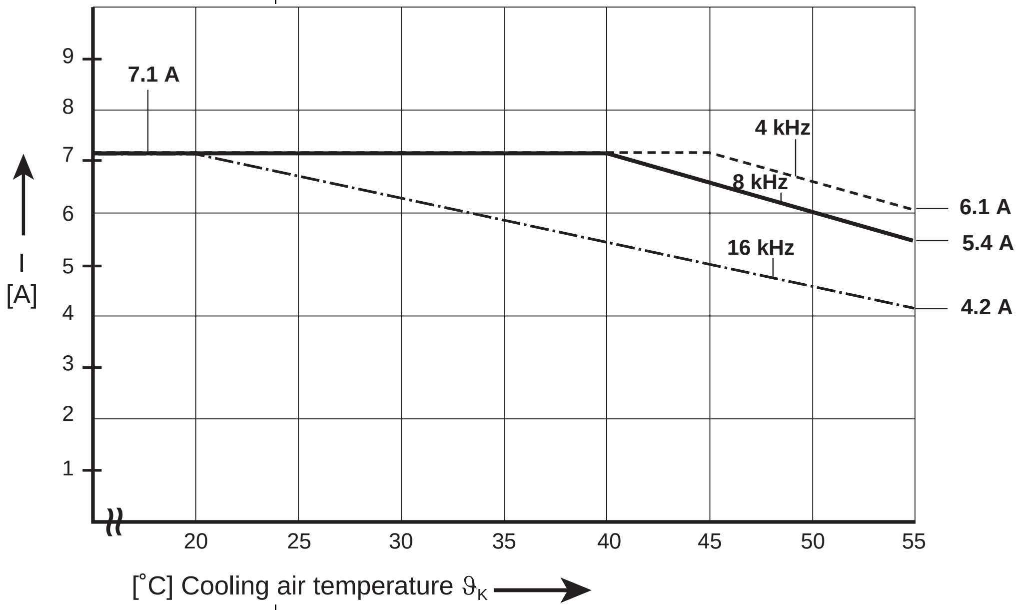


Figure 3.12 Max. current load of the CDA32.008,Cx.x / 1.5 kW / side-by-side with 20 mm clearance between the units / with accessory heat sink HS32.200

Current characteristic, CDA32.008,Cxx (1.5 kW)

Cooling method:	Cold plate with backplane (0.3 m) as additional cooling area
Motor cable length:	10 m
Rated current:	7.1 A
Switching frequency of power stage:	4, 8, 16 kHz
Mounting type:	not side-by-side
Mounting height:	1000 m

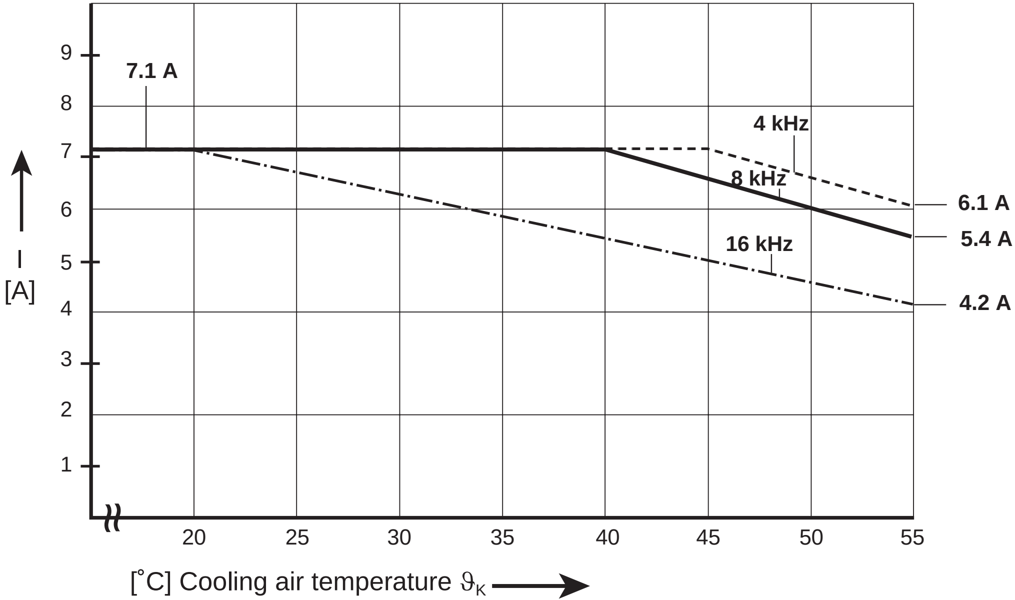


Figure 3.13 *Max. current load of the CDA32.008,Cx.x / 1.5 kW / not side-by-side / with backplane (0.3 m^2) as additional cooling area*

Current characteristic, CDA34.003,Cxx (0.75 kW)

Cooling method:	Cold plate without additional cooling area
Motor cable length:	10 m
Rated current:	2.2 A
Switching frequency of power stage:	4, 8, 16 kHz
Mains voltage:	3 x 400 V
Mounting type:	side-by-side
Mounting height:	1000 m

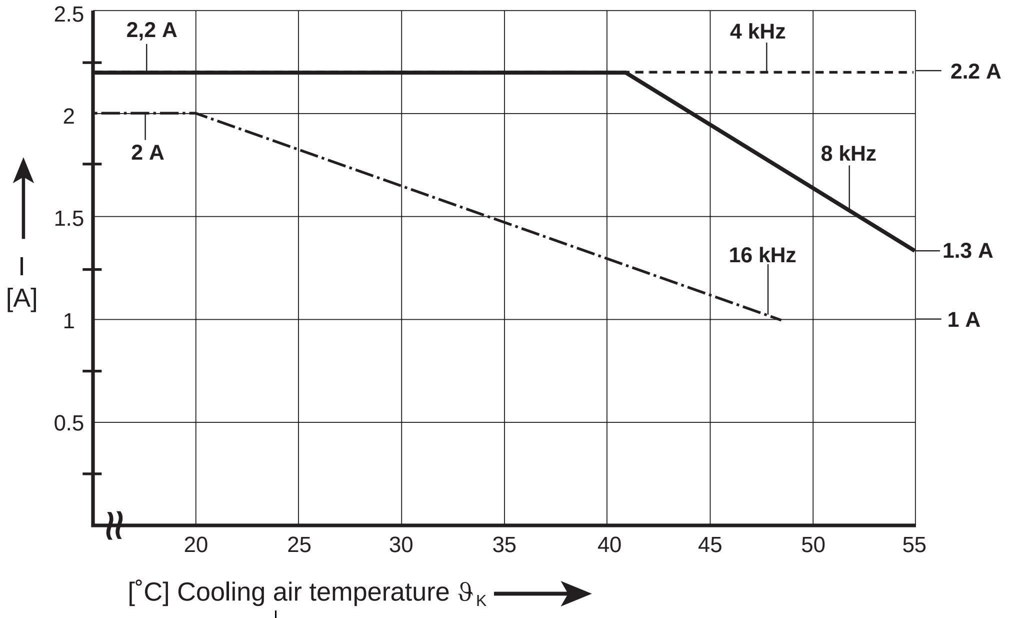


Figure 3.14 *Max. current load of the CDA34.003,Cx.x / 0.75 kW / side-by-side / without additional cooling area / mains voltage 3 x 400 V*

Current characteristic, CDA34.003,Cxx (0.75 kW)

Cooling method:	Cold plate without additional cooling area
Motor cable length:	10 m
Rated current:	2.2 A
Switching frequency of power stage:	4, 8, 16 kHz
Mains voltage:	3 x 460 V
Mounting type:	side-by-side
Mounting height:	1000 m

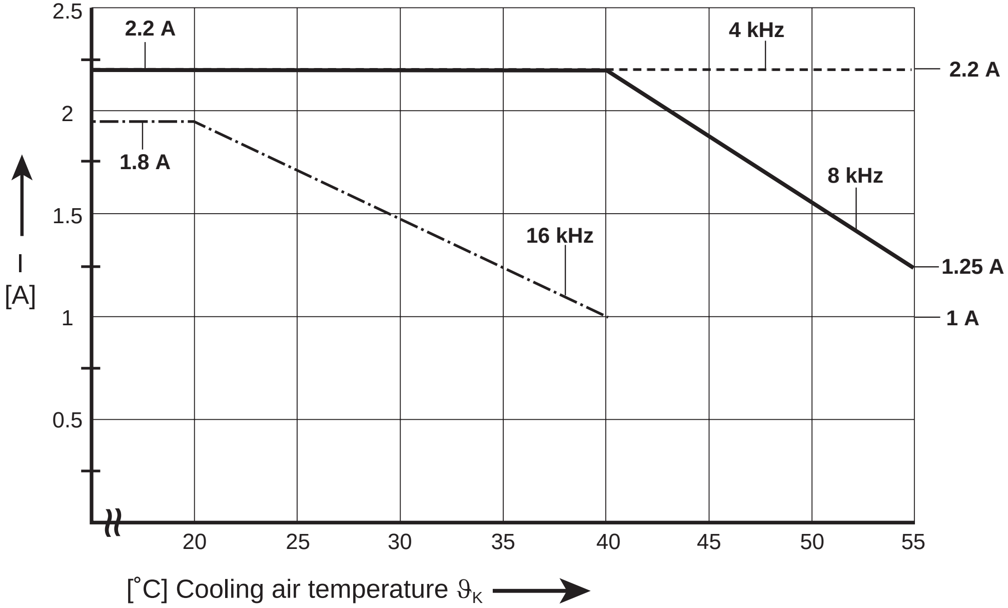


Figure 3.15 *Max. current load of the CDA34.003,Cx.x / 0.75 kW / side-by-side / without additional cooling area / mains voltage 3 x 460 V*

Current characteristic, CDA34.005,Cxx (1.5 kW)

Cooling method:	Cold plate without additional cooling area
Motor cable length:	10 m
Rated current:	4.1 A
Switching frequency of power stage:	4, 8, 16 kHz
Mains voltage:	3 x 400 V
Mounting type:	side-by-side
Mounting height:	1000 m

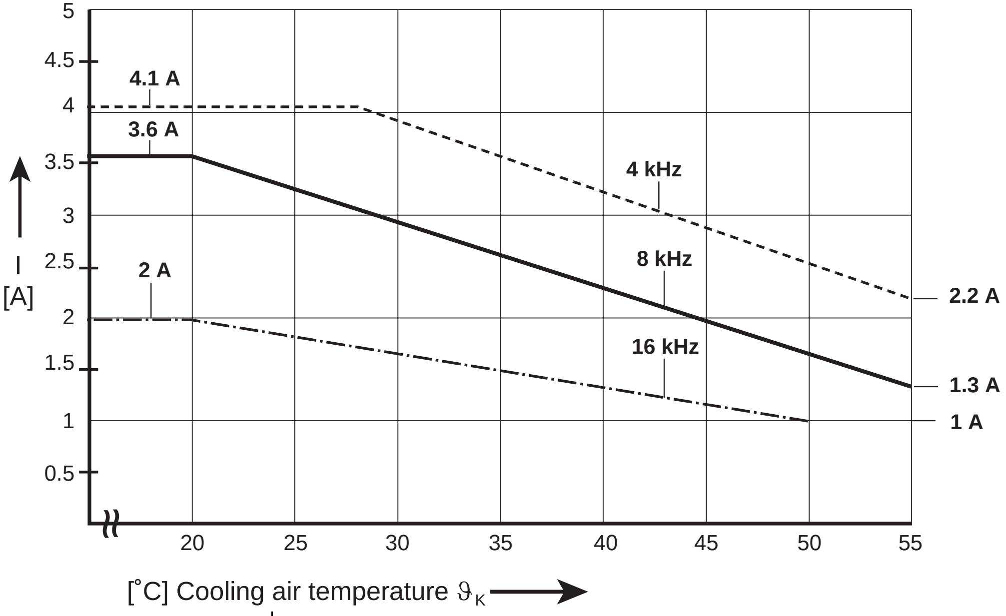


Figure 3.16 Max. current load of the CDA34.005,Cx.x / 1.5 kW / side-by-side / without additional cooling area / mains voltage 3 x 400 V

Current characteristic, CDA34.005,Cxx (1.5 kW)

Cooling method:	Cold plate without additional cooling area
Motor cable length:	10 m
Rated current:	4.1 A
Switching frequency of power stage:	4, 8, 16 kHz
Mains voltage:	3 x 460 V
Mounting type:	side-by-side
Mounting height:	1000 m

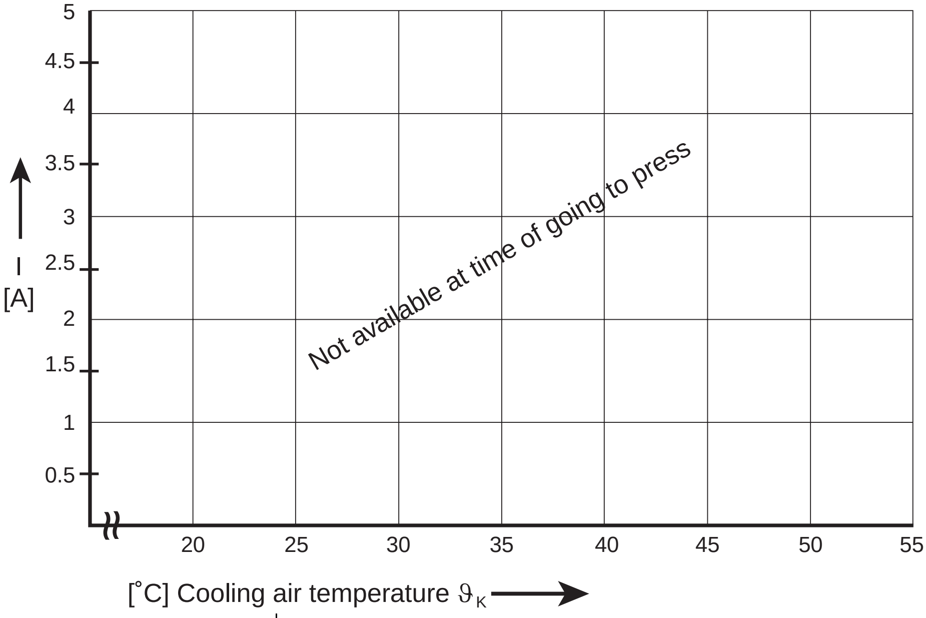


Figure 3.17 Max. current load of the CDA34.035,Cx.x / 1.5 kW / side-by-side / without additional cooling area / mains voltage 3 x 460 V

Current characteristic, CDA34.005,Cxx (1.5 kW)

Cooling method: Cold plate with additional heat sink HS32.200
Motor cable length: 10 m
Rated current: 4.1 A
Switching frequency
of power stage: 4, 8, 16 kHz
Mains voltage: 3 x 400 V
Mounting type: side-by-side
Mounting height: 1000 m

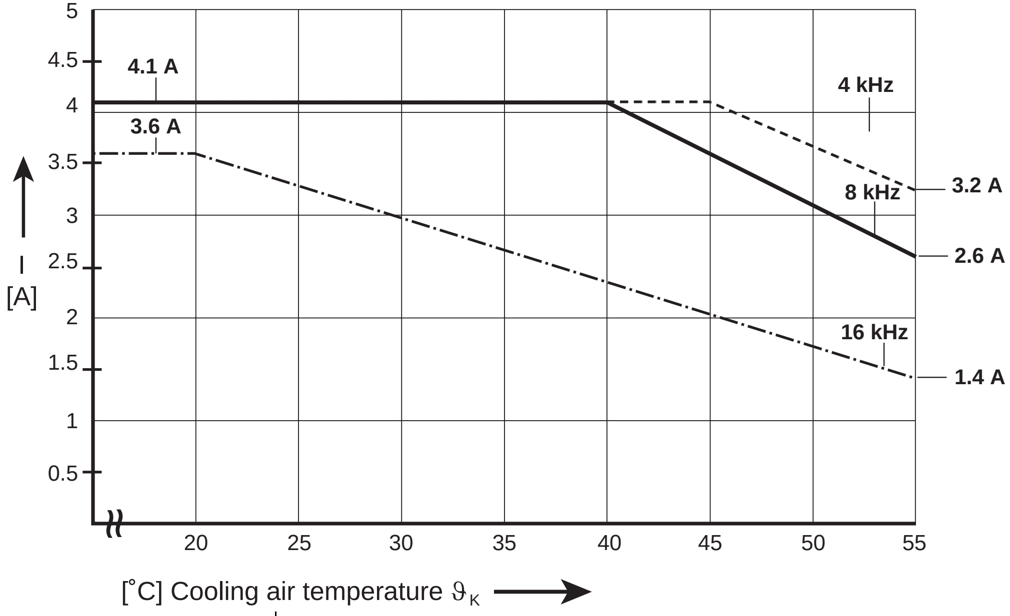


Figure 3.18 Max. current load of the CDA34.035,Cx.x / 1.5 kW / side-by-side / with additional heat sink HS32.200 / mains voltage 3 x 400 V

Current characteristic, CDA34.005,Cxx (1.5 kW)

Cooling method:	Cold plate with additional heat sink HS32.200
Motor cable length:	10 m
Rated current:	4.1 A
Switching frequency of power stage:	4, 8, 16 kHz
Mains voltage:	3 x 460 V
Mounting type:	side-by-side
Mounting height:	1000 m

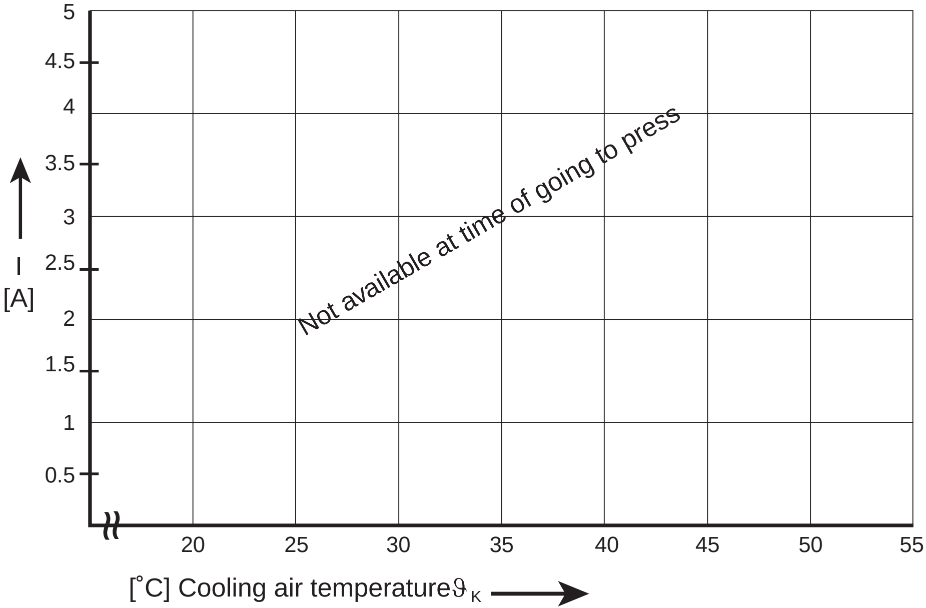


Figure 3.19 *Max. current load of the CDA34.035,Cx.x / 1.5 kW / side-by-side / with additional heat sink HS32.200 / mains voltage 3 x 460 V*

Current characteristic, CDA34.005,Cxx (1.5 kW)

Cooling method:	Cold plate with backplane (0.3 m^2) as additional cooling area
Motor cable length:	10 m
Rated current:	4.1 A
Switching frequency of power stage:	4, 8, 16 kHz
Mains voltage:	3 x 400 V
Mounting type:	not side-by-side
Mounting height:	1000 m

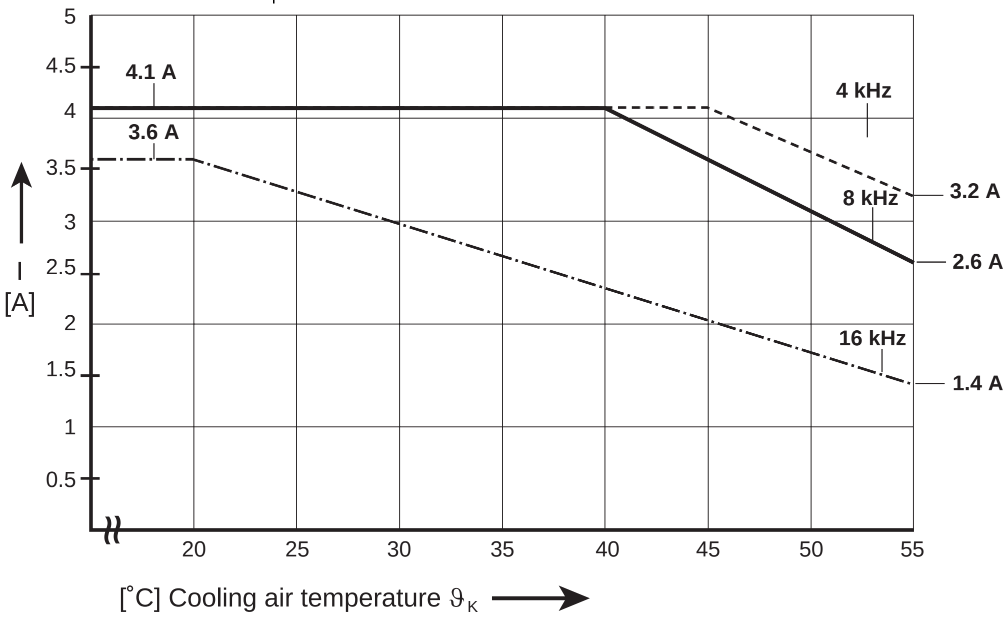


Figure 3.20 *Max. current load of the CDA 34.005,Cx.x / 1.5 kW / not side-by-side / with backplane as additional cooling area / mains voltage 3 x 400 V*

Current characteristic, CDA34.005,Cxx (1.5 kW)

Cooling method:	Cold plate with backplane (0.3 m^2) as additional cooling area
Motor cable length:	10 m
Rated current:	4.1 A
Switching frequency of power stage:	4, 8, 16 kHz
Mains voltage:	3 x 460 V
Mounting type:	not side-by-side
Mounting height:	1000 m

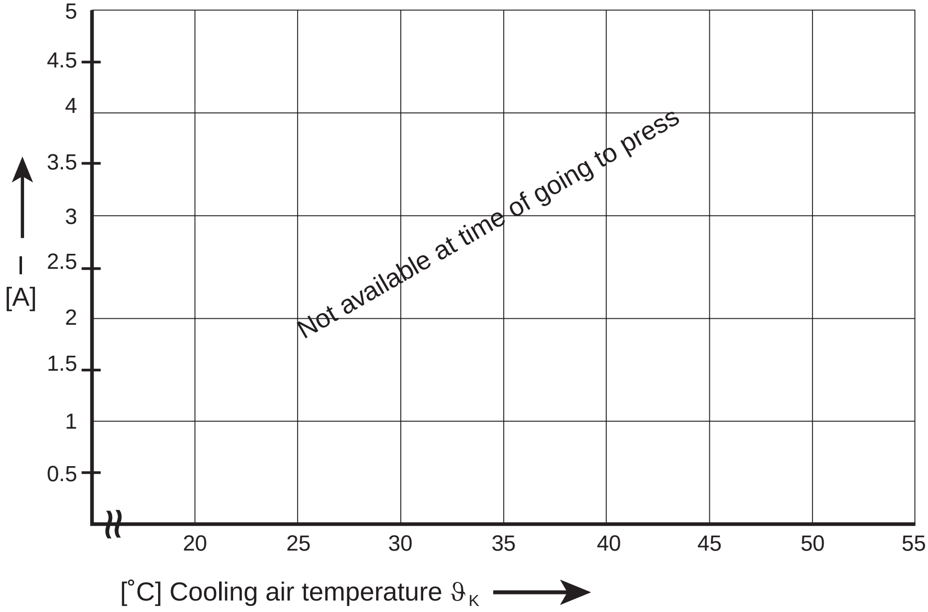


Figure 3.21 *Max. current load of the CDA 34.005,Cx.x / 1.5 kW / not side-by-side / with backplane as additional cooling area / mains voltage 3 x 460 V*

Current characteristic, CDA34.006,Wxx (2.2 kW)

Cooling method:	Wall mounting
Motor cable length:	10 m
Rated current:	5.7 A
Switching frequency of power stage:	4, 8, 16 kHz
Mains voltage:	3 x 400 V
Mounting type:	side-by-side
Mounting height:	1000 m

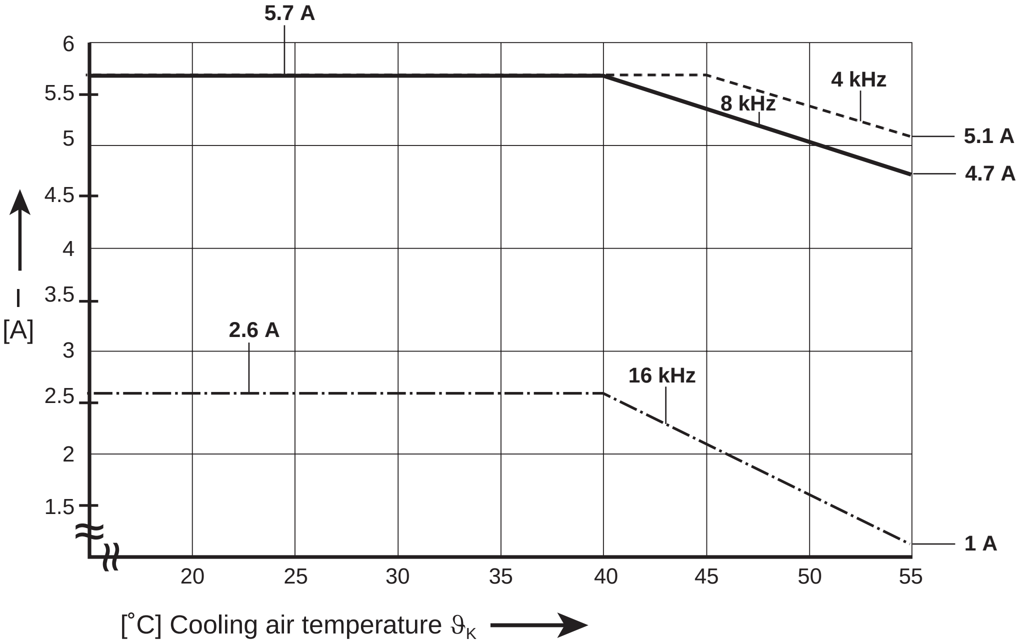


Figure 3.22 Max. current load of the CDA 34.006,Wx.x / 2.2 kW / side-by-side / wall mounting / mains voltage 3 x 400 V

Current characteristic, CDA34.006,Wxx (2.2 kW)

Cooling method:	Wall mounting
Motor cable length:	10 m
Rated current:	5.7 A
Switching frequency of power stage:	4, 8 kHz
Mains voltage:	3 x 460 V
Mounting type:	side-by-side
Mounting height:	1000 m

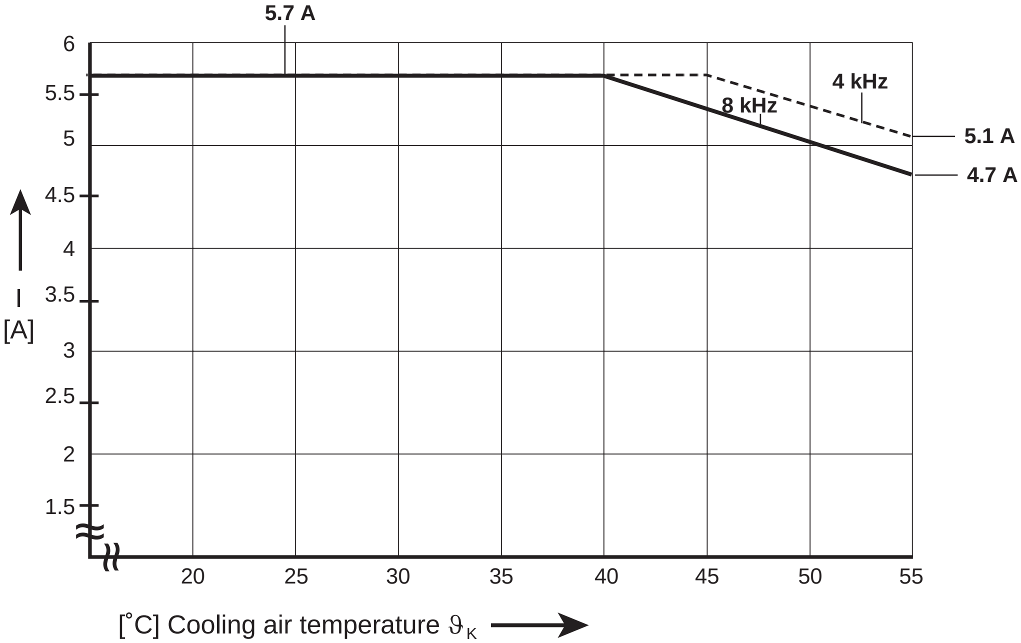


Figure 3.23 *Max. current load of the CDA 34.006,Wx.x / 2.2 kW / side-by-side / wall mounting / mains voltage 3 x 460 V*

Current characteristic, CDA34.008,Wxx (3 kW)

Cooling method:	Wall mounting
Motor cable length:	10 m
Rated current:	7.8 A
Switching frequency of power stage:	4, 8, 16 kHz
Mains voltage:	3 x 400 V
Mounting type:	side-by-side
Mounting height:	1000 m

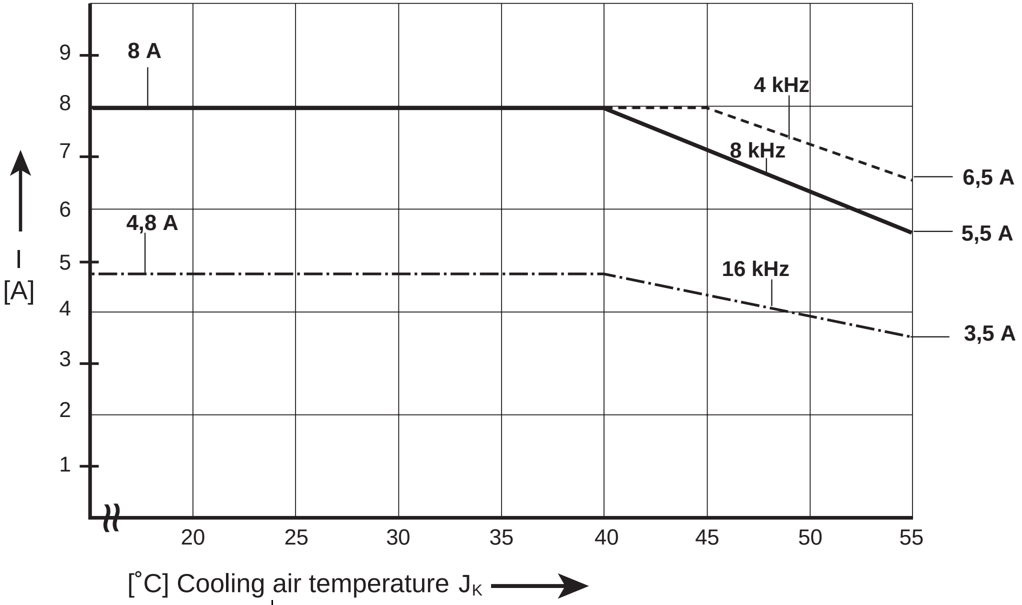


Figure 3.24 Max. current load of the CDA 34.008,Wx.x / 3 kW / side-by-side / wall mounting / mains voltage 3 x 400 V

Current characteristic, CDA34.010,Wxx (4 kW)

Cooling method:	Wall mounting
Motor cable length:	10 m
Rated current:	10 A
Switching frequency of power stage:	4, 8, 16 kHz
Mains voltage:	3 x 400 V
Mounting type:	side-by-side
Mounting height:	1000 m

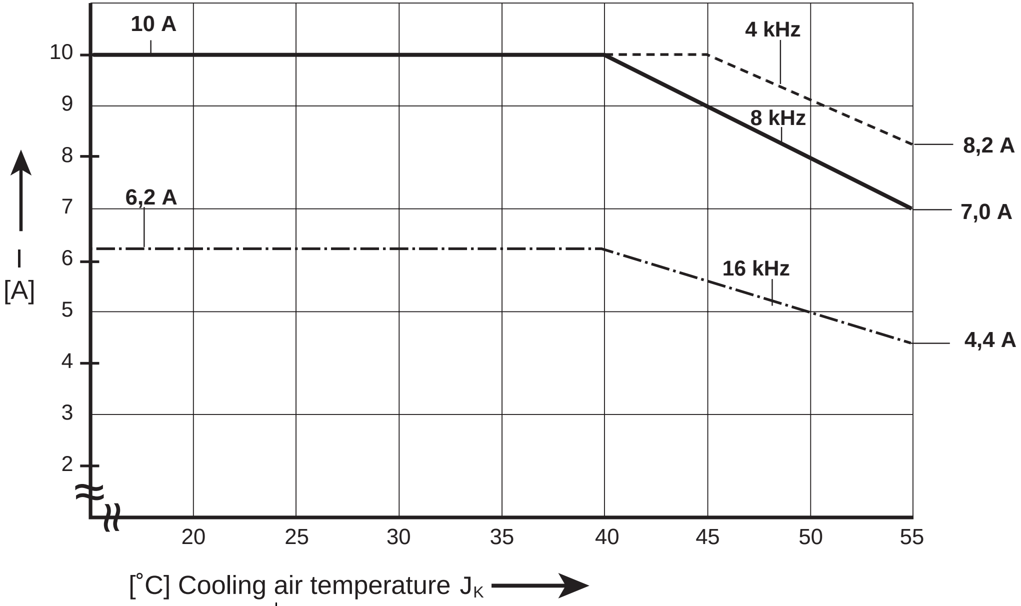


Figure 3.25 *Max. current load of the CDA 34.010,Wx.x / 4 kW / side-by-side / wall mounting / mains voltage 3 x 400 V*

Current characteristic, CDA34.010,Wxx (4 kW)

Cooling method:	Wall mounting
Motor cable length:	10 m
Rated current:	10 A
Switching frequency of power stage:	4, 8 kHz
Mains voltage:	3 x 460 V
Mounting type:	side-by-side
Mounting height:	1000 m

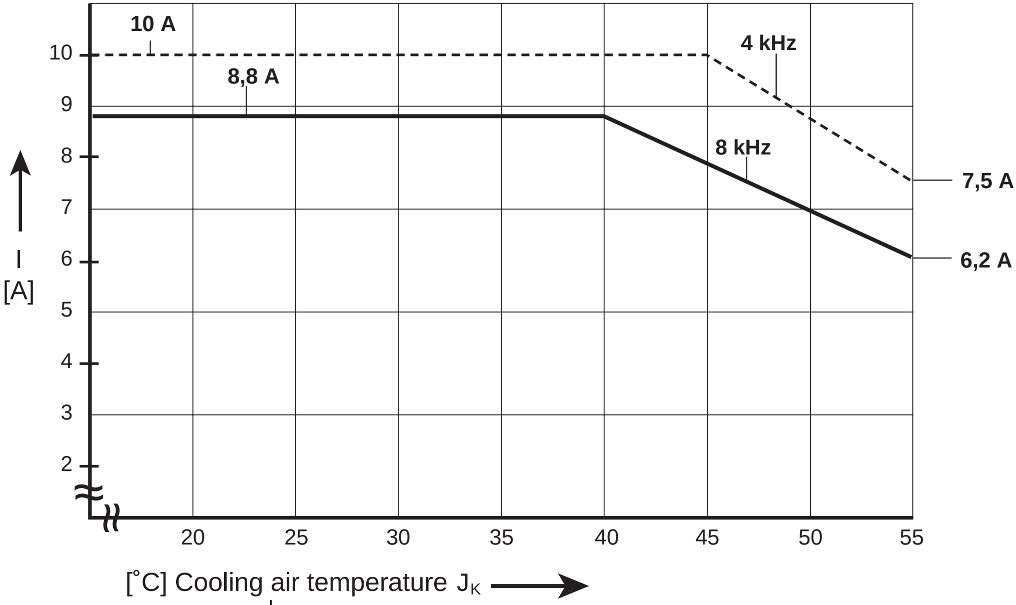


Figure 3.26 Max. current load of the CDA 34.010,Wx.x / 4 kW / side-by-side / wall mounting / mains voltage 3 x 460 V

The current characteristics of the other inverter modules
were not available at the time of going to press

Long motor cables

The specified rated currents relate to the current still available at the end of a 10/25 m long motor cable; see Table 3.24 to Table 3.26. If the motor cable is longer than 10/25 m, the current losses resulting from the additional motor cable length must be taken into account.

Clock Frequency	Mains voltage 1 x 230 V		Mains voltage 1 x 400 V		Mains voltage 1 x 460 V	
	Motor choke		Motor choke		Motor choke	
	without [mA per m]	with [mA per m]	without [mA per m]	with [mA per m]	without [mA per m]	with [mA per m]
4	10	*	15	*	20	*
8	15	*	30	*	40	*
16	25	*	60	*	70	*
* Not available at time of going to press						

Table 3.27 Current losses on motor cable dependent on clock frequency

Table 3.27 applies to motor cable lengths up to 150 m.

3.2.15 Calculation of effective inverter capacity utilization

The CDA3000 inverter modules have an overload capability of typically 1.8 x I_N for 30 s (1.5 x I_N for 60 s).

Calculation of effective inverter capacity utilization

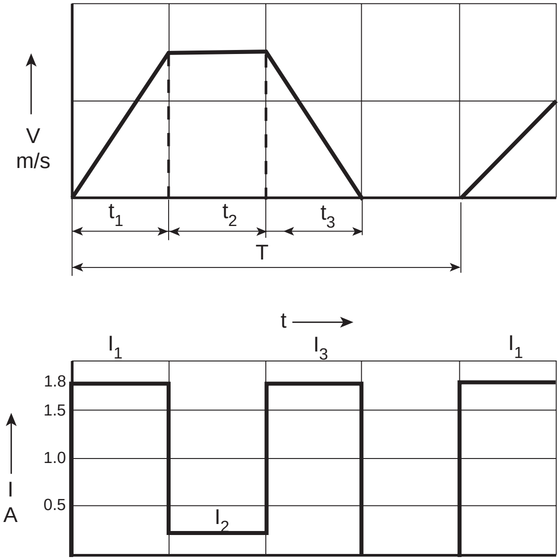


Figure 3.27 Effective inverter capacity utilization

$$I_{eff} = \sqrt{\frac{I_1^2 \cdot t_1 + I_2^2 \cdot t_2 + I_2^2 \cdot t_3}{T}}$$

The inverter module is defined by $I_{eff} < I_{N\text{-}Inverter}$. The condition $[I_{Load}^2 - I_{N\ Inverter}^2] \times t_{Overload} < 75A^2s$ must additionally be met, otherwise the inverter module will shut down due to overload.

For ease of effective value calculation we recommend the LUDRIVE drive dimensioning program.

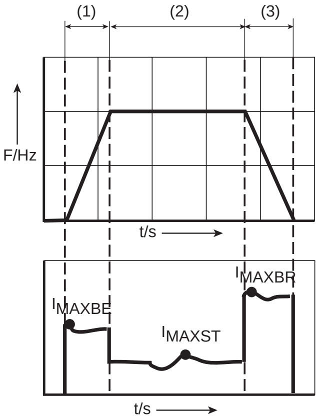
Calculation examples

Appli-cation	Acceleration		Current at V = constant		Deceleration		Stopping time	Effective inverter capacity utilization	Permissible	
	Current	Time	Current	Time	Current	Time			Yes	No
1	$1.8 \cdot I_N$	15 s	0	0	$1.8 \cdot I_N$	15 s	70 s	$I_{eff} \leq I_N$	X	
2	$1.8 \cdot I_N$	15 s	$0.3 \cdot I_N$	75 s	$1.8 \cdot I_N$	15 s	0 s	$I_{eff} \leq I_N$	X	
3	$1.5 \cdot I_N$	30 s	0	0	$1.5 \cdot I_N$	30 s	80 s	$I_{eff} \leq I_N$	X	
4	$1.5 \cdot I_N$	1 s	$0.7 \cdot I_N$	3 s	$1.5 \cdot I_N$	1 s	1 s	$I_{eff} \leq I_N$	X	
5	$1.8 \cdot I_N$	0.2 s	$0,2 \cdot I_N$	0.5 s	$1.8 \cdot I_N$	0.2 s	0.45 s	$I_{eff} \leq I_N$	X	
6	$1.8 \cdot I_N$	0.2 s	$0.3 \cdot I_N$	0.3 s	$1.8 \cdot I_N$	0.2 s	0.2 s	$I_{eff} \geq I_N$		X
7	$1.8 \cdot I_N$	0.1 s	$0.3 \cdot I_N$	0.3 s	$1.8 \cdot I_N$	0.1 s	0.2 s	$I_{eff} \leq I_N$	X	
8	$1.7 \cdot I_N$	0.1 s	0	0	$1.7 \cdot I_N$	0.1 s	0.4 s	$I_{eff} \leq I_N$	X	

Table 3.28 Calculation example for the effective inverter current

Software function: “Device capacity utilization”

To enable the calculation to be checked, the inverter module provides a peak current value storage facility for checking of the drive dimensioning as a standard feature in the “Device capacity utilization” software function. When the values have been read they can be reset.



(1) Acceleration (max. acceleration current in parameter I_{MAXBE})
(2) Stationary operation (max. current in stationary operation in parameter I_{MAXST})
(3) Braking (max. braking current in parameter I_{MAXBR})

Figure 3.28 Peak current value storage for checking of drive dimensioning

The peak current value memory continuously stores the absolute peak values in the acceleration, stationary operation and braking phases. The mean device capacity utilization can also be ascertained.

3.2.16 Measurement on the inverter module

Measurement on the inverter module is **not** necessary, because the inverter delivers all required actual values. Actual values such as:

- Motor frequency
- Motor speed
- Motor apparent current
- Motor active current
- Motor apparent power
- Motor active power
- Motor voltage
- DC-link voltage
- Motor temperature
- Heat sink temperature
- Device interior temperature
- etc.

are available. The actual values can be called up by way of the KP200 control unit or the DriveManager user software (with the digital scope function).

If measurements are nevertheless to be taken on the CDA3000, the following conditions must be met.

Measurement on the CDA3000 inverter module

Because of the non-sinusoidal variables at the input and output of the inverter, only measurements with special measuring equipment are permitted. Since such equipment is not usually available to practicians on-site, conventional measuring equipment can be used as a fallback. A measuring circuit with device data is shown in Figure 3.29 on the following page. However, it should be made clear that the measuring device displays - in particular at the inverter output - are only guide values.

When using an oscilloscope to represent the pulsed voltage, measurements should be taken with differential inputs.

In all measurement operations you should remember that the DC-link capacitor on the voltage transformer may still be live long after the device has been shut off.

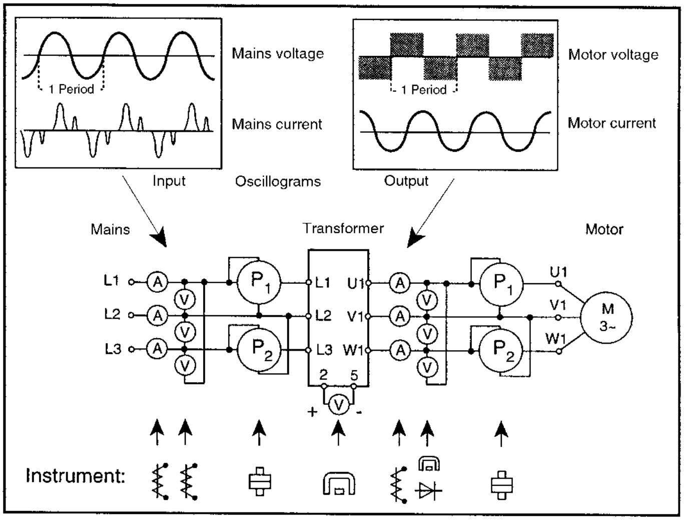


Figure 3.29 Measuring circuit for a voltage inverter (suggested configuration) with oscillograms (block diagrams)

3.3 Special applications

3.3.1 Project planning for three-phase AC motors

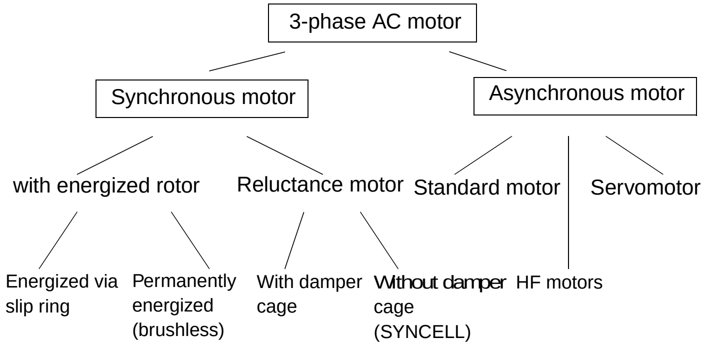
A wide variety of three-phase AC motors can be run on the CDA3000 inverter system. Three-phase AC motors are manufactured in synchronous and asynchronous design versions. The stator winding is designed such that, when in service in a three-phase AC system, a rotating field is created in the motor which drives the rotor. The rotation speed is determined by the following variables:

$$n_s = \frac{f \cdot 60}{P}$$

n_s = synchronous speed
P = number of pole pairs
f = stator frequency

The motor type is determined by the rotor introduced into the rotating field.

Overview of three-phase AC motors



Areas of application for three-phase AC motors

Motor type	Working principle	Application
Standard three-phase AC motor	asynchronous	In all industrial sectors. Around 10-15% of all motors are speed-adjustable by way of inverters.
Synchronous motor	synchronous	In the textile industry for: Spoolers, viscose pumps, galette drives or roller drives etc. Further areas of application are in the glass and paper industry as winding drives, etc.
Reluctance motor	asynchronous/ synchronous	In the textile industry for: Spoolers, viscose pumps, galette drives or roller drives etc. Further areas of application are in drafting equipment and for synchronous running of two axles.
High-frequency motor	asynchronous	In the timber processing industry as the main drive. Further areas of application are grinding and milling spindles, centrifuges, vacuum pumps and winders.
Asynchronous servomotor	asynchronous	In the packaging and food industries as a clock and positioning drive. Further applications as the main drive for machine tools.
Displacement-type armature motor	asynchronous with motor brake	In conveyor systems as a traction and lifting motor.

Table 3.29 Areas of application for three-phase AC motors

Project planning notes for three-phase AC motors

Motor type	Project planning notes
Standard three-phase AC motor	See section 2.5.1 and 3.3
Asynchronous servomotor	See section 2.5.2
Displacement-type armature motor	In a displacement-type armature motor the brake is ventilated by the magnetic field of the motor. The motor must always be run with the VFC control method. The “Current injection” software function must be adapted. **Note:** A high current flows when the motor is idling. Operation at low speeds is only permissible for short periods of time.
Reluctance motor	The reluctance motor is a special motor which must be tested anew prior to every production deployment (See section 2.5.3).
Synchronous motor	The synchronous motor is likewise a special motor which must be tested anew prior to every production deployment (See section 2.5.4).
High-frequency motors (HF motors)	HF motors are usually run with constant torque, at high frequencies up to 1600 Hz. For more information See section 2.5.5.

Table 3.30 Project planning notes for synchronous and asynchronous three-phase AC motors

3.3.2 Efficiency of the motor control methods

During commissioning of the inverter module three different motor control methods can be selected. The asynchronous motor is identified automatically by the inverter module based on the “plug-and-play” principle. All control loops are optimized in the process.

Voltage Frequency Control (VFC)

With VFC the voltage of the motor is modified proportional to the output frequency of the inverter module. This method is particularly suitable for reluctance motors, synchronous motors and special motors.

Sensorless Flux Control (SFC)

The new control method SFC, applicable to asynchronous motors, calculates the rotor speed and the current angle of the rotor from the electrical variables. Based on the calculated information, the currents to form the torque can be fed into the motor in a favorable way. In this way, outstanding control characteristics are attained even without the use of a cost-intensive encoder.

Field-Oriented Regulation (FOR)

In FOR the rotor and speed positions are ascertained with an encoder. Based on those measurement variables, the flux- and torque-forming currents can always be fed into the motor in optimum positions relative to each other. This produces maximum dynamics and smoothness.

General characteristics of the motor control methods	**VFC Voltage Frequency Control**	**SFC Sensorless Flux Control**	**FOR Field-Oriented Regulation**
Torque rise time	approx. 10 ms	<2 ms	< 2ms
Dynamic disturbance correction	NO	YES	YES
Standstill torque	NO	NO	YES
Correction time for a load surge of 1 x M_N	<100 ms	<100 ms	<100 ms
Anti-stall protection	limited	YES	YES
Speed manipulating range $M_{Const.}$	1:20	1:50	>1:10000
Static speed accuracy n/ n_N	<2%	<1%	quartz-accurate
Frequency resolution	0.01 Hz	0.0625 Hz	2^{-16} Hz
Motor principle	asynchronous synchronous reluctance	asynchronous	asynchronous
Multi-motor operation	yes	no	no
Encoder evaluation	no	no	yes

Table 3.31 Efficiency of the motor control methods with standard three-phase AC motor

Break-away and acceleration torques dependent on motor control method

Property	VFC Voltage Frequency Control	SFC Sensorless Flux Control	FOR Field-Oriented Regulation
Break-away torque[1] with standard motor (U_N = 400 V)	1.6 x M_N	1.8 x M_N	2 x M_N
Break-away torque[1] with servomotor (U_N = 330 V)	2.5 x M_N	2.6 x M_N	2.8 x M_N
Acceleration torque[1] with standard motor (U_N = 400 V)	1,2 x M_N	1.8 x M_N	2 x M_N
Acceleration torque[1] with servomotor (U_N = 330 V)	1.6 x M_N	1.8 x M_N	2 x M_N

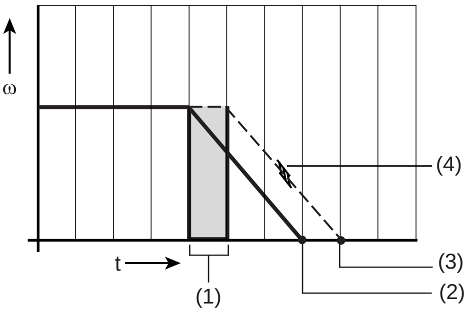
[1] $I_{Inverter}$ = 2 x I_{Motor}

Table 3.32 Break-away and acceleration torques

The table above indicates what typical torque is available on the motor shaft of an asynchronous machine when the machine is driven by a CDA3000 inverter module. The maximum motor rated current is limited by the inverter module to 2 x $I_{N\text{-}Motor}$.

For data relating to the servomotors refer to section 2.5.2.

Positioning accuracy with Start/Stop operation as a function of motor control method



$\varphi_F = \omega \cdot\cdot\ t_{RF}$

φ_F = Positioning error in °

ω = Velocity in mm/s

tRF = Response error (terminal scan cycle) in s

(1)	Scan cycle of control terminals (CDA3000 = 1 ms) on inverter (t_{RF}=response error)	
(2)	Destination position 1	(stop signal comes together with read-in of control signals on inverter)
(3)	Destination position 2	(Stop signal comes directly after read-in of control signals on inverter)
(4)	Slip range	(depending on control mode the braking ramp is slip-dependent)

Figure 3.30 Start/stop positioning

Property	VFC Voltage Frequency Control	SFC Sensorless Flux Control	FOR Field-Oriented Regulation
Braking time 100 ms, external moment of inertia = motor moment of inertia			
Standard motor (U_N = 400 V) 1500 rpm to 0 rpm	10°	9°	9°
Standard motor (U_N = 400 V) 1500 rpm to 0 rpm	4°	4°	3°
Servomotor (U_N = 330 V) 1500 rpm to 0 rpm	12°	10°	8°
Servomotor (U_N = 330 V) 1500 rpm to 0 rpm	6°	5°	4°
Braking time 500 ms, external moment of inertia = motor moment of inertia			

Table 3.33 Typical positioning errors referred to the motor shaft in °

Property	VFC Voltage Frequency Control	SFC Sensorless Flux Control	FOR Field-Oriented Regulation
Standard motor (U_N = 400 V) 1500 rpm to 0 rpm	9°	9°	9°
Standard motor (U_N = 400 V) 1500 rpm to 0 rpm	4°	4°	3°
Servomotor (U_N = 330 V) 1500 rpm to 0 rpm	12°	10°	8°
Servomotor (U_N = 330 V) 1500 rpm to 0 rpm	6°	5°	4°
Values referred to the motor shaft			

Table 3.33 Typical positioning errors referred to the motor shaft in °

10° positioning error, referred to the motor shaft, is equivalent to a positioning error of a traction drive (i=20, drive pinion 60 mm) of ±0.15 mm. For more information on start/stop operation refer to section 1.3.3.

$$\Delta_S = \frac{\pi \cdot d \cdot 10°}{360° \cdot i} = [mm]$$

d = Diameter of drive pinion in mm

3.3.3 Standard inverter operation

Initial commissioning automatically optimizes the control circuits such that, with inverter output assigned equal to motor output, the typical power output and torque characteristic shown in Figure 3.31 is produced.

Typical torque characteristic of a standard three-phase AC motor in standard inverter operation $P_{Inverter} = P_{Motor}$

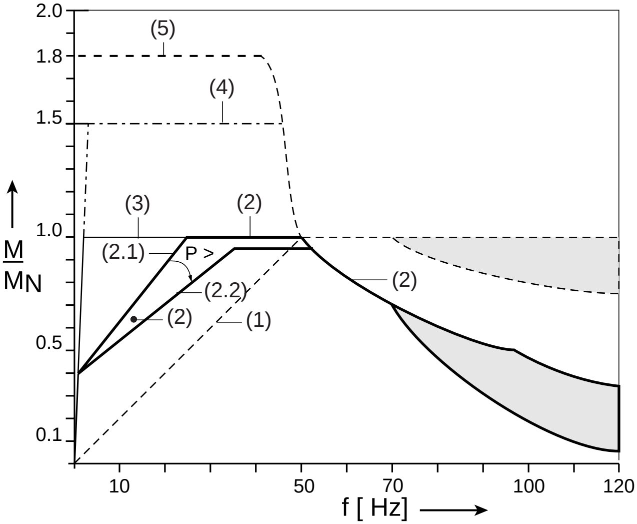


Figure 3.31 Typical torque characteristic of a standard three-phase AC motor

(1) Delivered power output of a standard three-phase AC motor in standard inverter operation

(2) Permissible torque characteristic of an internally cooled standard three-phase AC motor in standard inverter operation
(2.1) Typical characteristic at motor power output <4 kW
(2.2) Typical characteristic at motor power outputs >15 kW

Note: Precise data can only be given by the manufacturers of the motors.

(3) Permissible torque characteristic of an adequately externally cooled standard three-phase AC motor with standard inverter. It should, however, be noted that at motor power outputs >15 kW a rotor fan is very often used, meaning that the characteristic (3) may need to be reduced.

Note: **Note:** Precise data can only be given by the manufacturers of the motors.

(4) Maximum permissible torque of a standard three-phase AC motor to VDE 0530 Part 1 (120s).
Maximum torque with inverter modules which permit 150% overload and have activated motor control method SFC or FOR.

(5) Maximum torque with inverter modules which permit 180% overload and have activated motor control method SFC or FOR.

For break-away and acceleration torques dependent on motor control method refer to section 3.3.2.

Special applications

Design (solution)	Application
Motor power **lower** than power output of inverter modules	Area of application of solution: • In applications with acceleration times <500 ms, See section 2.3.1 and 2.5.1. • In applications requiring high overload torques
Motor power **higher** than power output of inverter modules	Area of application of solution: • In applications in which internally cooled motors are to be used in continuous operation (S1) over a very broad manipulating range. **Note:** The motor current consumer in continuous operation must not exceed the rated current of the inverter module.
Six-pole motor on inverter module	Area of application of solution: • In applications such as mills, mixers and extruders etc. For more information See section 2.2
Operation of a motor with field weakening	Area of application of solution: • In applications with falling load torque such as winders, coilers and lathes etc. For more information See section 1.3.4
Operation of special motors on inverter module	Area of application of solution: • See section 3.3.1

Table 3.34 Special applications

Design (solution)	Application
Operation of a motor with 25% field weakening	Area of application of solution: • In applications such as traction and lifting drives. For more information see section 3.3.4
Operation of a motor with 87 Hz characteristic	Area of application of solution: • In applications such as traction and lifting drives with expanded manipulating range at constant torque delivery. For more information see section 3.3.5
Several motors on one inverter module	Area of application of solution: • In conveying, textile machinery engineering etc. For more information see section 3.3.6

Table 3.34 Special applications

3.3.4 70 Hz characteristic with 25% field weakening

Traction and lifting drives which operate with 25% field weakening (70 Hz maximum frequency) offer a wide variety of advantages:

- 40% more break-away and acceleration torque can be attained without increasing the cost of the inverter drive solution.
- Greater economy can be achieved based on saving on an external cooler or reducing the motor power output by one type step.

Example: Drive design with 50 Hz (F_{max} = 50 Hz) and 70 Hz characteristic (F_{max} = 70 Hz)

- Speed manipulating range from 20 to 95 rpm on the gear output shaft
- Output torque on gear output shaft of 150 Nm
- Operation mode: S1 (continuous operation), ED = 100%
- There is no time requirement for the startup and braking response.

1. Drive design with 50 Hz

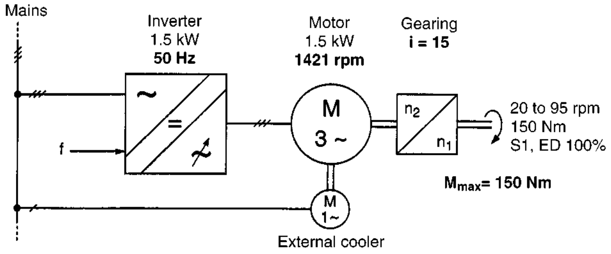


Figure 3.32 50 Hz drive design

The drive design shown above occurs in similar form in almost all fields of engineering. Initial commissioning automatically sets up all three motor control methods.

2. Drive design with 70 Hz

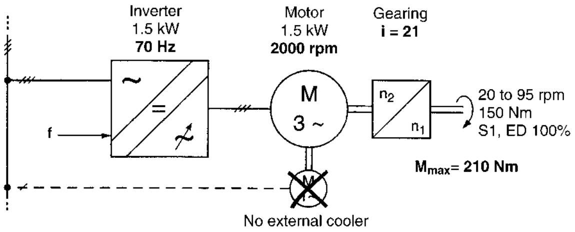


Figure 3.33 70 Hz drive design

In the 70 Hz drive design with 25% field weakening the maximum speed of the 1.5 kW motor is increased by way of the inverter module from 1421 rpm (50Hz) to 2000 rpm (70Hz). The adaptation of the desired output speed on the gearbox is compensated by a higher transmission. However, since a two-stage gearing is required in both cases, the increase in transmission has no influence on cost.

In this case, too, all the motor control methods are set up automatically by initial commissioning. In addition, the max. output frequency needs to be set to 70 Hz in the “Output frequency limitation” software function.

3. Comparison of gear output torques in drive designs with 50 Hz and 70 Hz characteristic.

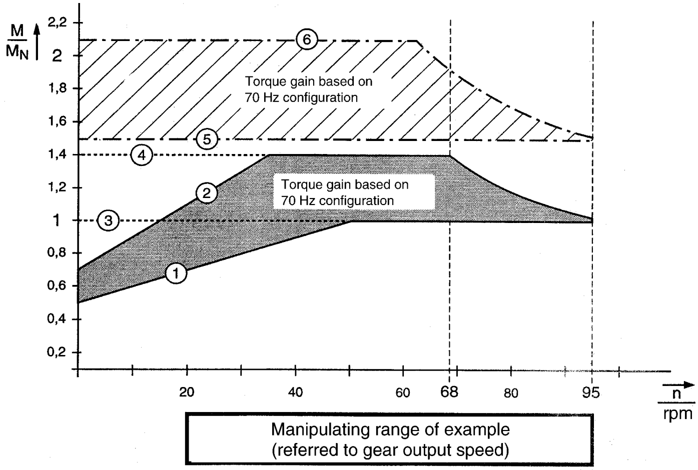


Figure 3.34 Comparison of gear output torque in a drive design for 50 and 70 Hz

Curve 50 Hz	**Curve 70 Hz**	**Explanation**
1	2	Typical permissible torque characteristic of an **internally cooled standard motor** (1.5 kW)
3	4	Typical permissible torque characteristic of an **externally cooled standard motor** (1.5 kW)
5	6	Maximum attainable torque for 60 s of a drive with 1.5 times overload and automatic load compensation

Table 3.35 Comparison of gear output torque in a drive design for 50 and 70 Hz

Summary: 40% higher acceleration torque

In a drive design for 70 Hz the motor is run at a speed higher by the factor 1.4. As a result the maximum power output delivered by the motor is achieved as low as a frequency of 50 Hz and remains constant beyond that level up to 70 Hz. Above 50 Hz the torque falls proportional to the inverter output frequency. The higher rotation speed of the motor shaft is compensated by s transmission ratio increased by a factor 1.4. As a result of the speed adjustment the available torque increases by 40% between 0 and 50 Hz and 0 and 68 rpm. This is equivalent to 40% more acceleration torque with no increase in cost.

40% more overload reserve and break-away torque

Proportional to the acceleration torque, a 40% higher maximum torque is of course also achieved (see characteristics 5 and 6 in Figure 3.34) and thus also a 40% higher break-away torque.

60% larger speed manipulating range

The motor speed increased by a factor of 1.4 produces an approx. 60% larger speed manipulating range on the gear output shaft. Referred to to the application set out in Figure 3.32, Figure 3.33 and Figure 3.34, the 70 Hz design even means that no external cooler is needed, and so the space take-up is reduced.

Or a reduction in motor power by one type step

A drive design with field weakening (70 Hz design) can, however, also be designed to usually produce a reduction in motor power by one type step. A reduced motor power saves space and money.

It should, however, be noted that the choice of maximum speed has a major influence on the required acceleration torque and thus on the acceleration time. In practice, at desired acceleration times below 400 ms no reduction in the motor power or inverter output by one type step is usually attained.

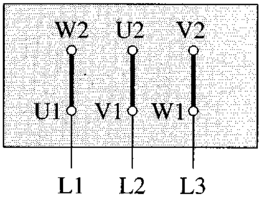
3.3.5 87 Hz characteristic / Expanded manipulating range

The operating range with constant torque of a 400 V / 50 Hz motor in star configuration can be expanded to 87 Hz in delta configuration.

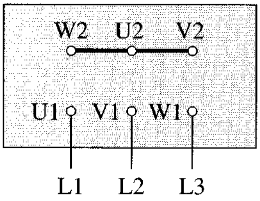
Example: Motor 4 kW / 50 Hz in delta configuration

- Rated power 4 kW
- Nominal speed 1420 rpm
- Rated voltage 230 / **400 V**
- Delta / **star configuration**

1. Reconfigure motor to delta configuration (230 V / delta)



△-circuit



Y-circuit

2. Select inverter output

$$P_{Inverter} \geq P_{Motor} \cdot \sqrt{3} \quad =$$

$= 4\ \mathrm{kW} \cdot 1.73 = 6.9\ \mathrm{kW}$

Selected inverter module: CDA34.017
Rated power 7.5 kW
Rated voltage 0 ... 400 V
Max. output frequency 0 ... 100 Hz

3. Drive solution: 87 Hz characteristic

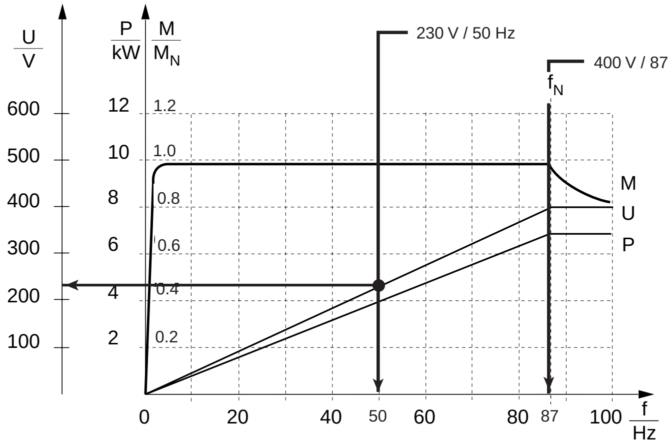


Figure 3.35 Constant torque range to 87 Hz

Design / Application

Design/solution	Applications
Motor with 4 kW / 50 Hz in star configuration on inverter module CDA34.010 (4 kW)	Area of application of solution: - In applications with constant torque delivery to 50 Hz
Motor with 4 kW / 50 Hz in delta configuration on inverter module CDA34.017 (7.5 kW)	Area of application of solution: - In applications with constant torque delivery to 87 Hz, e.g. lifting drives
	Precise data relating to the full-load power (S1, ED 100° %) can only be given by the motor manufacturers.
	During initial commissioning all the parameters for this application are automatically set.

Table 3.36 Applications

The choice of maximum frequency has a major influence on the acceleration power.

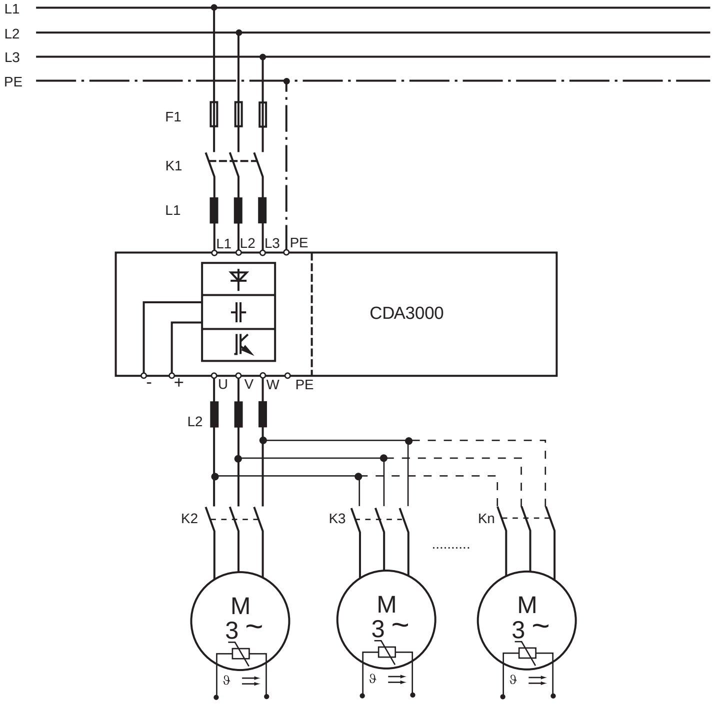
$$P_{MBE} = \frac{J_M \cdot n^2}{91,2 \cdot t_{BE}}$$

J_M	Moment of inertia of the motor (rotor) in [kgm]
t_{BE}	Acceleration time in [s]
P_{MBE}	Motor acceleration power in [W]

The acceleration power rises with the square of the speed increase (e.g. caused by the choice of max. 87 Hz instead of 50 Hz).

3.3.6 Multi-motor operation on one inverter

The CDA3000 inverter modules can be run with several motors configured in parallel. Depending on drive task, various project planning conditions must be met.



L1= Line choke, See section 6.1
L2= Motor choke, See section 6.2

Figure 3.36 Multi-motor operation on one inverter

Project planning notes for multi-motor operation

Subject	Project planning notes
Current configuration of inverter module	The sum of the motor currents must be less than the rated output current of the inverter module Σ of motor currents, $(I_{M1} + I_{M2} + I_{Mn}) < I_{inverter}$
Motor control method	Multi-motor operation is only permitted with the VFC motor control method.
Motor choke	A motor output choke must always be used (See Figure 3.36). The motor choke limits the du/dt and thus the leakage currents, and protects again switching voltage overload resulting from switching of the motor inductance.
Motor cable length	The total length of the overall motor cable is produced by adding the individual lengths per motor.
Motor protection	In multi-motor operation the parallel-connected motors cannot be protected by the inverter module. For that reason, depending on specific depending on the motor should be protected by means of external motor circuit-breakers or thermistor protective relays; see 3.2.13.
All motors have the same power output	In this application the torque characteristics of all motors remain roughly equal.
The motors have different power outputs	If the motor outputs are very different, problems may occur on startup and at low speeds. This is because of the high stator resistance of small motors and the resultant high voltage drop on the stator coil. In practice: With a power ratio of around 1:4 between the motors, the starting torque of the smallest motor is still approx. 70% of the nominal torque. If the torque of approx. 70% is not sufficient, a larger motor must be used. ⚠ If all the motors are started together, the small motor will start up later, because the slip frequency is higher.

Table 3.37 Project planning notes for multi-motor operation

Subject	Project planning notes
Speed ratio run	Differing motor output speeds can only be attained by using motors with differing nominal speeds, e.g. 1440 rpm and 2880 rpm. The speed ratio of approx. 1:2 is maintained during the speed change. The accuracy depends on the slip and thus on the load.
Shut-off and activation of individual motors	Shut-off of motors, See section 3.2.9 When connecting motors, ensure that the connection current is not higher than the inverter peak current. It is advantageous if the inverter load is >40%. This 40% base load backs up the output voltage of the inverter module at the moment of connection of the motor. ⚠ During connection the motor must not be run in the field weakening range, since the connected motor would otherwise have to run at reduced runup torque.

Table 3.37 Project planning notes for multi-motor operation

3.3.7 DC network operation

DC network operation of the CDA3000 inverter modules enables an energy exchange between the inverter modules.

The inverter modules which are run in DC network mode regeneratively (braking) feed energy into the DC network which is consumed by the motorized inverter modules. The regenerative energy does not need to be delivered from the mains.

DC network operation of several inverter modules minimizes the energy consumption from the mains and in most cases eliminates the need for use of braking chopper units.

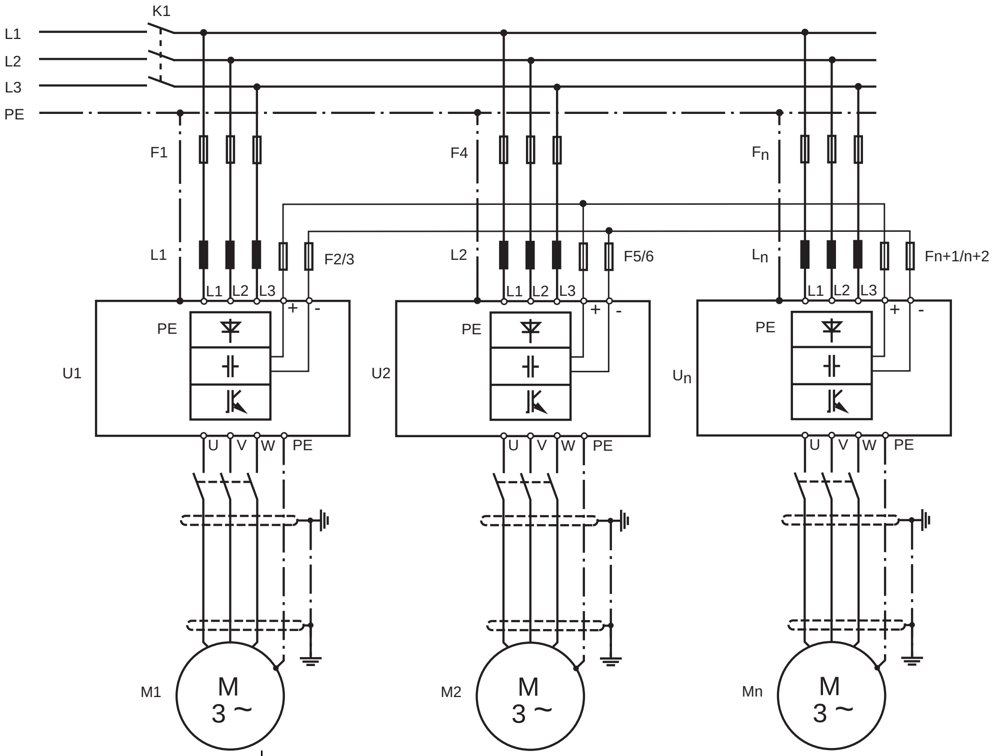


Figure 3.37 Circuitry example, DC network operation

Project planning notes for DC network operation

Subject	Project planning notes
Mains connection of the inverter modules	• All inverter modules must be operated with a line choke. The line choke limits the mains current and provides current/power symmetry of the inverter input circuits. • For more information on this subject refer to section 3.2.
Mains fuse (F1) with signal contact	• By the use of mains fuses with signal contact the "**Mains power supply failure**" fault can be responded to by shutting down the entire DC network. As a result the remaining inverter modules in the DC network are not overloaded.
Mains power connection condition	• It must be ensured that all inverter modules are connected **simultaneously** (K1) to the mains power.
DC link connection	• Make short cable connections to the common DC-link center point. • Use cable cross-section corresponding to mains power cable cross section (see Operation Manual and section 3.2). • Select DC-link fuses corresponding to the cable cross-section and local regulations. The fuses protect the cable. • The DC fuses can be omitted if the cable cross-section used to wire the DC network is at least as large as the mains power cable cross-section of the highest-powered inverter module in the network. **Tip:** Where the DC network comprises only two inverter modules only one fuse pair (F3/4) is sufficient for protection purposes. If the DC network is connected to the mains - while an inverter module has an internal short-circuit on the DC link - the defective inverter module is automatically isolated from the DC network by its PTC precharging circuit. All other inverter modules can continue in operation; see Figure 3.37.

Table 3.38 Project planning notes for DC network operation

Subject	Project planning notes
Design of the external braking resistors	If the energy balance in DC network operation is regenerative in individual operating situations, the inverter modules must be operated with external braking resistors to absorb the regenerative energy. The following conditions must be met when designing the braking resistors: 1. The ohmic value of the external braking resistor must not be less than the minimum ohmic connected load permitted by the inverter module. 2. Adding together the peak braking powers of all braking resistors operated in the DC network produces the peak braking power referred to the DC network. $P_{SDC} = P_{SW1} + P_{SW2} + ...P_{SWn}$ P_{SDC} = total peak braking power in the DC network P_{SW1} = peak braking power of braking resistor 1 3. The continuous braking power of the individual braking resistor is ascertained by calculation of the effective braking power. $P_{eff} = \sqrt{\frac{P_{SW}^{2} \cdot t_1 + P_{SW}^{2} \cdot t_2 + \ldots P_{SW} \cdot t_n}{T}}$ P_{SW} = peak braking power of the selected braking resistor t1, 2xn = braking time 1, 2 m ... n The permissible continuous braking power of the selected braking resistor must be > P_{eff}. The sampling time (T) must be <150 s.

Figure 3.38 Project planning notes for DC network operation

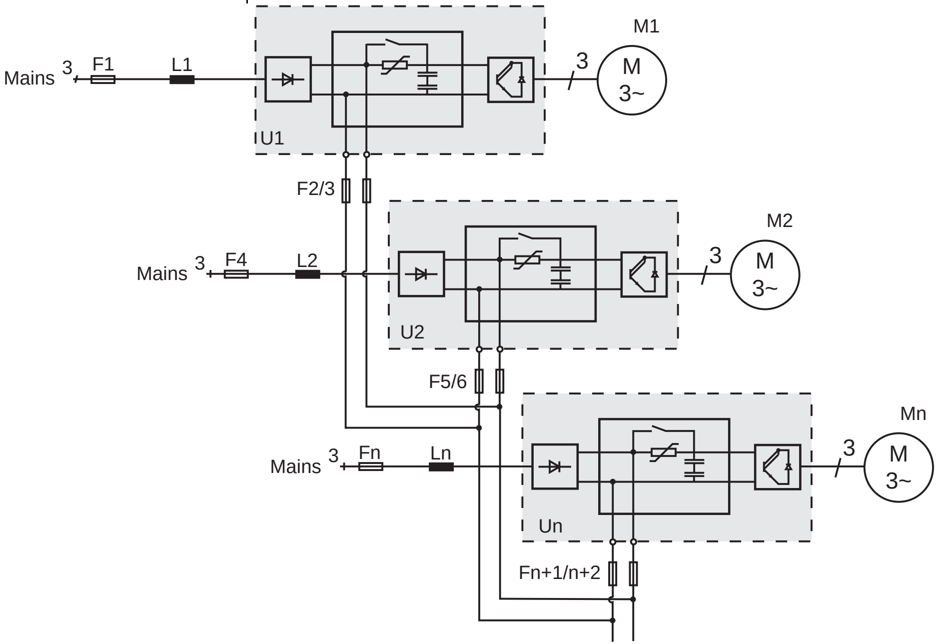


Figure 3.39 DC network operation with PTC precharging circuit

DC network operation with VF1000S/M/L, MC6000 and MC7000 is not permitted.

3.3.8 Design of the braking resistor

In regenerative operation, e.g. braking the drive, the motor feeds energy back into the inverter. This increases the voltage in the DC link. If the voltage exceeds a permissible value, the internal braking transistor is activated and the regenerative energy is converted into heat by way of the externally connected braking resistor.

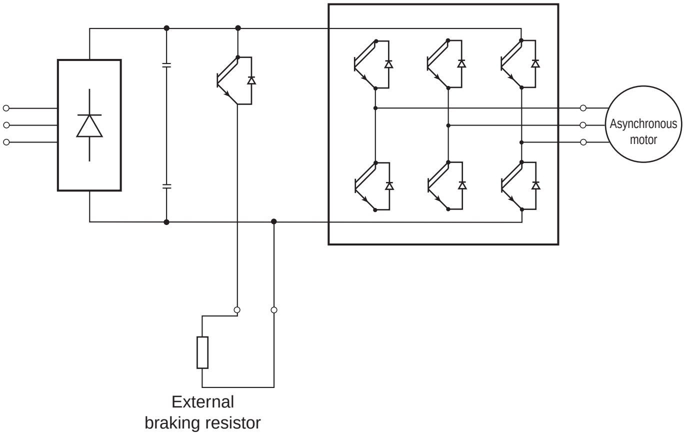


Figure 3.40 Block diagram of an inverter with braking chopper

Calculation of effective braking power

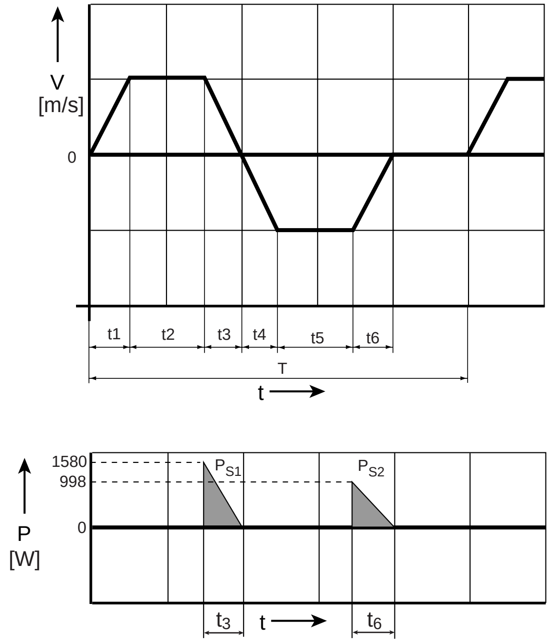


Figure 3.41 Effective braking power

$$P_{eff} = \sqrt{\frac{P_{s1}^{2} \cdot t_3 + P_{s2}^{2} \cdot t_6}{T}}$$

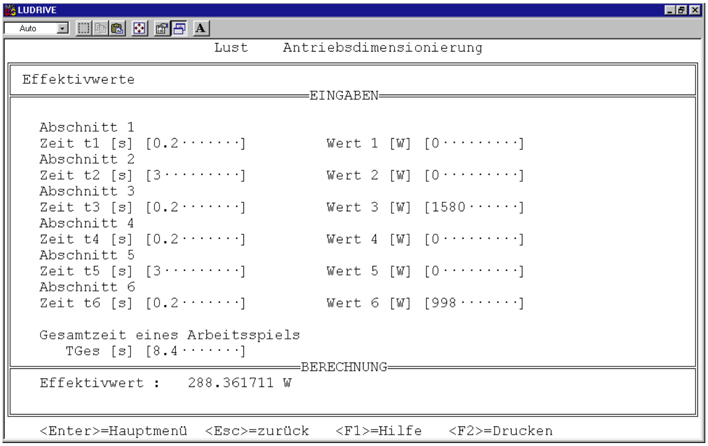
P_S = Peak braking power
P_D = Continuous braking power
T = Sampling time (work cycle)
t1 = 0.2 s
t2 = 3 s
t3 = 0.2 s
t4 = 0.2 s
t5 = 3 s
t6 = 0.2 s
T = 8.4 s

The continuous braking power of the braking resistor must be > P_{eff}. The sampling time T must be < 150 s.

Example: Calculation example for Figure 3.41

• Inverter module	CDA34.005
• Minimum ohmic resistance of an external braking resistor	180 Ω
• Load cycle see	Figure 3.41

1. Calculation with LUDRIVE



```
                       Lust    Antriebsdimensionierung

 Effektivwerte
                                   EINGABEN

   Abschnitt 1
   Zeit t1 [s] [0.2·······]        Wert 1 [W] [0·········]
   Abschnitt 2
   Zeit t2 [s] [3·········]        Wert 2 [W] [0·········]
   Abschnitt 3
   Zeit t3 [s] [0.2·······]        Wert 3 [W] [1580······]
   Abschnitt 4
   Zeit t4 [s] [0.2·······]        Wert 4 [W] [0·········]
   Abschnitt 5
   Zeit t5 [s] [3·········]        Wert 5 [W] [0·········]
   Abschnitt 6
   Zeit t6 [s] [0.2·······]        Wert 6 [W] [998·······]

   Gesamtzeit eines Arbeitsspiels
      TGes [s] [8.4·······]
                                  BERECHNUNG
   Effektivwert :   288.361711 W

   <Enter>=Hauptmenü  <Esc>=zurück   <F1>=Hilfe   <F2>=Drucken
```

Figure 3.42 Calculation of effective braking power with LUDRIVE

2. Choice of braking resistor (See section 6.3)

Braking resistor BR-270.02,541 was chosen

Peak braking power: 2080 W
Continuous braking power: 300 W
Resistance: 270 Ω

The resistance must not be less than the minimum ohmic connected load permitted by the inverter module.

Parallel/series configuration of braking resistors

By means of a parallel configuration of braking resistors the peak braking power can be adapted to the specific application.

By means of a series configuration the continuous braking power can be adapted to the specific application.

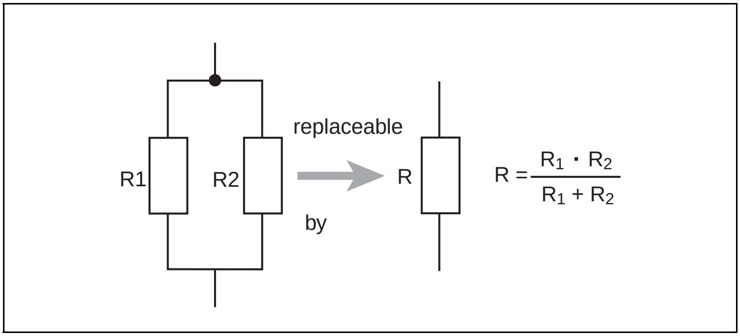


Table 3.39

Figure 3.43 Parallel configuration of two resistors

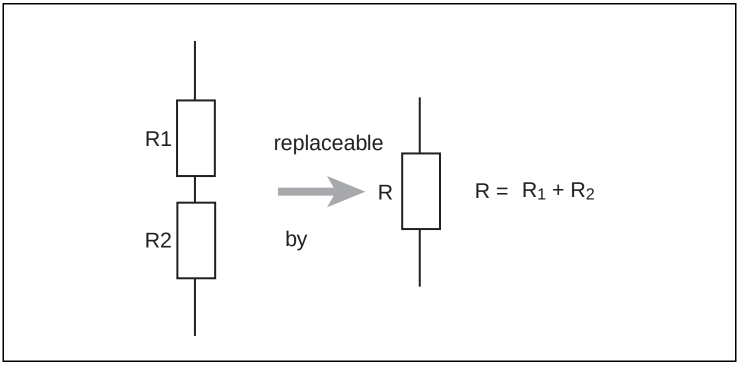


Table 3.40

Figure 3.44 Series configuration of tworesistors

$$P_S = \frac{U^2}{R_{BR}}$$

P_S = Peak braking power in [W]
U = DC-link voltage in [V]
(390 V or 750 V)
R_{BR} = Resistance of braking
resistor in [Ω]

Figure 3.45 Calculation of peak braking power

3.3.9 Power failure bridging

Not available at time of going to press.

4 Software functions

4.1 User interface and data structure

This section describes handling of the data sets and parameter setting of the CDA3000 inverter module.

Users can adapt the “active data set” of an inverter module to the specific application by way of the KEYPAD KP200 control unit or the user-friendly DRIVEMANAGER PC user software.

4.1.1 Data structure

Individual parameters, parameter groups (subject areas) or complete preset parameter sets can be selected. The complete preset parameter set is called an application data set.

Subject areas

For ease of handling the parameters of the CDA3000 inverter module are assembled into groups. The parameter groups are called subject areas, and permit function-oriented operation of the inverter module (See Figure 4.1).

Application data set

Application data sets are complete preset parameter sets for handling a wide variety of movement tasks (See Figure 4.2).

Loading an application data set into the RAM automatically configures the inverter module. All subject areas and the signal processing inputs and outputs are automatically preset to the desired solution.

Use of the application data sets simplifies and speeds up commissioning of the inverter module and thus the movement solution.

Available application data sets

- ➢ **“Traction and lifting drive”** for typical applications such as conveyor belt, rack, trolley, spindle and lifting gear drives
- ➢ **“Rotational drive”** for typical applications such as spindle, extruder and winding drives or centrifuges
- ➢ **“Field bus operation”** for integration of the inverter system into a network via CANLust, CANopen or PROFIBUS-DP
- ➢ **“Master-/Slave operation”** for reference coupling of several inverter modules

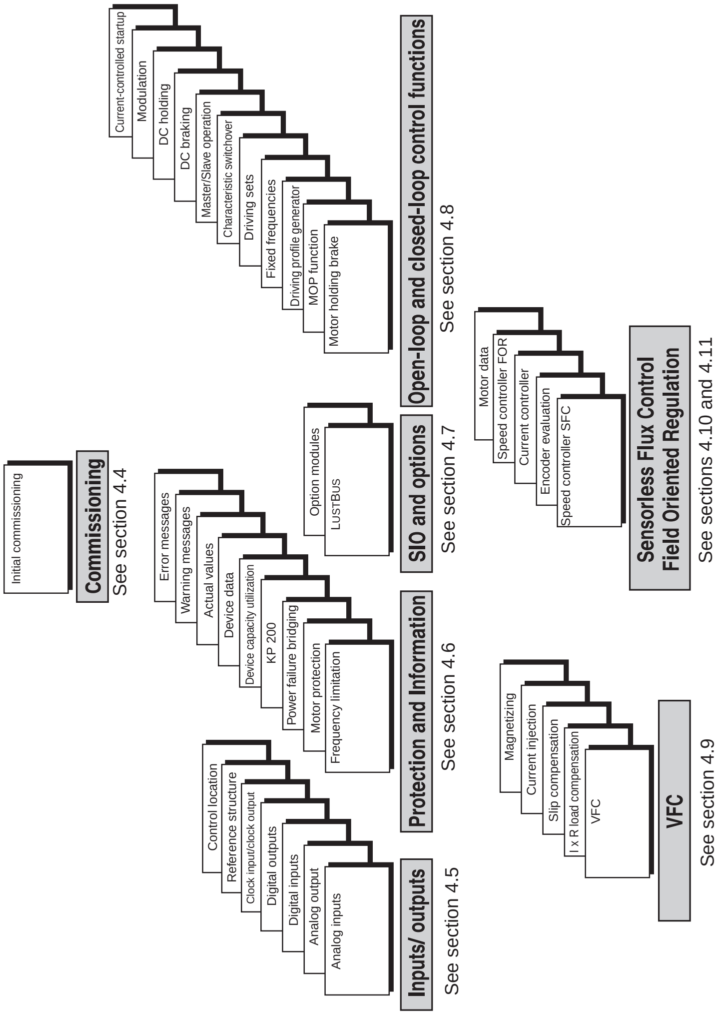


Figure 4.1 *Subject areas for function-oriented operation of the inverter module. The functions are described in the sections quoted.*

When the inverter module is started for the first time after delivery, application data set 1: “traction and lifting drive” is active.

After every subsequent start the user data set selected by way of the control terminals or by parameter setting is automatically loaded.

The application data sets are adapted further by way of the assistance parameter “ASTER”. By way of the application data sets and the assistance parameter 15 preset solutions can be selected; See section 4.3.

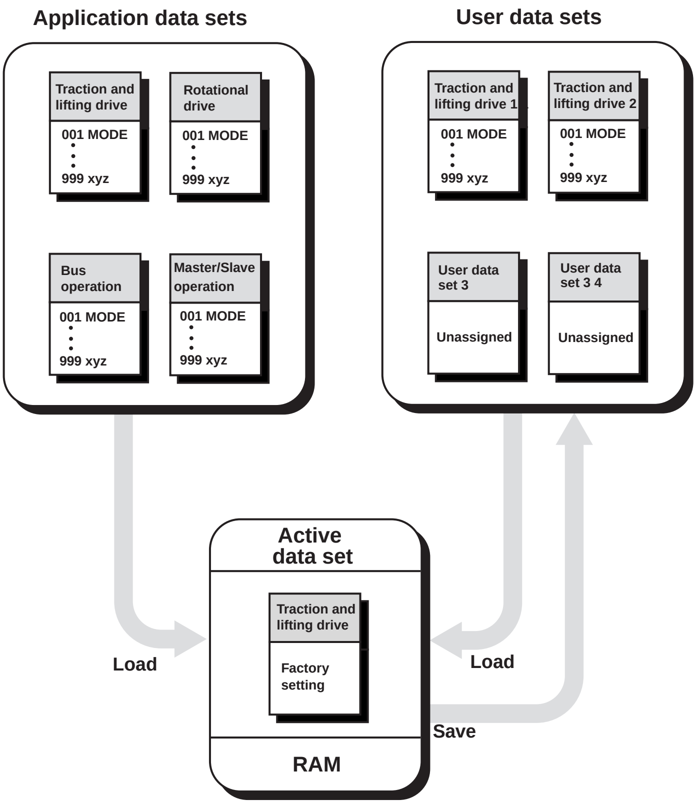


Figure 4.2 Data structure of the CDA3000

User data sets

When the application data set has been adapted to the specific application, this new data set can be stored as a **custom setting** in a user data set.

In the inverter module four user data sets can be managed (See 4.1).

The user data sets can be selected and activated via KEYPAD, DRIVEMANAGER, bus access or terminals.

Terminal 1	Terminal 2		User data set/Custom data set
0	0	⇨	User data set 1 001 MODE ⋮ 999 xyz
1	0	⇨	User data set 2 001 MODE ⋮ 999 xyz
0	1	⇨	User data set 3 001 MODE ⋮ 999 xyz
1	1	⇨	User data set 4 001 MODE ⋮ 999 xyz

Table 4.1 Example of selection of user data sets via terminals

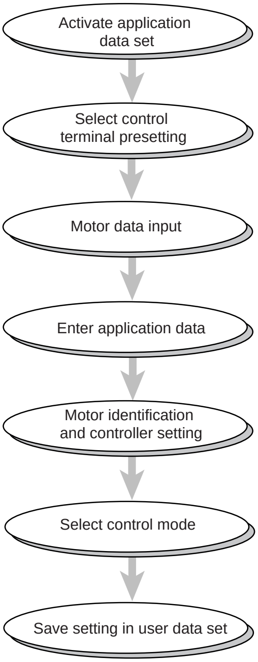
4.1.2 Initial commissioning

Selecting the “Initial commissioning” subject area calls up the parameter group for initial commissioning of the inverter module. The parameters of the subject area must be adapted successively to the specific application.

The automatic motor identification function ascertains the key parameters of the motor and sets the appropriate control circuits.

This identification function is necessary for the SFC[1] and FOR[2] control modes. Where the VFC[3] open-loop control mode is used it is only required if the particularly high demands are placed on the current control loop (e.g. very heavy load surges in operation).

Sequence of initial commissioning



Step	Function	Explanation
1	Activate application data set*)	- Traction and lifting drive - Rotational drive - Field bus operation - Bus operation
2	Set assistance parameter*)	- DRV_1 to 5 - ROT_1 to 3 - BUS_1 to 3 - M-S_1 to 4
3	Enter motor data	- Motor type - Rated current - Rated voltage - Nominal speed - Rated power - Rated frequency - cos φ
4	Specify moments of inertia	- Moment of inertia of special motors - Application
5	Automatic motor identification	- Electrical parameters of the motor are ascertained - Control circuits are set

Table 4.2 Sequence of initial commissioning

---

[1] Sensorless Flux Control

[2] Field Oriented Regulation

[3] Voltage Frequency Control

Step	Function	Explanation
6	Select control mode	• Voltage Frequency Control • Sensorless Flux Control • Field-Oriented Regulation
7	Save all settings in a user data set	• Initial commissioning complete
*) For more information on application data sets and assistance parameters refer to section 4.2.		

Table 4.2 Sequence of initial commissioning

Example: Initial commissioning

Motor:	Asynchronous motor 1.5 kW
Application:	Linear drive with limit switches, moment of inertia of application 0.003 kgm². Positioning is to be dynamic with a quick jog/slow jog profile.

1. Selection of an application data set to handle the movement task

1.1 Call up "Initial commissioning" subject area

1.2 Select parameter RUNMD and set to “1”

This activates the presetting for traction and lifting drives

1_DRV = Traction and lifting drive
2_ROT = Rotational drive
3_BUS = Field bus operation
4_M-S = Master-/Slave operation

2. Adaptation of the control terminal function to the application

2.1 Call up parameter ASTER and select setting DRV_3

The control terminal is assigned the quick jog/slow jog driving profile and limit switch evaluation functions.

3. Input of motor data

3.1 Read motor data from rating plate of motor

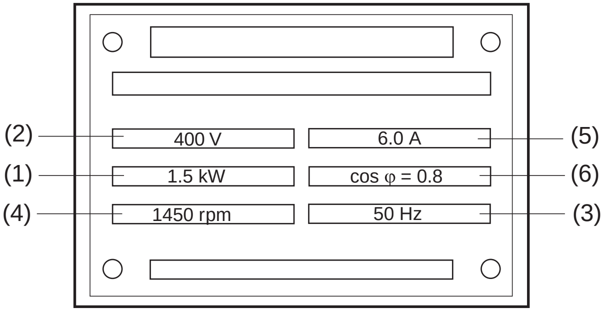


Figure 4.3 Motor rating plate

3.2 Call up the individual motor parameters and enter the read values

Parameter	Setting	Function
MOTYP	ASM	Motor type = asynchronous machine
(1) MOPNM	1.5 kW	Motor rated power
(2) MOVNM	400 V	Motor rated voltage
(3) MOFN	50 Hz	Motor rated frequency
(4) MOSNM	1450 rpm	Motor nominal speed
(5) MOCNM	6 A	Motor rated current
(6) MOCOS	0.8	cos φ of motor

Table 4.3 Parameters for the motor data

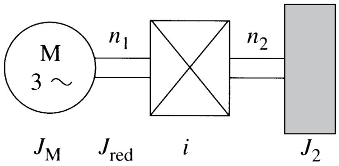
4. Enter moment of inertia of application

4.1 Enter moment of inertia of load

The moment of inertia of the load is necessary in order to attain an optimum dynamic response with the SFC and FOR control modes.

If no moment of inertia is specified, the external moment of inertia is set equal to that of the motor shaft (moment of inertia adaptation $J_M = J_{red}$).

Calculation of “reduced” moment of inertia on motor shaft



$$J_{red} = \frac{J_2}{(i)^2} = \frac{J_2}{(n_1 / n_2)^2}$$

$$J_{tot} = J_M + J_{red}$$

Figure 4.4 Example

➢ In the example the moment of inertia of the load is known:
Select parameter SCJ1 and set to 0.003 kgm²

4.2 Enter motor moment of inertia

If the motor is a standard motor to DIN VDE 0530, it is not necessary to give the moment of inertia of the motor shaft. In the case of a special motor (e.g. an asynchronous motor) it is required to optimize the control loop.

5. Start automatic motor identification

5.1 Call up parameter ENSC and set to “START”.

The motor identification takes approx. 3-4 minutes. When the identification is complete parameter ENSC is automatically reset to “STOP”.

6. Selection of control mode

6.1 Call up parameter CFCON and set to “SFC”.

The “Sensorless Flux Control” mode for optimum dynamics without speed feedback is activated.

7. Save all parameters to one of the four user data sets.

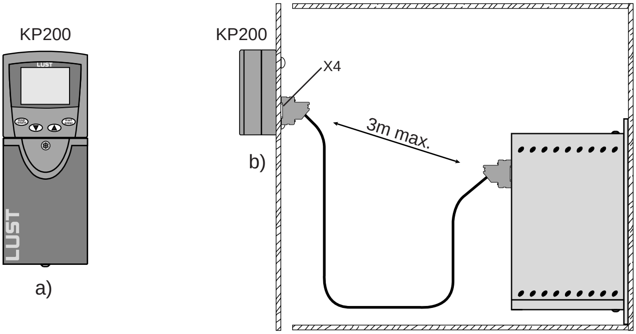
7.1 Call up parameter UMWR and enter the value “1” for user data set 1.

Note: Only by saving the data sets to one of the user data sets are the data from the volatile device RAM permanently stored. Otherwise changes to the active data set are lost on power-off or in the event of an error reset.

4.1.3 Operation via KEYPAD KP200

By way of the KEYPAD KP200 control unit the complete inverter module can be monitored and adjusted.

The KEYPAD can be mounted directly on the inverter module or be fixed to a switch cabinet door.



a) On the CDA3000 inverter module
b) On the switch cabinet door

Figure 4.5 Mounting the KEYPAD (max. cable length 3 meters)

The KEYPAD KP200 has a user-friendly menu structure which is identical to the menu structure of the KP100 for the SMARTDRIVE VF1000 inverters and for the MASTERCONTROL servocontrollers.

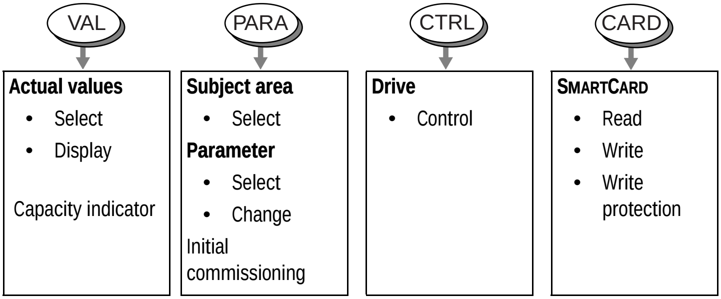
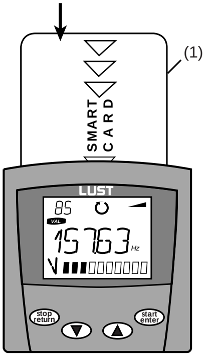


Figure 4.6 Overview of the KP200 menu structure

KP200 controls



start enter	Call up menu, subject area or parameter Save changes Start in "Control drive" mode
stop return	Quit menu, cancel changes Stop in "Control drive" mode
▲	Select menu, subject area or parameter Increase setting
▼	Select menu, subject area or parameter Reduce setting

Figure 4.7 Keys on the KEYPAD KP200 control unit

A user data set of the inverter module can be saved to the SMARTCARD and transferred to other drives.

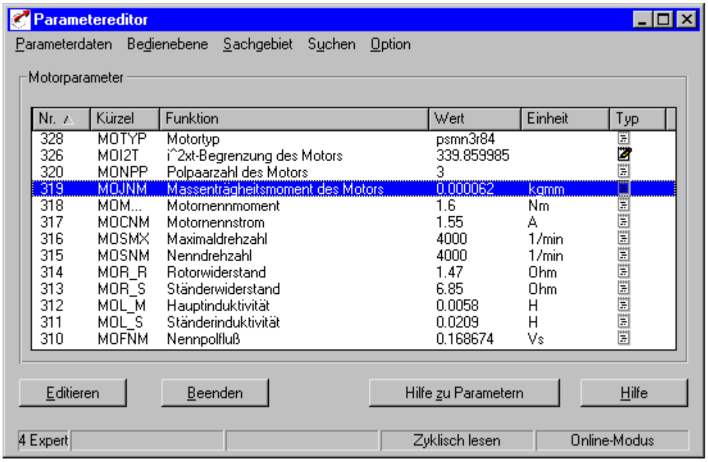
4.1.4 Operation via DRIVEMANAGER

The “DriveManager” PC user software for Windows® 95 and NT rounds off the skillfully designed and user-friendly operator control concept.

The “DRIVEMANAGER” software tool provides the following functions:

- ➢ User-friendly subject area and parameter editor with plain text display (See Figure 4.8)
- ➢ Status display to monitor the operation-specific actual and reference values
- ➢ Direct control of the inverter by PC
- ➢ User-friendly four-channel digital scope for real-time recording of actual values such as current curve or v/t diagram (See Figure 4.10)
- ➢ Comparison function for problem-solving and data administration and print functions

Subject area and parameter editor



Nr.	Kürzel	Funktion	Wert	Einheit	Typ
328	MOTYP	Motortyp	psmn3r84		
326	MOI2T	i^2xt-Begrenzung des Motors	339.859985		
320	MONPP	Polpaarzahl des Motors	3		
319	MOJNM	Massenträgheitsmoment des Motors	0.000062	kgmm	
318	MOM...	Motornennmoment	1.6	Nm	
317	MOCNM	Motornennstrom	1.55	A	
316	MOSMX	Maximaldrehzahl	4000	1/min	
315	MOSNM	Nenndrehzahl	4000	1/min	
314	MOR_R	Rotorwiderstand	1.47	Ohm	
313	MOR_S	Ständerwiderstand	6.85	Ohm	
312	MOL_M	Hauptinduktivität	0.0058	H	
311	MOL_S	Ständerinduktivität	0.0209	H	
310	MOFNM	Nennpolfluß	0.168674	Vs	

Figure 4.8 User-friendly subject area and parameter editor with plain text display

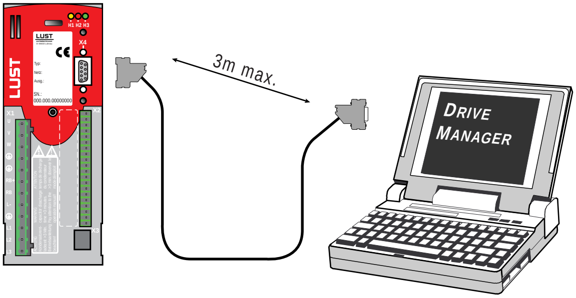


Figure 4.9 CDA3000 with DRIVEMANAGER

Digital scope

With the digital scope up to four channels can be recorded simultaneously, permitting comprehensive diagnosis.

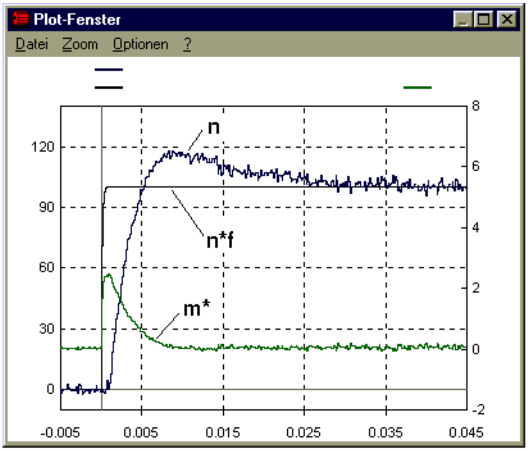


Figure 4.10 Example: Speed step response

4.2 Device and terminal view

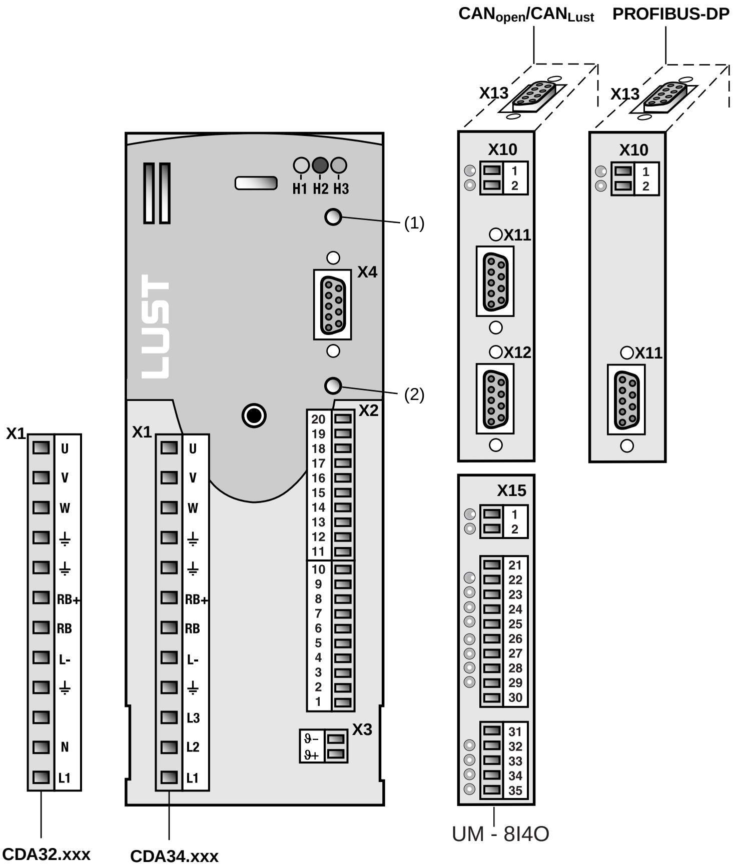


Figure 4.11 Layout, CDA3000

No.	Designation	Function
H1, H2, H3	LEDs	Device status display
X1	Power terminal	Mains, motor, braking resistor, DC feed
X2	Control terminal	4 digital inputs 3 digital outputs (of which 1 relay) 2 analog inputs 1 analog output

Table 4.4 Key to Figure 4.11

No.	Designation	Function
X3	PTC terminal	PTC, Klixon evaluation or linear temperature transmitter
X4	RS232 terminal X4	for DRIVEMANAGER or KEYPAD KP200
X10	Voltage supply for communication module	+ 24 V, ground
X11	CAN-In / PROFIBUS-DP	
X12	CAN-Out	
X13	Address coding plug	
X15	User module UM-8I4O	Voltage supply, 8 digital inputs, 4 digital outputs
(1)	Reset button	
(2)	Boot button	

Table 4.4 Key to Figure 4.11

4.2.1 Specification of control terminals

Des.	Terminal	Specification	floating
Analog inputs			
ISA00	X2-2	• U_{IN} = +10 V DC, ±10 V DC I_{IN} = (0) 4-20 mA DC, software-switchable to: • 24 V digital input, PLC-compatible (IEC1131) • Switching level Low/High: <4.8 V / >8 V DC • Resolution 10-bit • R_{in}=110kΩ • Floating against digital ground	U: ±1% of MV I: ±1% of MV
ISA01	X2-3	• U_{IN} = +10 V DC, software-switchable to: • 24 V digital input, PLC-compatible (IEC1131) • Switching level Low/High: <4.8 V / >8 V DC • Resolution 10-bit • R_{in}=110 kΩ • Floating against digital ground	U: ±1% of MV
Analog output			
MV = measured value			

Table 4.5 Specification of control terminals

Des.	Terminal	Specification	floating
OSA00	X2-5	• PWM PWM 2nd order filter • PWM with carrier frequency 19.8 kHz • R_{OUT}=100 Ω • U_{out}=+10 V DC • I_{max}=5 mA • Short-circuit-proof	✔
Digital inputs			
ISD00	X2-9	• Limit frequency 5 kHz • PLC-compatible (IEC1131) • Switching level Low/High: <5 V / >12 V DC • I_{max} at 24 V = 10 mA • R_{IN} = 3 kΩ • Delay ≈ 2µs	✔
ISD01	X2-10	• Limit frequency 500 kHz • PLC-compatible (IEC1131) • Switching level Low/High: <5 V / >12 V DC • I_{max} at 24 V = 10 mA • R_{IN} = 3 kW • Delay ≈ 2µs • Data input in reference coupling	✔
ISD02	X2-11	• Limit frequency 500 kHz • PLC-compatible (IEC1131) • Switching level Low/High: <5 V / >12 V DC • I_{max} at 24 V = 10 mA • R_{IN} = 3 kΩ • Delay ≈ 2µs • A-input with square encoder evaluation for 24V HTL encoder against GND_EXT • Permissible pulse counts 32...16384 pulses per rev. (2^n with n = 5..14)	✔
ISD03	X2-12	• Limit frequency 500 kHz • PLC-compatible (IEC1131) • Switching level Low/High: <5 V / >12 V DC • I_{max} at 24 V = 10 mA • R_{IN} = 3 kΩ • Delay ≈ 2µs • B-input with square encoder evaluation for 24V HTL encoder against GND_EXT • Permissible pulse counts 32...16384 pulses per rev. (2^n with n = 5..14)	✔
MV = measured value			

Table 4.5 Specification of control terminals

Des.	Terminal	Specification	floating
ENPO	X2-8	- Power stage enable = High level - Switching level Low/High: <5 V / >12 V DC - I_{max} at 24 V = 10 mA - R_{IN} = 3 kΩ - Delay ≈ 2µs - PLC-compatible (IEC1131)	✔
Digital outputs			
OSD00	X2-15	- Short-circuit-proof - PLC-compatible (IEC1131) - I_{max} = 50 mA - Protection against inductive load - High-side driver	✔
OSD01	X2-16	- Short-circuit-proof with 24V supply from inverter module - PLC-compatible (IEC1131) - I_{max} 50mA - No internal freewheeling diode; provide external protection - High-side driver - Data output with reference coupling	✔ (restricted)
Relay output			
OSD02	X2-18 X2-19 X2-20	- Relay 48 V / 1 A AC, changeover contact - Usage category AC1 - Operating delay approx. 10 ms	✔
Motor temperature			
PTC1/2	X3-1 X3-2	- Measured voltage max. 12 V DC - Measuring range 100 Ω - 15 kΩ - suitable for PTC to DIN 44082 - suitable for temperature sensor KTY84, yellow - Sampling time 5 ms	✔
Voltage supply			
+10.5V	X2-1	- Auxiliary voltage U_R =10.5 V DC - Short-circuit-proof - I_{max} = 5 mA	–
+24V	X2-6 X2-7 X2-13	- Auxiliary voltage U_V = 24 V DC - Short-circuit-proof - I_{max} = 200 mA (overall, also includes the driver currents for outputs OSDox)	✔
MV = measured value			

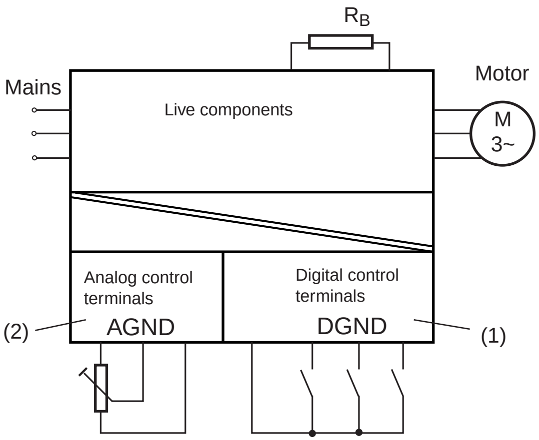
Table 4.5 Specification of control terminals

4.2.2 Isolation method and connection tips

The isolation in the inverter module safely isolates all control terminals from the live circuit components. The reference potentials of the control terminals are in turn split such that all analog and digital signals are each connected to one reference potential (DGND and AGND). As a result of this split an n analog signal, e.g. for the speed reference, is immune to interference entering the inverter module over the digital signal lines.

The two analog inputs may be used either both with analog or both with digital function.

If the analog inputs are to be assigned digital functions, when using the internal 24 V auxiliary voltage it is necessary to interconnect the two grounds (DGND and AGND).



(1) DGND = Digital ground
(2) AGND = Analog ground

Figure 4.12 Isolation method for the control terminals

4.3 Preset solutions

The inverter module contains preset solutions for the most common applications. The object of these presets is to find the optimum device setup for the application with minimal parameter setting.

Based on the application-specific basic settings for the “traction and lifting drive” and “rotational drive” areas, all software functions relevant here are already optimized to these applications. With two additional basic settings the inverter module can be very easily preset for operation on the field bus and for network operation with several inverter modules (Master-/ Slave operation).

When one of these four basic settings has been selected the inverter module also offers the user the opportunity to select various control terminal settings. In this way the inputs and outputs of the inverter module are adapted to the signals required in the process.

With the total of 15 available presets the inverter module can be adapted with a small number of parameters to virtually any application, thereby greatly reducing commissioning times.

Application data set: “Traction and lifting drive”

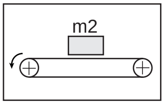
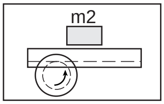
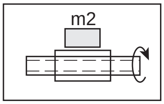
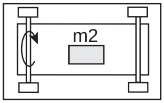
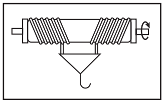
Application data set	Designation	Application
Traction and lifting drive Section 4.3.1	Conveyor belt	
	Rack drive	
	Spindle drive	
	Trolley drive	
	Lifting drive	

Table 4.6 Application-specific basic settings

Application data set: “Rotational drive”

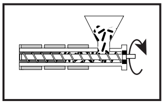
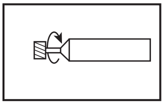
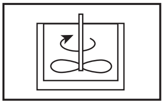
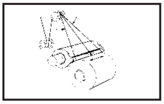
Application data set	Designation	Application
Rotational drive Section 4.3.2	Extruder	
	Spindle drive	
	Stirrer	
	Winding drive	

Table 4.7 Application-specific basic settings

Application data set: “Field bus operation”

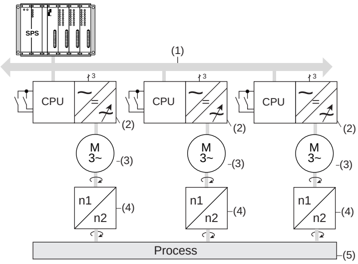
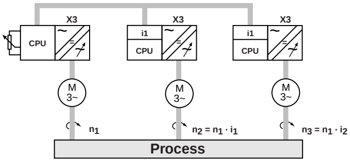
Application data set	Application
Field bus operation Section 4.3.3	

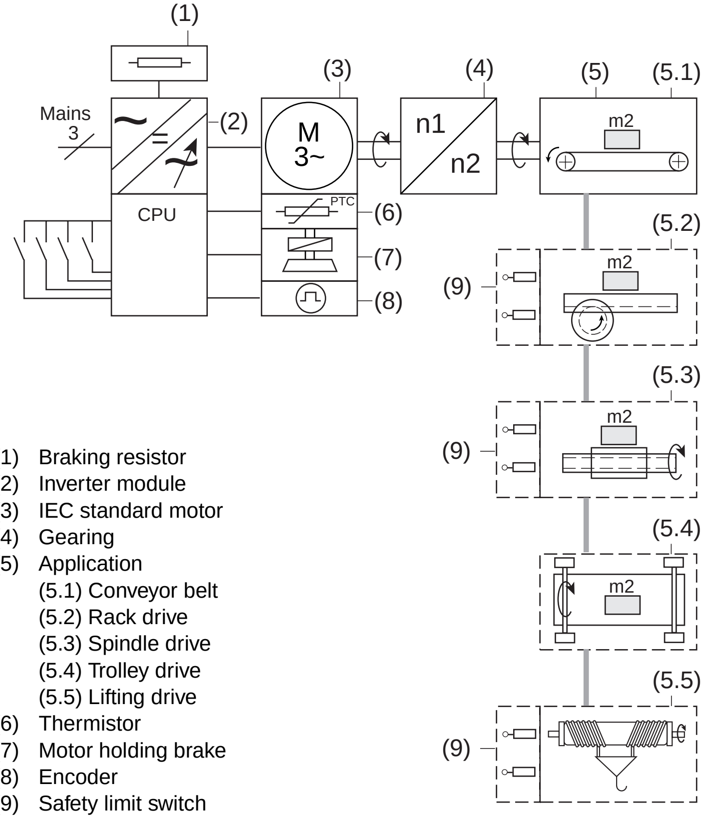
Table 4.8 Application-specific basic settings

Application data set: “Master-/Slave operation”

Application data set	Application
Master-/Slave operation Section 4.3.4	

4.3.1 Traction and lifting drive

Loading of application data set 1 into the RAM causes the inverter module automatically to adopt the configuration of the software functions as well as all inputs and outputs for the "traction and lifting drive" application (see Figure 4.13).



(1) Braking resistor
(2) Inverter module
(3) IEC standard motor
(4) Gearing
(5) Application
    (5.1) Conveyor belt
    (5.2) Rack drive
    (5.3) Spindle drive
    (5.4) Trolley drive
    (5.5) Lifting drive
(6) Thermistor
(7) Motor holding brake
(8) Encoder
(9) Safety limit switch

Figure 4.13 Drive solution: "traction and lifting drive"

Overview of traction and lifting drive

The assistance parameter “ASTER” provides a further automatic configuration of the inputs and outputs.

With the aid of the assistance parameter you are able to activate five different traction and lifting drive solution at the press of a button, without having to read through the Operation Manual in detail to do so.

Setting of parameter ASTER for traction and lifting drives

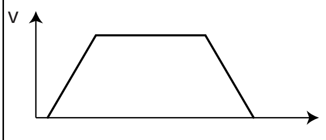
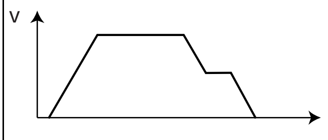
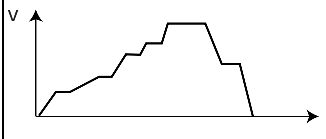
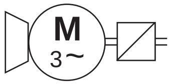
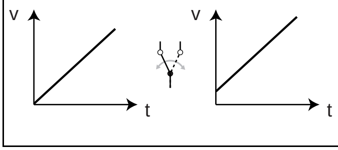
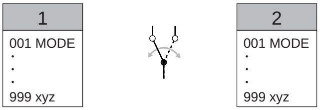
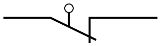
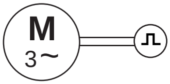
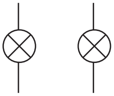
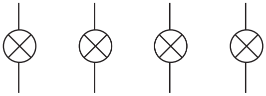
Function	ASTER =	DRV_1[1]	DRV_2[2]	DRV_3[3]	DRV_4[4]	DRV_5[5]
	Quick jog driving profile	✔	✔	✔	✔	✔
	Quick jog/slow jog driving profile	✔	✔	✔		✔
	Table sets with fixed frequencies and ramps					✔
	Motor brake actuation	✔	✔	✔	✔	✔
	Characteristic data switchover for load adjustment		✔			

Table 4.9 Application-specific basic settings

Function	ASTER =	DRV_1 1)	DRV_2 2)	DRV_3 3)	DRV_4 4)	DRV_5 5)
	User data set switchover		✔	✔	✔	✔
	Limit switch evaluation			✔		✔
	Encoder evaluation (necessary for control mode FOR)				✔	✔
	Messages: • Ready to start • Speed reached	✔	✔	✔	✔	✔
	Warnings: • Inverter module overloaded • 80% of IN reached • Motor overloaded • Inverter ambient temperature too high					✔

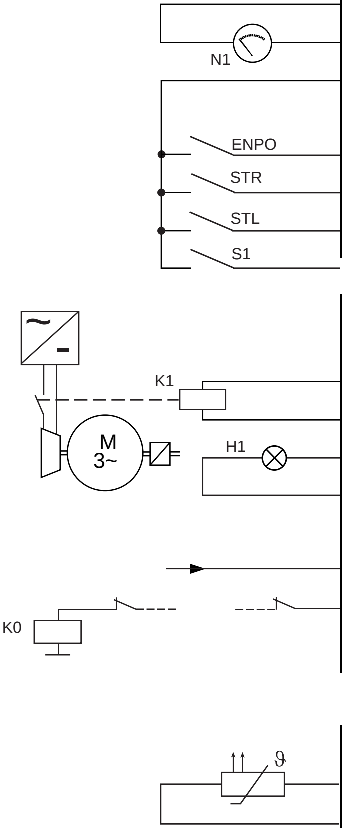
1) DRV_1 (Page 27) 2) DRV_2 (Page 29) 3) DRV_3 (Page 31)
4) DRV_4 (Page 34) 5) DRV_5 (Page 36)

Table 4.9 Application-specific basic settings

(ASTER = DRV_1)

Traction and lifting drive (configuration 1)

Function	Application
• Clock drive with time-optimized quick jog driving profile or • Quick jog/slow jog driving profile	• Conveyor belt • Trolley drive • Rack drive • Spindle drive • etc.

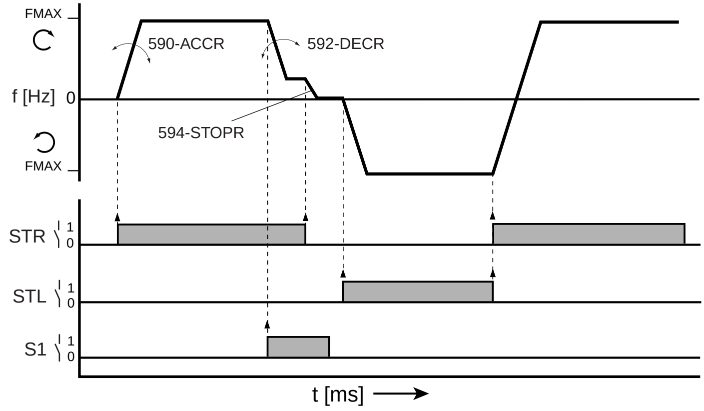


X2	Function
1	Reference voltage 10V, 10mA
2	not assigned
3	not assigned
4	Actual frequency 0 ... 10 V corresponding to 0 ... FMAX
5	
6	Auxiliary voltage 24 V max. 200 mA
7	
8	Power stage hardware enable
9	Start/Stop quick jog clockwise
10	Start/Stop quick jog anti-clockwise
11	Selection of slow jog
12	not assigned
13	Auxiliary voltage 24 V
14	Output signal for Motor holding brake
15	
16	“Reference reached” message
17	Digital ground
18	Relay contact (break)
19	Relay contact (make) for "ready" signal
20	

X3	Function
1	Motor PTC evaluation
2	

Figure 4.14 Control terminal assignment with ASTER=DRV_1

Input signals



ACCR Acceleration ramp
DECR Braking ramp
STOPRStop ramp

Figure 4.15 Example of a quick jog/slow jog driving profile for two directions of rotation (ASTER=DRV_1)

Output signals

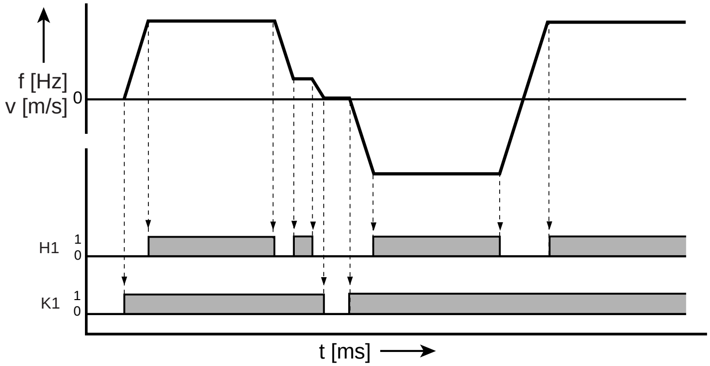


Figure 4.16 Output signals dependent on driving profile (ASTER = DRV_1 to DRV_5)

(ASTER=DRV_2)

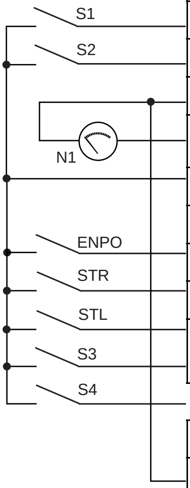
Traction and lifting drive (configuration 2)

Function

- Clock drive with time-optimized quick jog driving profile or
- Quick jog/slow jog driving profile
- Application switchover
- Switchover of setting when load changed

Application

- Conveyor belt
- Trolley drive
- Rack drive
- Spindle drive
- Lifting drive
- etc.

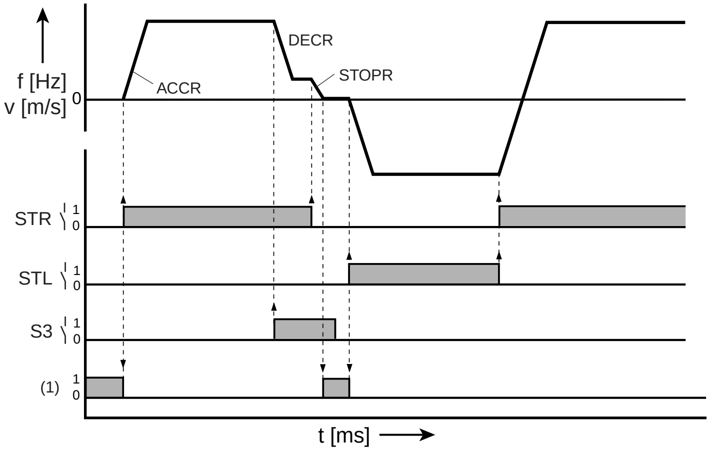


X2	Function (1...10)
1	Reference voltage 10 V, 10 mA
2	User data set selection
3	
4	Actual frequency 0 ... 10 V corresponding to 0 ... FMAX
5	
6	Auxiliary voltage 24 V max. 200 mA
7	
8	Power stage hardware enable
9	Start/Stop quick jog clockwise
10	Start/Stop quick jog anti-clockwise
11	Selection of slow jog
12	Characteristic data set switchover
13	Auxiliary voltage 24 V
14	DGND

Figure 4.17 Control terminal assignment with ASTER=DRV_2

The remaining configuration of control terminals X2:15 to 20 (outputs) and X3 is as shown in Figure 4.14 and Figure 4.16.

Input signals



(1) DC braking torque

Figure 4.18 Example of use of the control terminal presetting with ASTER = DRV_2

The output signals are shown in Figure 4.16.

User data set switchover (switchable offline)

S1	S2	Active UDS	Example
0	0	UDS 1 for application 1	x-axis, traction drive
1	0	UDS 2 for application 2	y-axis, traction drive
0	1	UDS 3 for application 3	z-axis, lifting drive
1	1	UDS 4 for application 4	Sorting belt

Table 4.10 User data set switchover

Characteristic data set switchover (switchable online)

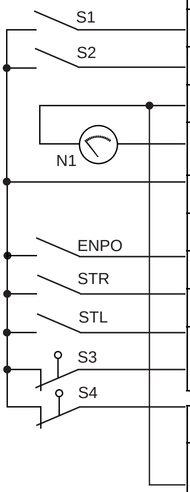
S4	Active characteristic data set	Example
0	Characteristic data set 1	Lifting drive with load
1	Characteristic data set 2	Lifting drive without load

Table 4.11 Characteristic data set switchover

(ASTER=DRV_3)

Traction and lifting drive (configuration 3)

Function	**Application**
• Clock drive with time-optimized quick jog driving profile or • Quick jog/slow jog driving profile • Application switchover • Evaluation of safety limit switches	• Rack drive • Spindle drive • Trolley drive • Lifting drive • etc.

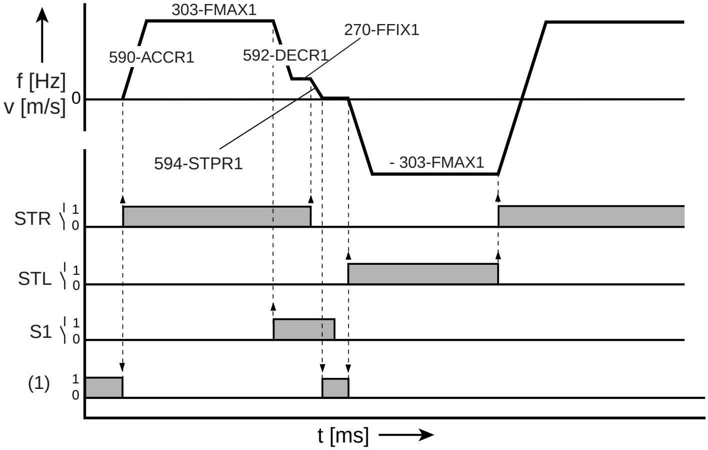


X2	Function
1	Reference voltage 10 V, 10 mA
2	User data set switchover
3	Selection of slow jog
4	Actual frequency 0 ... 10 V corresponding to 0 ... FMAX
5	
6	Auxiliary voltage 24 V max. 200 mA
7	
8	Power stage hardware enable
9	Start/Stop quick jog clockwise
10	Start/Stop quick jog anti-clockwise
11	Limit switch right
12	Limit switch left
13	Auxiliary voltage 24 V
14	DGND

Figure 4.19 Control terminal assignment with ASTER=DRV_3

The remaining configuration of control terminals X2:15 to 20 (outputs) and X3 is as shown in Figure 4.14 and Figure 4.16.

Input signals



(1) DC braking torque

Figure 4.20 Example of use of the control terminal default with ASTER=3

The output signals are shown in Figure 4.16.

User data set switchover (switchable offline)

S1	Active UDS	Example
0	UDS 1 for application 1	x-axis, traction drive
1	UDS 2 for application 2	z-axis, lifting drive

Table 4.12 User data set switchover

Limit switch evaluation

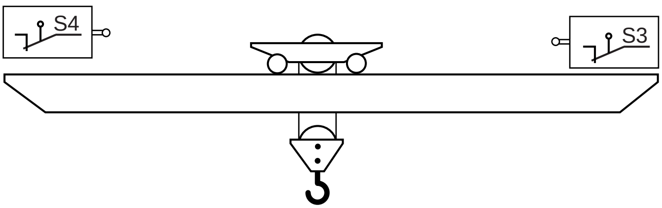


Figure 4.21 Example of a limit switch evaluation

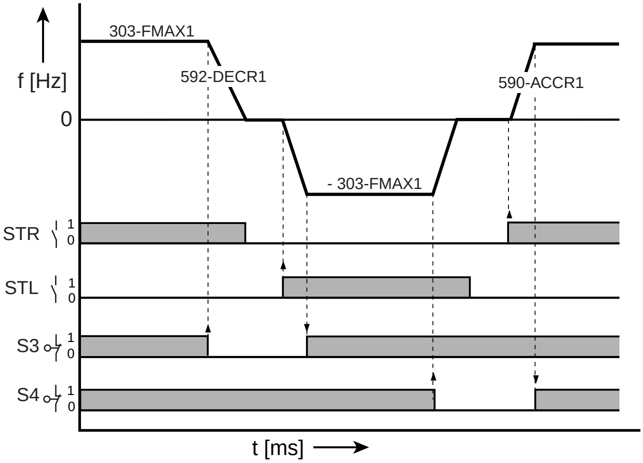


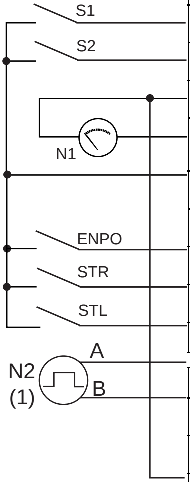
Figure 4.22 Limit switch evaluation of S4 and S3
Example: *Limit switch right resets Start Clockwise. Resetting of Start Clockwise is not evaluated. The Start Anti-clockwise command can be used to move out of the limit switch zone.*

The limit switch must not be overrun. The signal must be applied continuously (no pulse evaluation).

(ASTER=DRV_4)

Traction and lifting drive (configuration 4)

Function	**Application**
- Clock drive with time-optimized quick jog driving profile - Switchover for application - Encoder evaluation	- Conveyor belt - Rack drive - Spindle drive - Trolley drive - Lifting drive - etc.



X2	Function
1	Reference voltage 10 V, 10 mA
2	User data set switchover
3	
4	Actual frequency 0 ... 10 V corresponding to 0 ... FMAX
5	
6	Auxiliary voltage 24 V max. 200 mA
7	
8	Power stage hardware enable
9	Start/Stop clockwise
10	Start/Stop anti-clockwise
11	Encoder track A
12	Encoder track B
13	Auxiliary voltage 24 V
14	DGND

Figure 4.23 Control terminal assignment with ASTER=DRV_4

(1) The encoder is evaluated only in control mode FOR.

The remaining configuration of control terminals X2:15 to 20 (outputs) and X3 is as shown in Figure 4.14 and Figure 4.16.

A HTL encoder (see Figure 4.24) can be connected to terminals X2:11 and 12. Permissible pulse counts are in the range from 32 pulses per rev to 16384 pulses per rev (2^n where n=5 to 14).

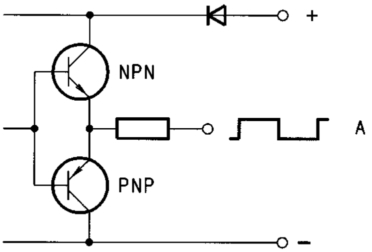


Figure 4.24 Block diagram, HTL output circuit

Input signals

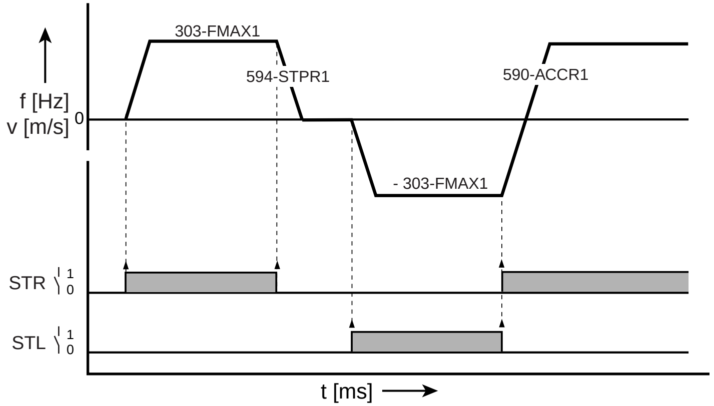


Figure 4.25 Example of a quick jog driving profile for two directions of rotation (ASTER=DRV_4)

The output signals are shown in Figure 4.14.

User data set switchover (switchable offline)

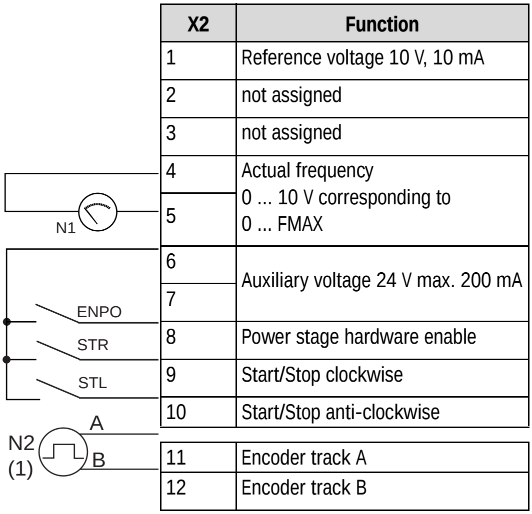
S1	S2	Active UDS	Example
0	0	UDS 1 for application 1	x-axis, traction drive
1	0	UDS 2 for application 2	y-axis, traction drive
0	1	UDS 3 for application 3	z-axis, lifting drive
1	1	UDS 4 for application 4	Sorting belt

Table 4.13 User data set switchover

(ASTER=DRV_5)

Traction and lifting drive (configuration 5)

Function	**Application**
• Clock drive with time-optimized quick jog driving profile • Selection of fixed frequencies • Encoder evaluation • Limit switch evaluation • Switchover of applications	• Conveyor belt • Rack drive • Trolley drive • Spindle drive • Lifting drive



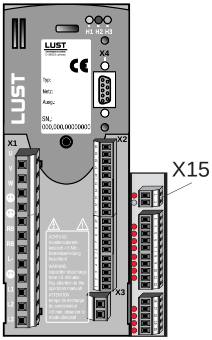
X2	Function
1	Reference voltage 10 V, 10 mA
2	not assigned
3	not assigned
4	Actual frequency 0 ... 10 V corresponding to 0 ... FMAX
5	
6	Auxiliary voltage 24 V max. 200 mA
7	
8	Power stage hardware enable
9	Start/Stop clockwise
10	Start/Stop anti-clockwise
11	Encoder track A
12	Encoder track B

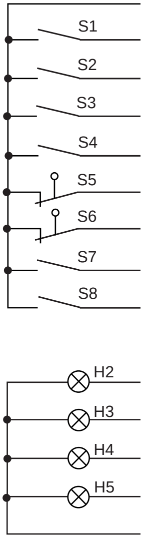
Figure 4.26 Control terminal assignment with ASTER=DRV_5

(1) The encoder is evaluated only in control mode FOR. For notes on the encoder see also Figure 4.24.

The configuration of control terminals X2:13 to 20 (outputs) and X3 is as shown in Figure 4.14 and Figure 4.16.

Control terminals of user module UM-8I4O





X15	Function
1	24 V supply +20%, 0.6 A
2	Digital ground
21	Auxiliary voltage 24 V
22	Selection of table sets for fixed frequencies
23	
24	
25	
26	Limit switch right
27	Limit switch left
28	User data set switchover
29	
30	Digital ground
31	Warning “Inverter module overloaded”
32	Warning “Motor overloaded”
33	Warning “80% of I_N exceeded”
34	Warning “Ambient temperature too high”
35	Digital ground

Figure 4.27 Assignment of control terminal expansion with ASTER=DRV_5

Input signals

v/t diagram

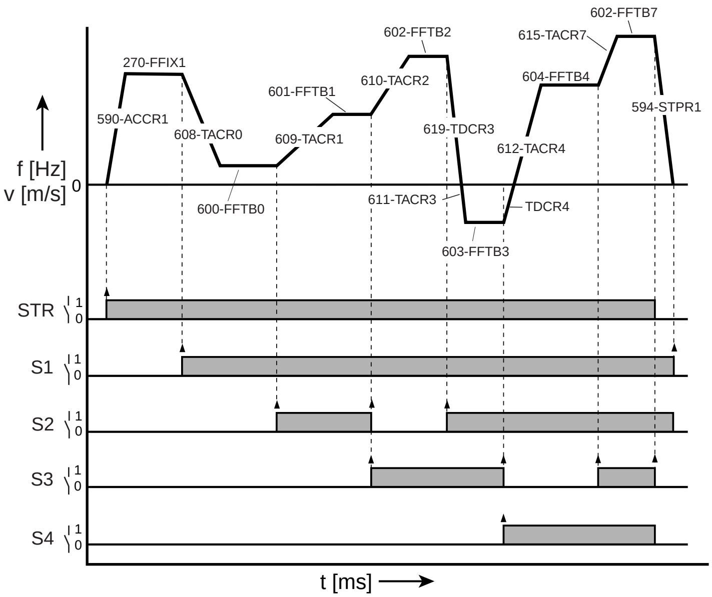


Figure 4.28 Example of use of table sets with fixed frequencies and ramps (ASTER=DRV_5)

The configuration of control terminals X2:13 to 20 (outputs) and X3 is as shown in Figure 4.14 and Figure 4.16.

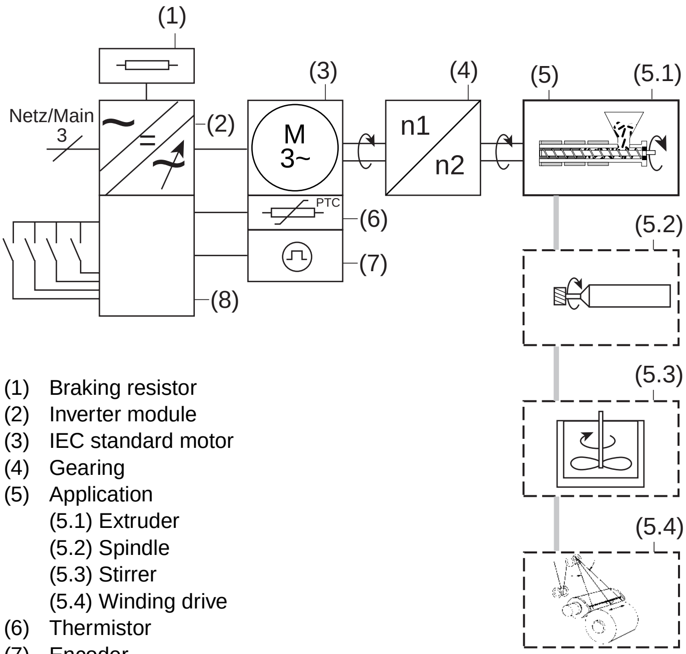
User data set switchover (switchable offline)

S1	S2	Active UDS	Example
0	0	UDS 1 for application 1	x-axis, traction drive
1	0	UDS 2 for application 2	y-axis, traction drive
0	1	UDS 3 for application 3	z-axis, lifting drive
1	1	UDS 4 for application 4	Sorting belt

Table 4.14 User data set switchover

4.3.2 Rotational drive

Loading of application data set 2 into the RAM causes the inverter module automatically to adopt the configuration of the software functions as well as all inputs and outputs for the "rotational drive" application (see Figure 4.29).



- (1) Braking resistor
- (2) Inverter module
- (3) IEC standard motor
- (4) Gearing
- (5) Application
  - (5.1) Extruder
  - (5.2) Spindle
  - (5.3) Stirrer
  - (5.4) Winding drive
- (6) Thermistor
- (7) Encoder
- (8) Control unit

Figure 4.29 Drive solution: "rotational drive"

Overview of rotational drives

The assistance parameter “ASTER” provides a further automatic configuration of the inputs and outputs.

With the aid of the assistance parameter you are able to activate five different traction and lifting drive solution at the press of a button, without having to read through the Operation Manual in detail to do so.

Setting of assistance parameter ASTER for rotational drives

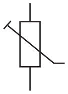
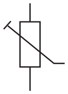
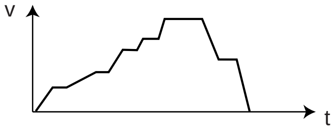
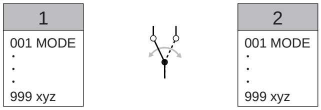
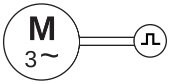
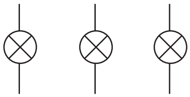
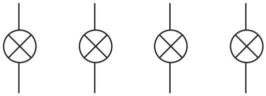
Function	Aster =	ROT_1 1)	ROT_2 2)	ROT_3 3)
	Speed input -10 V ... +10 V switchable to 0 ... 10 V, 0(4) ... 20 mA	✓	✓	✓
	Speed correction 0 to 10 V		✓	✓
	Speed change via button (MOP function)	✓		
	Table sets with fixed frequencies and ramps			✓
	User data set switchover			✓
	Encoder evaluation (necessary for control mode FOR)		✓	✓

Table 4.15 Application-specific basic settings

Function	Aster =	ROT_1 1)	ROT_2 2)	ROT_3 3)
	Messages: • Reference reached • Standstill • Ready to start	✔	✔	✔
	Warnings: • Inverter module overloaded • 80% of IN reached • Motor overloaded • Inverter ambient temperature too high			✔

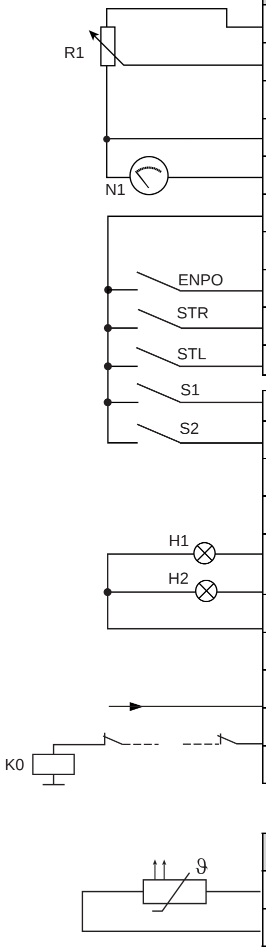
1) ROT_1 (Page 42) 2) ROT_2 (Page 44) 3) ROT_3 (Page 46)

Table 4.15 Application-specific basic settings

(ASTER=ROT_1)

Rotational drive (configuration 6)

Function	Application
- Analog speed input for two directions of rotation - Adjustment of speed via button (MOP function)	- Spindle - Winding drive - Vacuum pumps - Extruder - Stirrer - etc.



X2	Function
1	Reference voltage 10 V, 10 mA
2	Reference -10 V ... + 10 V
3	not assigned
4	Actual frequency 0 ... 10V corr. to 0 ... FMAX
5	
6	Auxiliary voltage 24V max. 200 mA
7	
8	Power stage hardware enable
9	Start/Stop clockwise
10	Start/Stop anti-clockwise
11	Increase speed
12	Reduce speed
13	Auxiliary voltage 24 V
14	Digital ground
15	Message: “References reached”
16	Standstill
17	Digital ground
18	Relay contact (break)
19	Relay contact (make) for "ready" signal
20	

X3	Function
1	Motor PTC evaluation Function inactive
2	

Figure 4.30 Control terminal assignment with ASTER=ROT_1

Input signals

v/t diagram

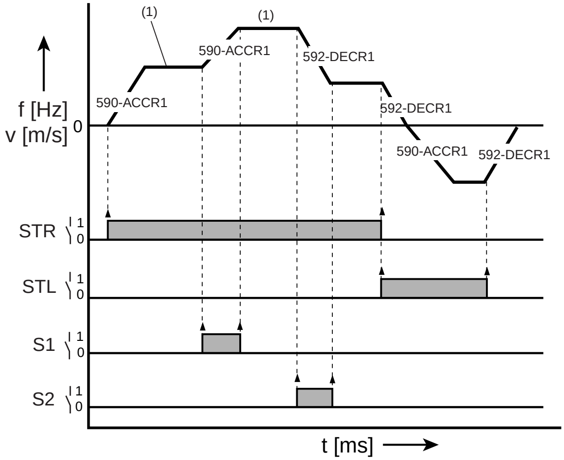
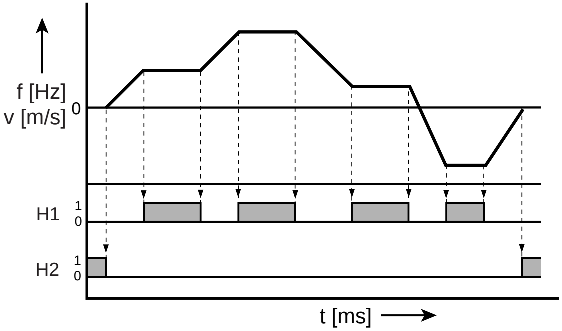


Figure 4.31 Example of a driving profile for two directions of rotation (ASTER=ROT_1)

Output signals



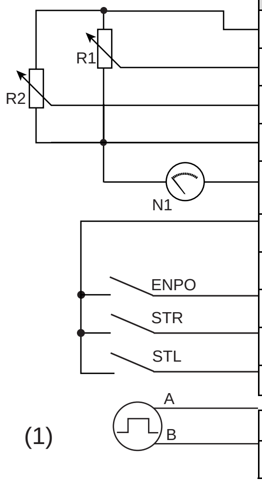
H1 Speed reached
H2 Standstill

Figure 4.32 Output signals dependent on driving profile (ASTER=ROT_1, ROT_2 and ROT_4)

(ASTER=ROT_2)

Rotational drive (configuration 7)

Function	**Application**
• Analog speed input for two directions of rotation • Adjustment of speed via correction value • Encoder evaluation	• Spindle • Winding drive • Extruder • etc.



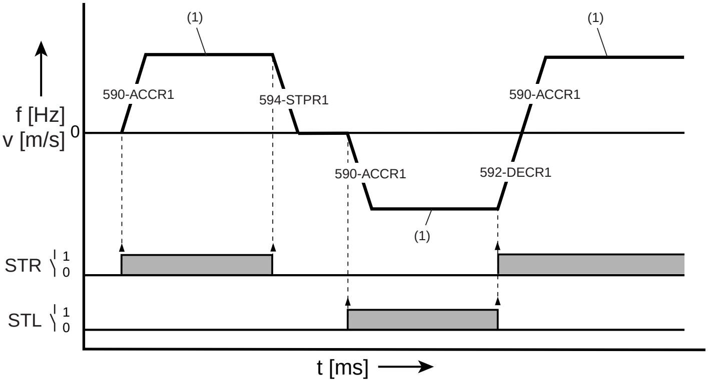
X2	Function
1	Reference voltage 10 V, 10 mA
2	Reference -10 V ... 10 V
3	Correction value 0 V ... + 10 V
4	Actual frequency 0 ... 10 V corresponding to 0 ... FMAX
5	
6	Auxiliary voltage 24 V max. 200 mA
7	
8	Power stage hardware enable
9	Start/Stop clockwise
10	Start/Stop anti-clockwise
11	Encoder track A
12	Encoder track B

Figure 4.33 Control terminal device with ASTER=ROT_2

(1) The encoder is evaluated only in control mode FOR. For notes on the encoder see also Figure 4.24.

The configuration of control terminals X2:13 to 20 and X3 is as shown in Figure 4.30 and Figure 4.32.

Input signals



(1) Reference value of ISA00

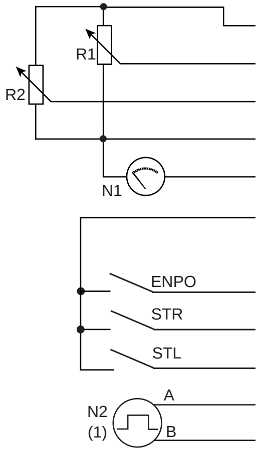
Figure 4.34 Example of a driving profile for two directions of rotation (ASTER=ROT_2)

The output signals are shown in Figure 4.32.

(ASTER=ROT_3)

Rotational drive (configuration 8)

Function	Application
Analog speed input for two directions of rotation Adjustment of speed via correction value Selection of fixed frequencies Switchover of applications Encoder evaluation	Spindle Winding drive etc.



X2	Function
1	Reference voltage 10 V, 10 mA
2	Reference -10 V ... +10 V
3	Correction value 0 V ... + 10 V
4	Actual frequency 0 ... 10 V corresponding to 0 ... FMAX
5	
6	Auxiliary voltage 24 V max. 200 mA
7	
8	Power stage hardware enable
9	Start/Stop clockwise
10	Start/Stop anti-clockwise
11	Encoder track A
12	Encoder track B

Figure 4.35 Control terminal assignment with ASTER=ROT_3

(1) The encoder is evaluated only in control mode FOR. For notes on the encoder see also Figure 4.24.

The configuration of control terminals X2:13 to 20 (outputs) and X3 is as shown in Figure 4.30 and Figure 4.32.

X15	Function
1	24 V supply ± 20 %, 0.6 A
2	Digital ground
21	Auxiliary voltage 24 V
22	Selection of table sets for fixed frequencies
23	
24	
25	
26	User data set selection
27	
28	not assigned
29	
30	Digital ground
31	Warning “Inverter module overloaded”
32	Warning “Motor overloaded”
33	Warning “80% of I_N exceeded”
34	Warning “Ambient temperature too high”
35	Digital ground

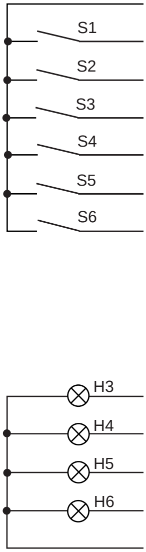


Figure 4.36 Assignment of control terminal expansion with ASTER=ROT_3

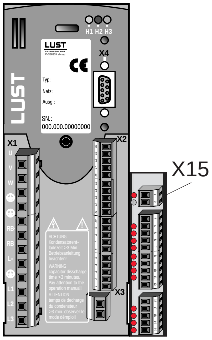


Figure 4.37 Position of terminal strip X5

Input signals

v/t diagram

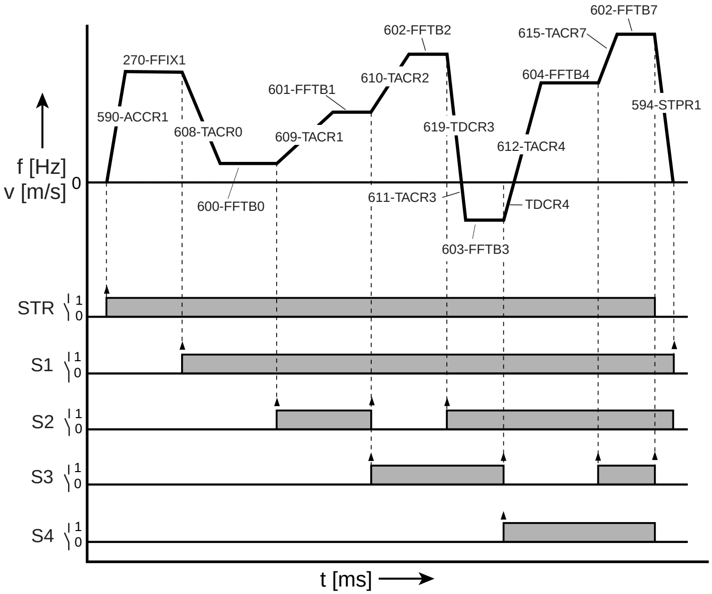


Figure 4.38 Example of use of table sets with ramps (ASTER=ROT_3)

The output signals are shown in Figure 4.32.

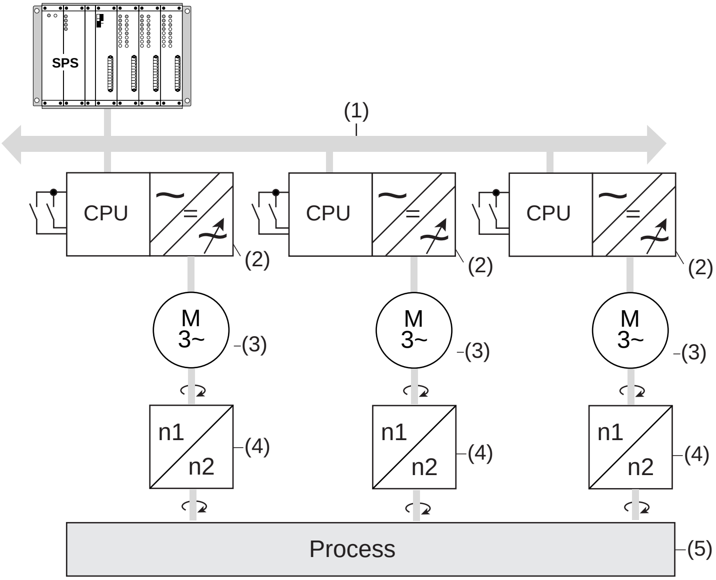
User data set switchover (switchable offline)

S1	S2	Active UDS	Example
0	0	UDS 1 for application 1	Spindle 1
1	0	UDS 2 for application 2	Spindle 2
0	1	UDS 3 for application 3	Spindle 3
1	1	UDS 4 for application 4	Sorting belt

Table 4.16 User data set switchover

4.3.3 Field bus operation

Loading application data set 3 presets the inverter functions for field bus operation. This requires that an appropriate communication module is fitted to the CDA3000.



(1) Field bus
(2) Inverter module
(3) IEC standard motor
(4) Gearing
(5) Application

Figure 4.39 Drive solution: "Field bus operation"

Setting of parameter ASTER for field bus operation

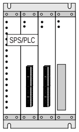
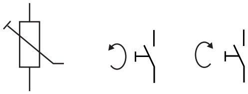
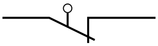
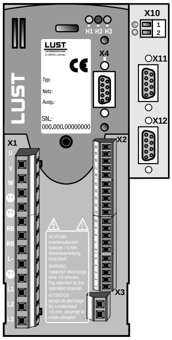
Function	ASTER	BUS_1 1)	BUS_2 2)	BUS_3 3)
	Reference and control via PLC	✔	✔	✔
IN1 IN2 IN3 IN4 OUT1 OUT2 OUT3	Digital inputs and outputs readable and writable over the bus	✔		
	Manual mode independent of bus		✔	✔
	Limit switch evaluation			✔
1) BUS_1 (Page 51) 2) BUS_2 (Page 52) 3) BUS_3 (Page 54)				

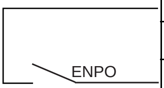
Table 4.17 Preset control terminal functionality

(ASTER=BUS_1)

Field bus operation (configuration 9)

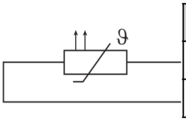
Function	Application
• Control of the inverter module over the field bus • All digital inputs and outputs can be set and read over the bus.	• Traction and lifting drive • Rotational drive





X2	Function (1...10)
1	Reference voltage 10V, 10mA
2	Analog input 1
3	Analog input 2
4	Analog ground
5	Analog output
6	Auxiliary voltage 24 V max. 200 mA
7	
8	Power stage hardware enable
9	Digital input 1
10	Digital input 2

11	Digital input 3
12	Digital input 4
13	Auxiliary voltage 24 V
14	Digital ground
15	Digital output 1:
16	Digital output 2:
17	Digital ground
18	Digital output 3:
19	Relay with
20	changeover contact



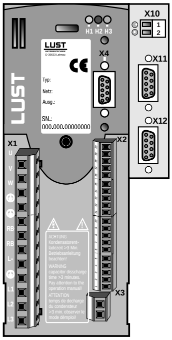
X3	Function
1	Motor PTC connection Function inactive
2	

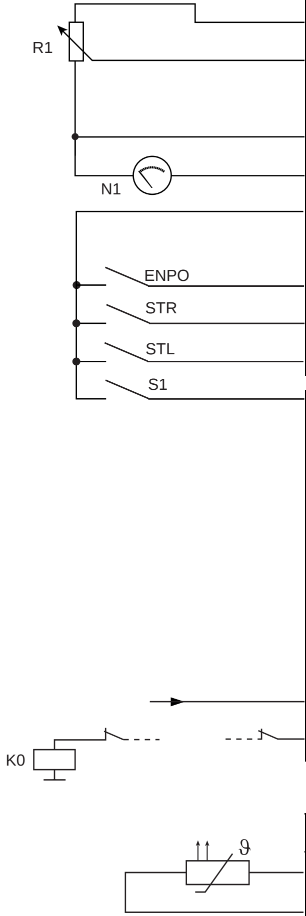
Figure 4.40 Control terminal configuration with ASTER=BUS_2

(ASTER=BUS_2)

Field bus operation (configuration 10)

Function	Application
• Control of the inverter module over the field bus • Control of the device in emergency also independently of field bus • Manual/automatic switchover • Setting and reading of digital inputs and outputs over the bus	• Traction and lifting drive • Rotational drive



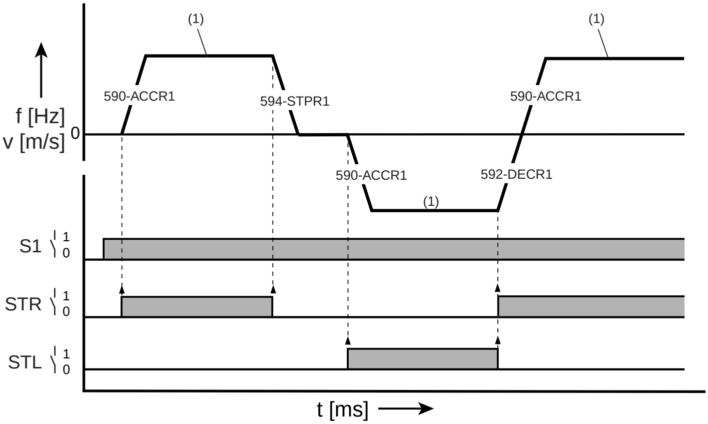


X2	Function
1	Reference voltage 10 V, 10 mA
2	Reference for manual mode 0 V ... +10 V
3	not assigned
4	Actual frequency 0 ... 10 V corr. to 0 ... FMAX
5	
6	Auxiliary voltage 24 V max. 200 mA
7	
8	Power stage hardware enable
9	Start/Stop clockwise for manual mode
10	Start/Stop anti-clockwise for manual
11	Selection of manual mode
12	Digital input
13	Auxiliary voltage 24 V
14	Digital ground
15	Digital output 1:
16	Digital output 2:
17	Digital ground
18	Relay contact (break)
19	Relay contact (make) for "ready" signal
20	

X3	Function
1	Motor PTC connection Function inactive
2	

Figure 4.41 Control terminal configuration with ASTER=BUS_2

Input signals



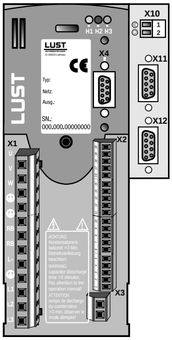
(1) Analog reference value of ISA00

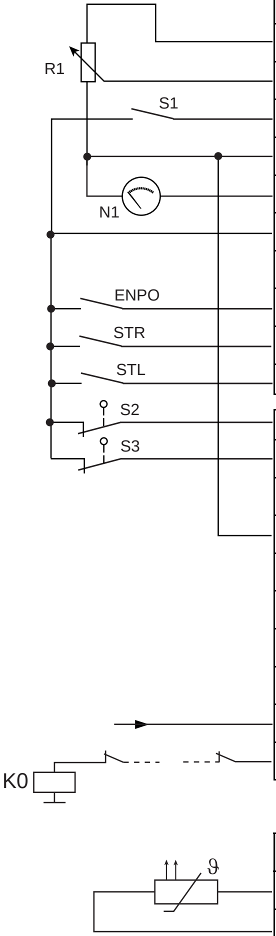
Figure 4.42 Example of use of manual mode independent of bus mode ASTER=BUS_2

(ASTER=BUS_3)

Field bus operation (configuration 11)

Function	Application
• Control of the inverter module over the field bus • Control of the device in emergency also independently of bus • Manual/automatic switchover • Evaluation of safety limit switches	• Traction and lifting drive





X2	Function
1	Reference voltage 10 V, 10 mA
2	Reference for manual mode 0 V ... +10
3	Selection of manual mode
4	Actual frequency 0 ... 10 V corr. to 0 ... FMAX
5	
6	Auxiliary voltage 24 V max. 200 mA
7	
8	Power stage hardware enable
9	Start/Stop clockwise for emerg.op.
10	Start/Stop anti-clockwise for
11	Limit switch right
12	Limit switch left
13	Auxiliary voltage 24 V
14	Digital ground
15	Digital output 1:
16	Digital output 2:
17	Digital ground
18	Relay contact (break)
19	Relay contact (make) for "ready" signal
20	

X3	Function
1	Motor-PTC connection Evaluation inactive
2	

Figure 4.43 Control terminal configuration with ASTER=BUS_3

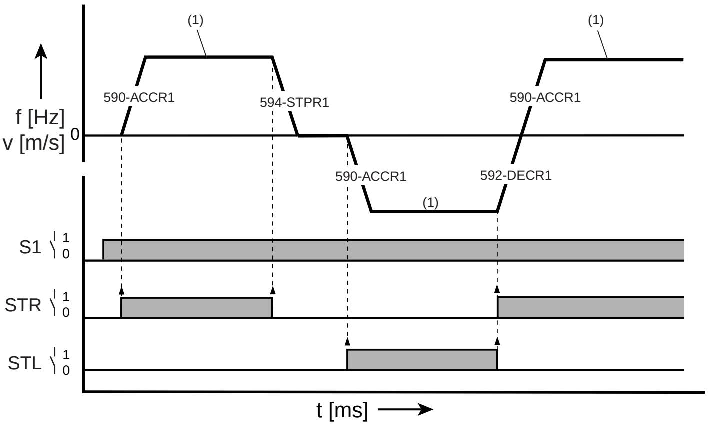
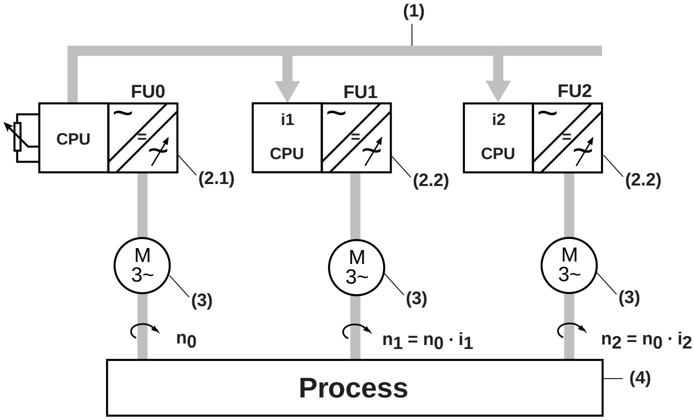


Figure 4.44 Example of use of emergency operation independent of bus mode ASTER=BUS_3

The mode of functioning of the limit switch evaluation is shown in Figure 4.21 and Figure 4.22.

4.3.4 Master-/Slave operation

Application data set 4 includes a setup for Master-/Slave operation between inverter modules. In this way the speeds of a maximum of six drives are permanently coupled together.



(1) Reference coupling
(2) Inverter module
(2.1) Master
(2.2) Slave
(3) IEC standard motor
(4) Application

Figure 4.45 Drive solution: “Master-/Slave operation”

In Master-/Slave operation the reference values of the inverter modules are permanently coupled together. This reference coupling can be effected with up to six units, with one unit being the master. The reference value of the master is also the guide value for the devices connected to the master (slaves). The master transmits the reference value to the slaves by way of a data telegram. In each slave the guide value received from the master can be scaled, meaning that any desired transmission ratios can be set. In this way it is possible to replace mechanical speed couplings.

The coupling of the electrical axles in VFC and SFC control modes causes the motors to run at a fixed ratio to each other. Only in the FOR control mode do the motors run speed-synchronous.

Characteristics of the control methods in comparison

Characteristics	VFC Voltage Frequency Control	SFC Sensorless Flux Control	FOR Field-Oriented Regulation
Speed manipulating range $M=M_{Nom}$	1 : 20	1 : 50	>1 : 10000
Static speed accuracy referred to the nominal speed	typically 1 to 5 %	typically 0.5 %	quartz-accurate
Frequency resolution	0.01 Hz	0.065 Hz	2^{-16} Hz

Table 4.18 Comparison of motor control methods

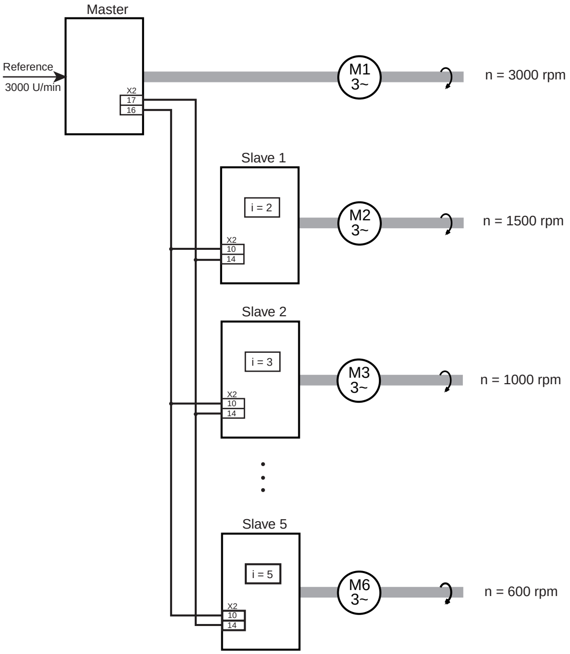


Figure 4.46 Master-/Slave coupling via two control cables

Note: The motors run speed-synchronously, not angle-synchronously. In primary frequency coupling a dead time of max. 2 ms is created between two axles.
A maximum of five slave drives can be connected.

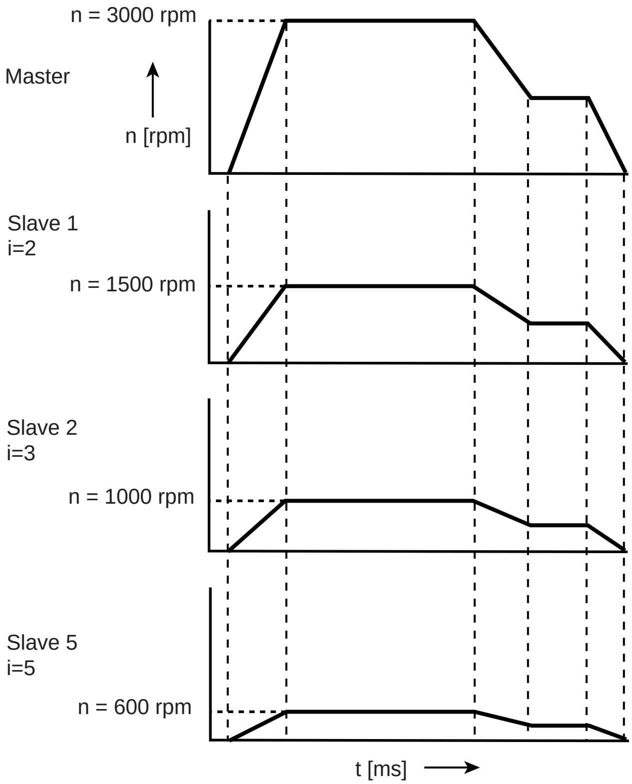
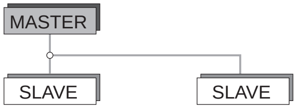
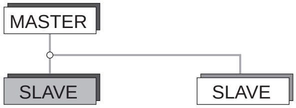
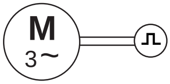
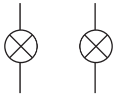


Figure 4.47 Speed curve in Master-/Slave operation

Setting of parameter ASTER for Master-/Slave operation

Function	ASTER	M-S1 1)	M-S2 2)	M-S3 3)	M-S4 4)
	Inverter module is master	✓	✓		
	Inverter module is slave			✓	✓
	Speed change via button (MOP function)	✓		✓	
	Encoder evaluation		✓		✓
	Messages: • Standstill • Ready to start	✓	✓	✓	✓
	Message: • Reference reached			✓	✓

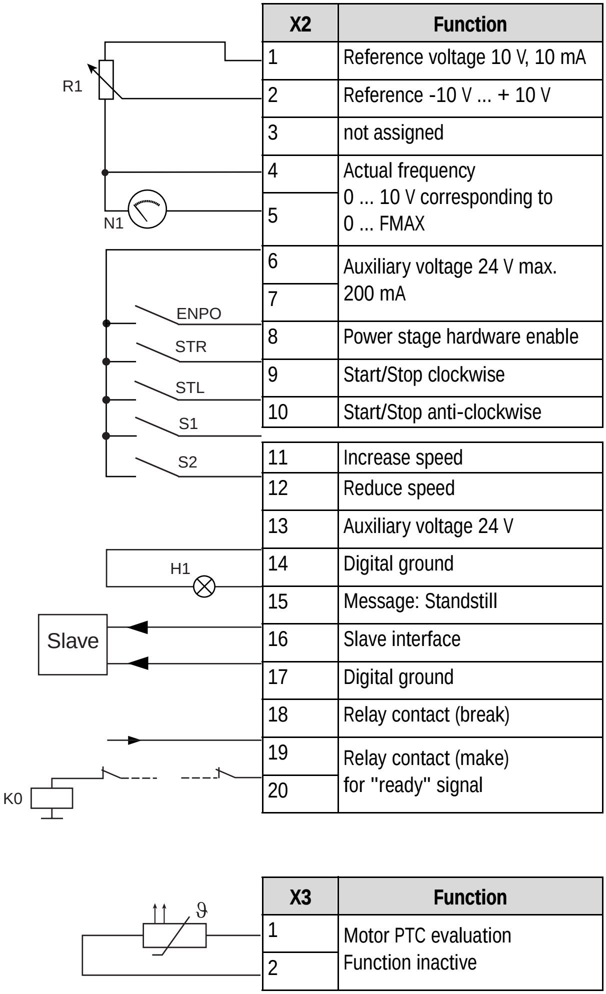
1) M-S1 (Page 60) 2) M-S2 (Page 62) 3) M-S3 (Page 64) 4) M-S4 (Page 66)

Table 4.19 Application-specific basic settings

(ASTER = M-S1)

Master-/Slave operation (configuration 12)

Function	**Application**
- Speed synchronism of several drives with programmable transmission ratio - Inverter module is master - Analog guide value input - Adjustment of guide value via button (MOP function)	- Replacement of mechanical gears and line shafts (not angle-synchronous) - Winding drive - Drafting equipment - Trolley drive



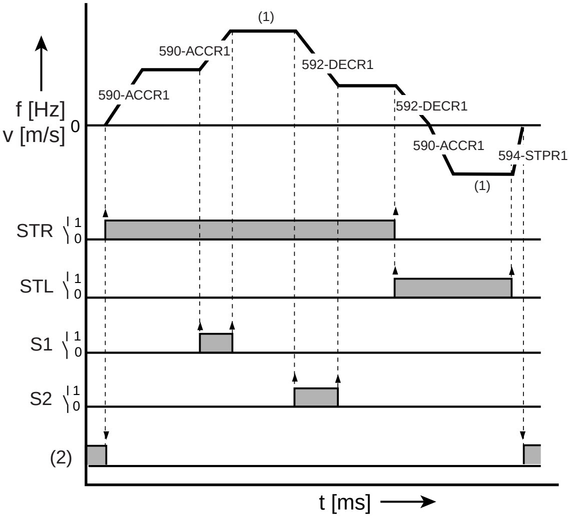
X2	Function
1	Reference voltage 10 V, 10 mA
2	Reference -10 V ... + 10 V
3	not assigned
4	Actual frequency 0 ... 10 V corresponding to 0 ... FMAX
5	
6	Auxiliary voltage 24 V max. 200 mA
7	
8	Power stage hardware enable
9	Start/Stop clockwise
10	Start/Stop anti-clockwise
11	Increase speed
12	Reduce speed
13	Auxiliary voltage 24 V
14	Digital ground
15	Message: Standstill
16	Slave interface
17	Digital ground
18	Relay contact (break)
19	Relay contact (make) for "ready" signal
20	

X3	Function
1	Motor PTC evaluation Function inactive
2	

Figure 4.48 Control terminal assignment with ASTER = M-S1

Input signals

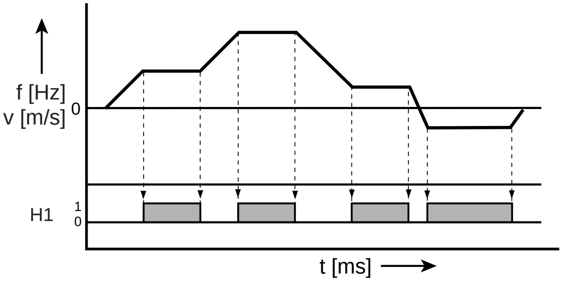
v/t diagram



(1) Analog reference value of ISA00
(2) DC braking torque

Figure 4.49 Example of a driving profile for two directions of rotation (ASTER=M-S1)

Output signals



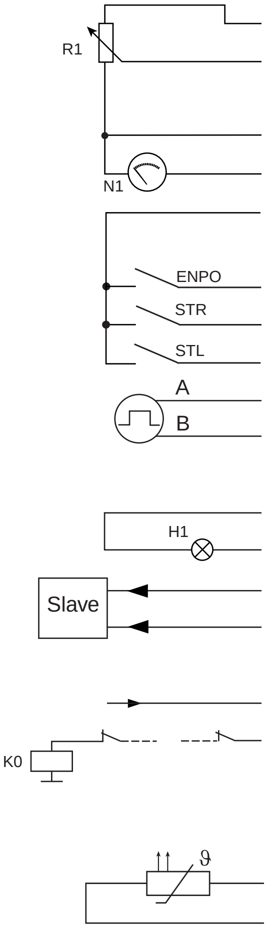
H1 Standstill

Figure 4.50 Output signals dependent on driving profile (ASTER=M-S1 and M-S2)

(ASTER = M-S2)

Master-/Slave operation (configuration 13)

Function	**Application**
• Speed synchronism of several drives with programmable transmission ratio • Inverter module is master • Analog guide value input • Encoder evaluation	• Replacement of mechanical gears and line shafts (not angle-synchronous) • Winding drive • Drafting equipment • Trolley drive

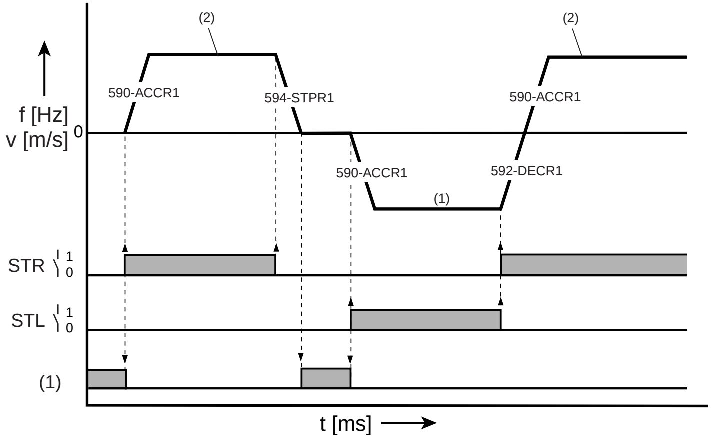


X2	Function
1	Reference voltage 10V, 10mA
2	Reference -10 V ... + 10 V
3	not assigned
4	Actual frequency 0 ... 10V corr. to 0 ... FMAX
5	
6	Auxiliary voltage 24 V max. 200 mA
7	
8	Power stage hardware enable
9	Start/Stop clockwise
10	Start/Stop anti-clockwise
11	Encoder track A
12	Encoder track B
13	Auxiliary voltage 24 V
14	Digital ground
15	Message: Standstill
16	Slave interface
17	Digital ground
18	Relay contact (break)
19	Relay contact (make) for "ready" signal
20	

X3	Function
1	Motor PTC evaluation Function inactive
2	

Figure 4.51 Control terminal assignment with ASTER = M-S2

Input signals



(1) DC braking torque
(2) Analog reference value of ISA00

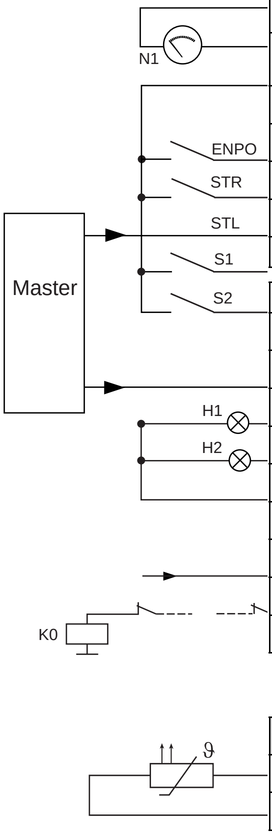
Figure 4.52 Example of a driving profile for two directions of rotation (ASTER=M-S2)

The basic characteristic of the output signals is shown in Figure 4.50.

(ASTER = M-S3)

Master-/Slave operation (configuration 14)

Function	**Application**
• Speed synchronism of several drives with programmable transmission ratio • Inverter module is slave • Adjustment of guide value via button (MOP function)	• Replacement of mechanical gears and line shafts (not angle-synchronous) • Winding drive • Drafting equipment • Trolley drive

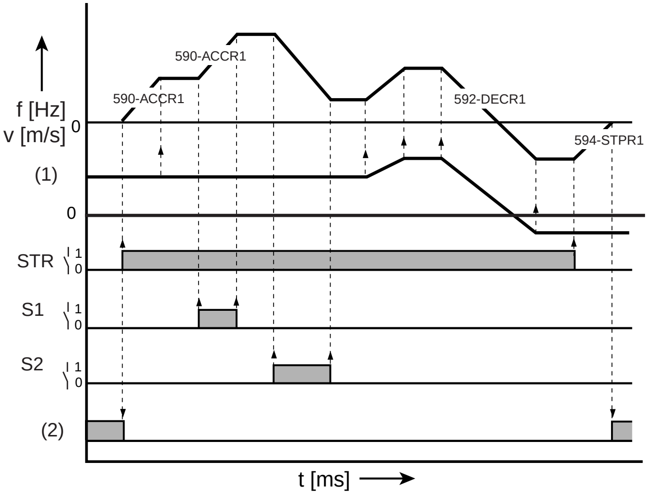


X2	Function
1	Reference voltage 10 V, 10 mA
2	Reference -10 V ... + 10 V
3	not assigned
4	Actual frequency 0 ... 10 V corresponding to 0 ... FMAX
5	
6	Auxiliary voltage 24 V max. 200 mA
7	
8	Power stage hardware enable
9	Start/Stop clockwise
10	Master interface
11	Increase speed
12	Reduce speed
13	Auxiliary voltage 24 V
14	Digital ground
15	“Reference reached” message
16	Message: Standstill
17	Digital ground
18	Relay contact (break)
19	Relay contact (make) for "ready" signal
20	

X3	Function
1	Motor PTC evaluation Function inactive
2	

Figure 4.53 Control terminal assignment with ASTER = M-S3; with S1 and S2 an offset can be added to or subtracted from the guide value

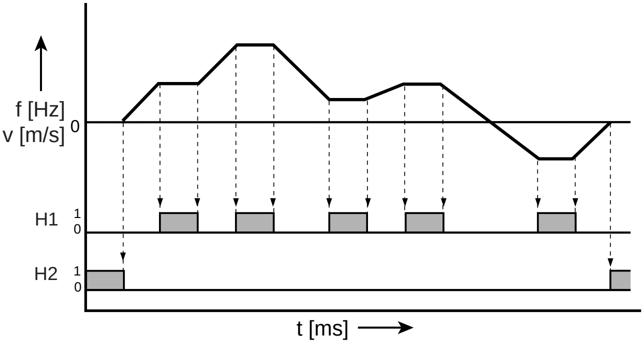
Input signals



(1) Guide value from master
(2) DC braking torque

Figure 4.54 Example of a driving profile with Master-/Slave coupling (ASTER = M-S3)

Output signals



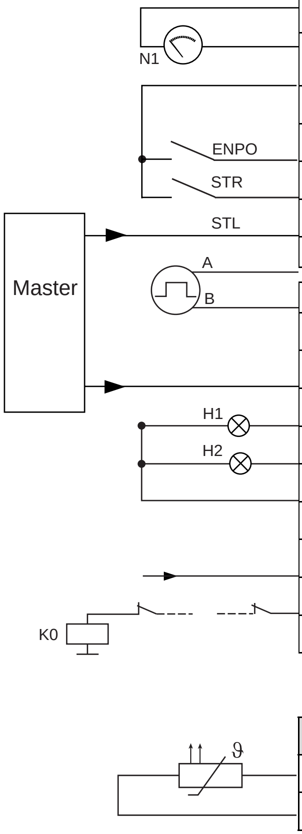
H1 Reference reached
H2 Standstill

Figure 4.55 Output signals dependent on driving profile (ASTER = M-S3 and M-S4)

(ASTER = M-S4)

Master-/Slave operation (configuration 15)

Function	Application
• Speed synchronism of several drives with programmable transmission ratio • Inverter module is slave • Encoder selection	• Replacement of mechanical gears and line shafts (not angle-synchronous) • Winding drive • Drafting equipment • Trolley drive

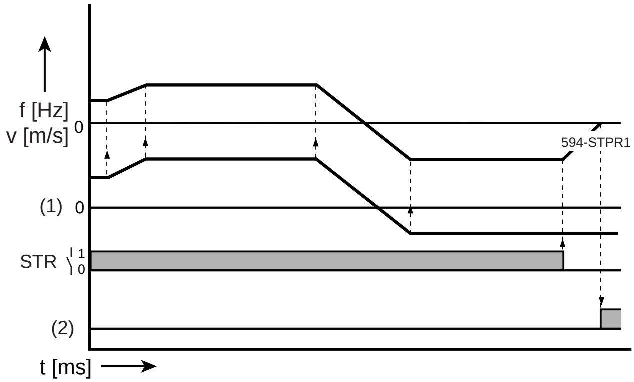


X2	Function
1	Reference voltage 10V, 10mA
2	Reference -10 V ... + 10 V
3	not assigned
4	Actual frequency 0 ... 10 V corresponding to 0 ... FMAX
5	
6	Auxiliary voltage 24 V max. 200 mA
7	
8	Power stage hardware enable
9	Start/Stop clockwise
10	Master interface
11	Encoder track A
12	Encoder track B
13	Auxiliary voltage 24 V
14	Digital ground
15	“Reference reached” message
16	Message: Standstill
17	Digital ground
18	Relay contact (break)
19	Relay contact (make) for "ready" signal
20	

X3	Function
1	Motor PTC evaluation Function inactive
2	

Figure 4.56 Control terminal assignment with ASTER = M-S4

Input signals



(1) Guide value from master
(2) DC braking torque

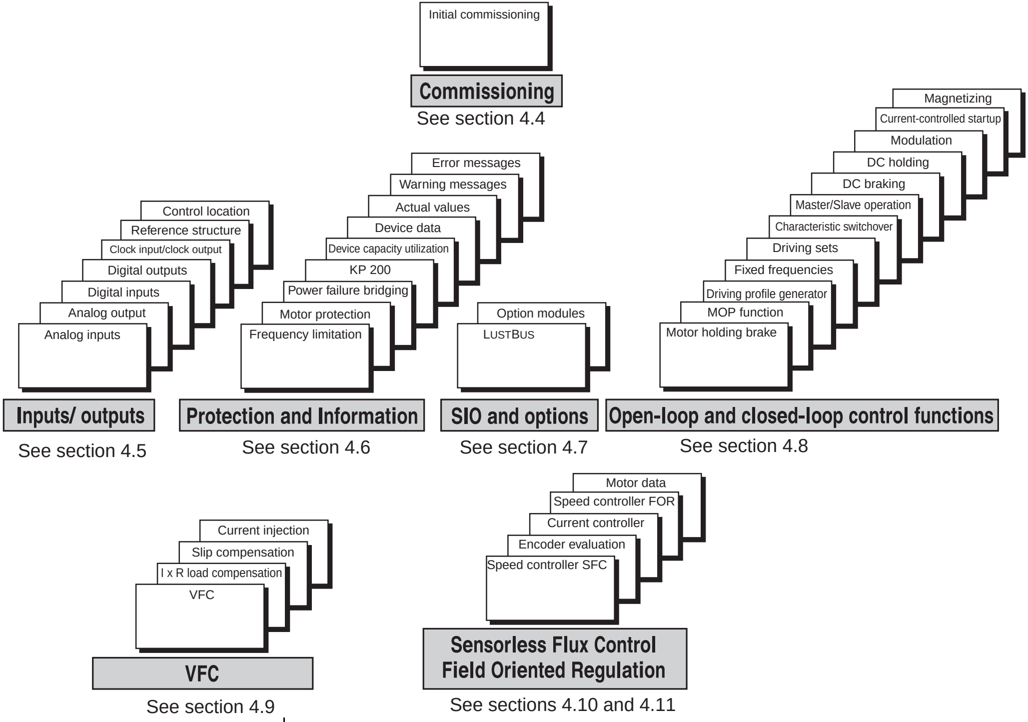
Figure 4.57 Example of a driving profile with Master-/Slave coupling (ASTER = M-S4)

The basic characteristic of the output signals is shown in Figure 4.55.

Software functions/Subject areas

For ease of handling the parameters of the CDA3000 inverter module are assembled into groups. The parameter groups are called subject areas, and permit function-oriented operation.

This section gives an overview of the performance capability of the software functions. For a detailed description of the software functions refer to the CDA3000 Application Manual.



Commissioning

Subject area	Function	Effect
Initial commissioning	Automatic adaptation of the inverter module to the application and the motor. All control circuits are automatically optimized.	Quick commissioning of the inverter module.

Inputs/outputs

Subject area	Function	Effect
Analog inputs	Flexible function assignment and free scaling of the analog inputs	Adaptation of the internal analog input signal processing of the inverter module to the process variables.
Analog outputs	Selection and free scaling of the actual values for delivery at the analog output.	Adaptation of the output variable to the process. Rapid diagnosis and monitoring of actual values with the aid of a simple voltmeter.
Digital inputs	Flexible function assignment of all digital inputs.	The inverter can be used to control the input signals and to influence the reference structure and the open-loop and closed-loop control functions.
Digital outputs	Flexible function assignment of all digital outputs.	The output signals can be used to deliver control signals and process messages.
Control location	Identification of the source from which the control commands (e.g. Start) are received.	The inverter module can be controlled from various locations.
Reference structure	Influencing of the internal processing of reference values.	For special requirements the internal configuration of the reference values can be changed.

Protection and information

Subject area	Function	Effect
Frequency limitation	Limitation of the maximum and definition of the minimum rotating field frequency	The application is protected against excessive speeds. A minimum speed can be defined.
Motor protection	Monitoring of the motor temperature by means of an integral motor circuit-breaker and a thermoswitch or thermistor evaluation.	The motor is protected against destruction due to overheating.
Power failure bridging	After a power failure the inverter module is fed in SFC and FOR mode by the rotational energy of the motor.	A short-time interruption of the mains voltage merely results in a reduction in motor speed, which can be reset to the original level when the power is restored.
KP200	Password setting for the user levels and definition of the permanently visible actual value and a bar graph display	Protection of the inverter module against unauthorized access. An actual value relevant to the process can be read from the KEYPAD.
Device capacity utilization	Storage of the max. current in the phases: Acceleration, stationary operation and deceleration. The mean device capacity utilization is additionally registered.	Good verifiability of the inverter dimensioning and helpful diagnosis of drive system faults.
Device data	Delivery of all data of the inverter module.	Unique identification of the inverter module and the device software.
Display	Display of all information of importance for the drive system.	Rapid diagnosis and monitoring of the drive system.
Warning signals	When a programmable limit value is exceeded for various actual values a warning is delivered.	An impending fault in the drive system is signaled in good time, enabling appropriate countermeasures to be initiated.

Error messages	Display of faults in the drive system with detailed information as to the cause.	Quick localization of the cause of the error.

SIO and options

Subject area	Function	Effect
LustBus	Parameter setting of the diagnostic interface.	Adaptation of the inverter module interface to a PC.
Option modules	Parameter setting of the option modules, e.g. CAN bus address. Parameter setting of the field bus modules and I/O status of the user module.	The option modules are adapted to the field bus and the user module to the process.

Open-loop and closed-loop control functions

Subject area	Function	Effect
Motor holding brake	Actuation of a motor holding brake when a programmable lower frequency limit is infringed.	Safe standstill even when inverter is inactive.
MOP function	Facility to increase or reduce the reference value with two digital inputs.	The motor speed can very easily be adapted to the process by means of two buttons.
Fixed frequencies	Fixed rotating field frequencies selectable by way of digital inputs.	Preprogrammed speeds can be selected by way of a switch.

Driving profile generator	Setting of the acceleration and deceleration times and of the ramp shape (linear, sinusoidal).	Tuning of the motor dynamics to the application.
Driving sets	Facility for setting the parameters of eight fixed frequencies with associated acceleration and deceleration ramps.	Digital selection of fixed frequencies with variable dynamics.
Characteristic data set switchover	Online switchover of the characteristic parameters, driving set parameters and speed control parameters.	Adaptation of the motor to various load situations.
Master-/Slave operation	Speed coupling of several inverter modules with adjustable transmission ratio.	Mechanical transmissions can be replaced in the VFC and SFC control modes by fixed-ratio running. Only in FOR mode is there speed synchronism.
DC braking	Feed of a direct current into the motor, causing it to brake.	No braking resistor is required to stop motors. The braking energy is converted as heat in the motor.
DC holding	Shutdown of the motor after braking with direct current.	Rotation due to the load on the motor is counteracted.
Modulation	Setting of the switching frequency of the inverter power stage.	Optimization of the drive system in terms of power loss, smooth running and noise.
Current-controlled startup	Reduction of the dynamics of acceleration and braking processes when a programmable current limit is reached.	Acceleration and braking processes can be run with max. dynamics without risk of a current overload shut-off. In stationary operation the motor is protected against stalling.

Voltage Frequency Control

Subject area	Function	Effect
V/F characteristic	Adaptation of the inverter module to the motor and to the load characteristic of the application.	The motor generates the optimum torque for the application.
I x R load compensation	Automatic adaptation of the V/F characteristic to the load situation. Compensation for the voltage drop on the stator resistor of the motor.	In case of load surges a higher torque is available, and the motor heats up less.
Slip compensation	Increase in output frequency proportional to the load on the motor.	The slip of the motor is compensated and the speed thereby kept constant independent of the load.
Current injection	An adjustable current is injected into the motor up to a limit frequency.	Increase in starting torque
Remagnetization	Prior to acceleration of the motor a magnetic field is injected into the motor.	When the motor is started the full torque is available immediately.

Sensorless Flux Control / Field Oriented Regulation

Subject area	Function	Effect
Speed controller SFC	Setting of the speed control loop for Sensorless Flux Control	Very smooth running and good dynamics of the drive without encoder evaluation.
Encoder evaluation	Input of the encoder data.	Adaptation of the inverter module to the encoder of the motor.

Current controller	Setting of the current control loop	Optimum current usage of the motor and prevention of current overload shut-offs.
Speed controller FOR	Setting of the speed control loop for Field-Oriented Regulation.	Very smooth running and good dynamics of the drive with encoder evaluation.

This section gives an overview of the performance capability of the software functions. For a detailed description of the software functions refer to the CDA3000 Application Manual.

---

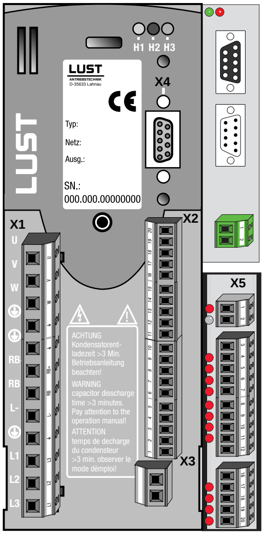
5 Communication and user modules

5.1 Principle of function

Communication and user modules expand the functionality of the CDA3000 drive system. On the base module there are two slots, into each of which one expansion module can be plugged.

Characteristics:

- Usability of the modules on all inverter sizes
- Simple retrofitting of expansion module by the user
- On inverter modules up to 15kW side mounting, on modules above 22kW on the front of the device
- With side mounting the base unit is 25 mm wider



Communication module

e.g. CANLust
CANopen
PROFIBUS-DP

Control terminal expansion

e.g. eight additional inputs and four additional outputs

Figure 5.1 Inverter module with one control terminal expansion module and one communication module

5.2 User module

With the user module UM-8I40 the digital inputs and outputs of the inverter module are expanded by eight inputs and four outputs. The functionality of the expanded inputs and outputs corresponds to that of the I/Os of the inverter module.

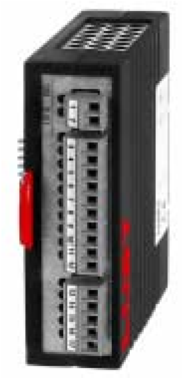


Figure 5.2 UM 8I4O

Technical data	UM-8I40		
Voltage supply	24 VDC ±20 %		
Current consumption	0.6 A		
Eight inputs	Input voltage for signal “0”		from 0 to 5 V
	Input voltage for signal “1”		>15 V
	Input current with signal “1”		3.5 mA to 7.0 mA (6 mA at 24 VDC)
Four outputs	Output current	Permissible range with signal “1”	min. 5 mA max. 0.5 A
		Mean	125 mA
		Total current	0.5 A
		Short-circuit current per output	max. 1.2 A short-time
Dimensions (W x H x D)	28 x 90 x 90 [mm]		

Table 5.1 Technical data

5.3 CAN-BUS

The CAN bus is a field bus which is in widespread use in automation. Its data transfer was standardized in ISO 11898. However, most CAN networks work with custom conventions for the communication and interpretation of user data.

Openness is attained through the use of the CANopen device profiles. These profiles define the mode of communication (CiA/DS30x) and the interpretation of the user data (CiA/ DS40x).

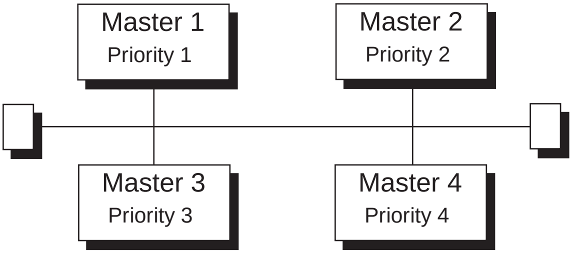


Figure 5.3 Topology of CAN

A CAN network is a multimaster network - that is to say, any station can autonomously send messages on the bus which can in turn be received by any other station on the bus.

Typically, however, transmissions are exchanged between two stations on the bus.

The basic rule is: Any one can evaluate the information from an identifier for its own ends. But only one station can have transmission rights for each identifier.

Each transmission is assigned a priority by the selection of the identifier for that transmission. The priority is antiproportional to the identifier number - that is, a rise in the significance of the identifier results in fall in the priority of the transmission. The monitoring of priorities and assignment of access rights on the bus is controlled by hardware means by the CAN controller.

CAN bus	
Topology	Line
Data transfer	ISO 11898
Transmission speed	25 kBit/s to 500 kBit/s
Transmission range	1000 m to 40 m
Data security	Hd 6
Number of stations	30
Number of data bytes	0 to 8
Bus access	Master/Master

Table 5.2 CAN characteristics

5.3.1 Interconnection of inverter modules on the CAN bus

Figure 5.4 Communication module CM-CAN1 or CM-CAN2

CM-CAN 1	
Ambient temperature	-10°C to 60°C
Voltage supply	24 ± 20%
Current consumption	< 100 mA
Protection	Ip 20
Standards	VBG 4
Address input	Coding via bus connector, coding plug, address switch or parameter in the device

Table 5.3 Technical data, CM-CAN2

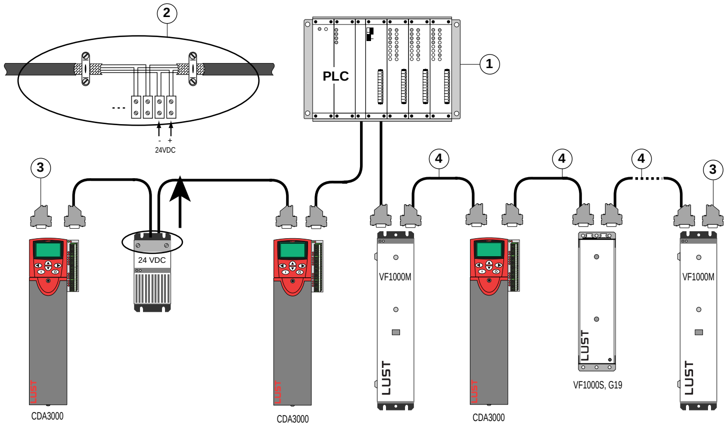


Figure 5.5 Interconnection of Lust drive units on the CAN bus

1 Control
2 Connection of 24 V supply voltage
3 Bus termination plug with resistor 120 Ω
4 Lust system bus cable type I or self-defined cable

Voltage supply, CAN bus	
Voltage	24 V ±20%
Voltage ripple	3 Vss
Current	100 mA per station

Table 5.4 Voltage supply

Cable type for self-assembly

If the supplied cables are not of the required length, it is also possible to make your own cables (1:1 connection). This relates to LS-BUS cable type I.

Cable type	Shielded with at least nine wires
Wires	Twisted-pair, 0.25 mm^2
Surge impedance	120 Ω
Length	Any, total distance must not exceed 80 mm

Table 5.5 Cable type

Shielding

Lust devices are connected by 9-pin connectors.

In the case of connections with D-SUB connectors, ensure that the shield is connected via the connector housing (2). For that reason the screw fittings (1) of the connectors must always be tightened.

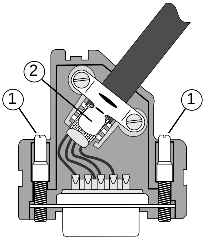


Figure 5.6 Open connectors with strain relief and cable shield

5.3.2 Communication via CAN$_{LUST}$

Two modes are available for control of the inverter modules via CAN:

1. Control of the drive unit by way of the state machine defined in DRIVECOM profile no. 22 of January 1994 for Interbus.
2. Direct selection of the following functions of the drive unit by way of the control word:
   - Transfer of reference and actual values
   - Starting and stopping the drive
   - Selection of fixed frequencies and ramps
   - Error resets
   - User data set switchover
   - Characteristic switchover
   - Setting of digital outputs of the device
   - Transfer of various states of the device
   - Transfer of states of the digital inputs of the device

DRIVECOM state machine (mode 1)

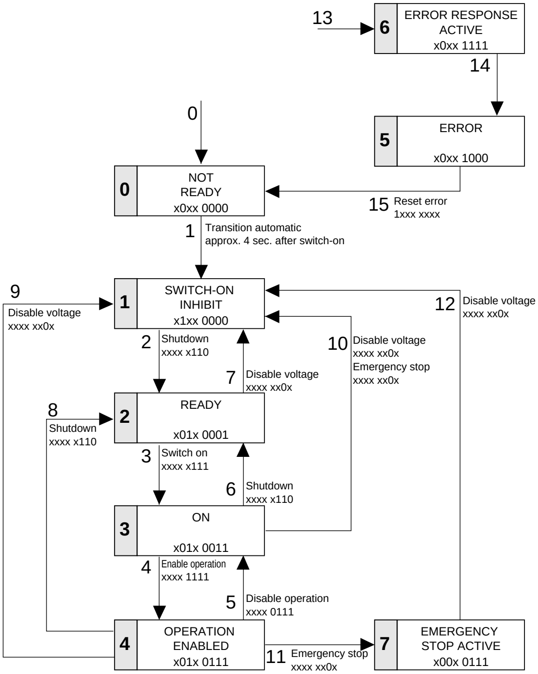


Figure 5.7 DRIVECOM state machine

DRIVECOM control word

The 16 bits of the control word result from the logical linking of control commands which act on the state machine. The following bits of the DRIVECOM status word are supported:

Bit	Function
0	Activate
1	Disable power
2	Emergency stop
3	Enable operation
4	Mode-dependent, more detailed definition: DRIVECOM profile no. 22 of January 1994
5	
6	
7	Reset fault

Table 5.6 DRIVECOM control word

Bit	Function
8	Reserve
9	Reserve
10	Reserve
11	vacant
12	vacant
13	vacant
14	vacant
15	vacant

Table 5.6 DRIVECOM control word

DRIVECOM status word

In the status word the current state of the device and additional messages are displayed. The following bits of the DRIVECOM status word are supported:

Bit	Status
0	Ready for start
1	On
2	Operation enabled
3	Fault
4	Power disabled
5	Emergency stop
6	Switch-on inhibit
7	Warning
8	No function
9	Remote
10	Reference reached
11	Limit value
12	Mode-dependent More detailed definition: DRIVECOM profile no. 22 of January 1994
13	
14	vacant
15	vacant

Table 5.7 DRIVECOM status word

Direct function selection (mode 2)

CANLust control word

An inverter function is selected directly by setting the relevant bit.

Bit	Function
0	Enable control
1	Invert reference
2	Braking
3	Set device to error state
4	Selection of table reference
5	Selection of table reference
6	Selection of table reference
7	Reset error
8	Data set selection
9	Selection of user mode
10	Selection of user mode
11	OSD 00 reference state
12	OSD 01 reference state
13	OSD 02 reference state
14	Reserve
15	Reserve

Table 5.8 *CAN_{Lust} control word*

CAN_{Lust} status word

The following device states are signaled with the status word:

Bit	Function
0	Device in error state
1	One or more warning thresholds has been exceeded
2	Reference reached
3	Reference limitation active
4	Power stage activated
5	Speed 0Hz
6	Clockwise
7	Anti-clockwise

Table 5.9 *CAN_{Lust} status word*

Bit	Function
8	Status of input ENPO
9	Reserve
10	Reserve
11	Reserve
12	Actual status of ISD 00
13	Actual status of ISD 01
14	Actual status of ISD 02
15	Actual status of ISD 03

Table 5.9 *CAN_{Lust} status word*

5.3.3 Communication via CAN_{open}

Not available at time of going to press.

Summary:

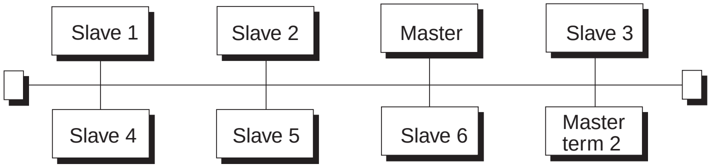
- Control of the CDA3000 via CAN_{open}
- Reference and actual value transfer
- State machine to CiA DS-402

5.4 PROFIBUS-DP

The PROFIBUS is a non-manufacturer-specific, standardized field bus of which the openness is guaranteed by the international standard EN 50170.

PROFIBUS comprises the three variants PROFIBUS-DP, PROFIBUS-FMS and PROFIBUS-PA. The PROFIBUS-DP version is aligned to the fast data transfer rates and short response times required in drive engineering.

Bus topology



Device type	Function
DP-Master class 1	Centralized control
DP-Master class 2	Programming, project planning or operator control device
Slave	Peripheral device (I/O, drive, valves)

Table 5.10 Topology of PROFIBUS-DP

PROFIBUS-DP	
Topology	Line
Data transfer	RS 485
Bus access	Master-/Slave access
Transmission speed	9.6 kBit/s to 12 MBit/s
Transmission range	1200 m to 100 m
Data security	Hd 4
Number of stations	max. 127 (32 per segment)
Number of data bytes	1 to 246 Bytes

Table 5.11 PROFIBUS characteristics

There are two ways of connecting LUST drive units to PROFIBUS-DP:

1) PROFIBUS-DP Gateway CP-DP 1
   - Cost-optimized PROFIBUS interface for interconnection of several (up to 10) drive units on PROFIBUS-DP
   - Drive units from the CDA3000, MC7000 and CDA3000 product families can be run together on a PROFIBUS-DP Gateway
   - For connection to the PROFIBUS-DP Gateway the drive units must be fitted with the CAN_{Lust} interface.

2) PROFIBUS-DP module
   - PROFIBUS-DP expansion module for CDA3000
   - Optimized for connection of a CDA3000 inverter module to the PROFIBUS-DP
   - Supports the expanded PROFIBUS-DP functions in accordance with Directive 2.084

5.4.1 Interconnection of LUST drive units with the PROFIBUS-DP Gateway

The PROFIBUS-DP Gateway connects up to 10 LUST drive units to the PROFIBUS-DP. The drives are thereby turned into full-scale PROFIBUS-DP stations.

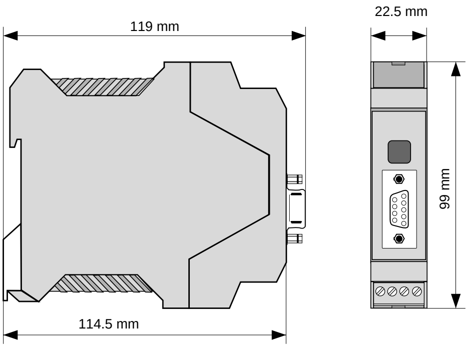


Figure 5.8 PROFIBUS Gateway type DP-CPx

PROFIBUS-DP Gateway CP-DP1	
Ambient temperature	0 ... 50°C
Voltage supply	+24 V DC ±20%
Current consumption	max. 1.4 A
Protection	IP20
Address input	DIL switch

Table 5.12 Technical data, PROFIBUS-DP Gateway

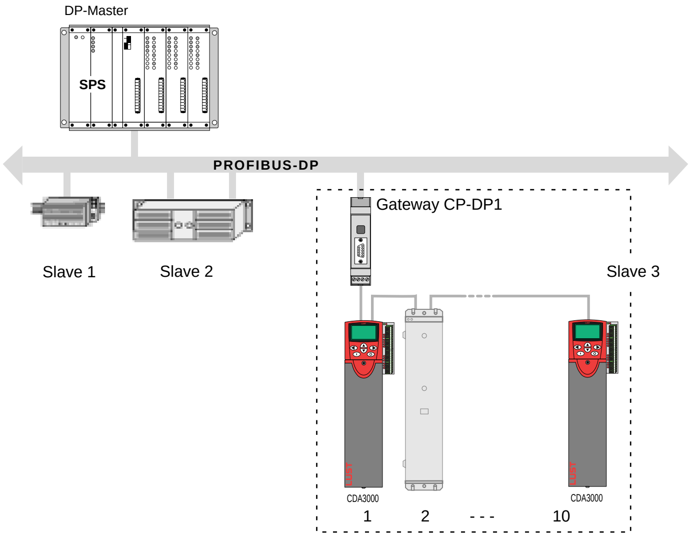


Figure 5.9 PROFIBUS-DP layout with Lust drive units

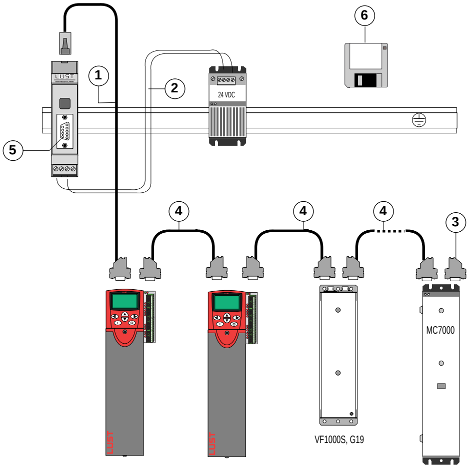


Figure 5.10 Interconnection of several drive units on PROFIBUS-DP

1 Gateway cable
2 24 V supply voltage
3 Bus termination plug (supplied with Gateway)
4 Lust system bus cable type I or self-assembled cable
5 Connection to PROFIBUS-DP
6 Floppy disk with GSD files (supplied with Gateway)

Cable type for self-assembly

If the supplied cables are not of the required length, it is also possible to make your own cables (1:1 connection). This relates to LS-BUS cable type I.

Cable type	Shielded with at least 9 wires
Wires	Twisted-pair, 0.25 mm^2
Surge impedance	120 Ω
Length	Any, total distance must not exceed 80 m

Table 5.13 Cable type

Shielding

Lust devices are connected by 9-pin connectors.

In the case of connections with D-SUB connectors, ensure that the shield is connected via the connector housing (2). For that reason the screw fittings (1) of the connectors must always be tightened.

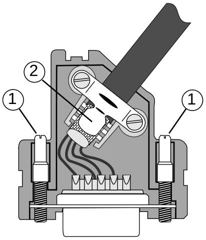


Figure 5.11 Open connectors with strain relief and cable shield

5.4.2 Interconnection via the PROFIBUS-DP module

Not available at time of going to press.

Summary:

- Layout and technical data of the PROFIBUS-DP module

5.4.3 Communication via PROFIBUS-DP

By way of the PROFIBUS-DP the drive units can be controlled and their parameters set in accordance with the profile for variable-speed drives (PROFIDRIVE).

The unambiguous transfer of parameters and process data is achieved by the configuration of “parameter process data objects” (PPOs). The PROFIBUS-DP Gateway supports PPOs 1 to 4.

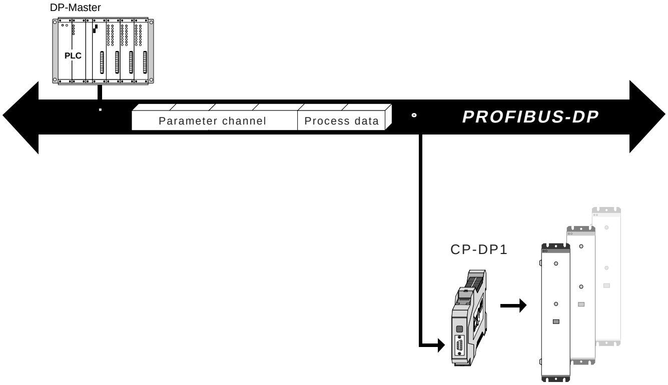


Figure 5.12 Parameter process data object for user data traffic

The PPO illustrated in Figure 5.12 includes a control word and a reference value for process data transfer from the master to the slave as well as a status word and an actual value for the reverse direction. The parameter area in the PPO is optional, which means it must be planned as required during slave configuration and is then transferred together with the process data area on a permanent basis in a cyclic telegram.

	PKW				PZD					
	PKE 1st word	IND 2nd word	PWE 3rd word	4th word	PZD1 STW1 ZSW1 1st word	PZD2 HSW HIW 2nd word	PZD3 3rd word	PZD4 4th word	PZD5 5th word	PZD6 6th word
PPO1	☐	☐	☐	☐	☐	☐				
PPO2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
PPO3					☐	☐				
PPO4					☐	☐	☐	☐	☐	☐

Table 5.14 PPO 1 to PPO 4

PKW:	Parameter identifier value	STW1:	Control word 1
PZD:	Process data	ZSW1:	Status word 1
PKE:	Parameter identifier	HSW:	Primary reference
IND:	Index	HIW	Primary actual
PWE:	Parameter value		

Selection aid for PPOs

Is transfer of parameter data required?			
yes		no	
Are reference and actual values to be transferred as 16-bit values?		Are reference and actual values to be transferred as 16-bit or 32-bit values?	
16 bits	32 bits	16 bits	32 bits
PPO 1	PPO 2	PPO 3	PPO 4

Table 5.15 Selection of a PPO

Transparent mode

In addition to the standardized control concept in accordance with the PROFIDRÌVE profile, LUST-PROFIBUS modules offer another operation mode in which no interpretation of the data is performed by the Gateway. With this “transparent mode” the internal CAN can be accessed directly.

Transparent mode provides the following functions:

- Control of the drive unit according to the DRIVECOM state machine
- Direct selection of the following functions of the drive unit by way of the control word:
  - Transfer of reference and actual values
  - Starting and stopping the drive
  - Selection of fixed frequencies and ramps
  - Error resets
  - User data set switchover
  - Characteristic switchover
  - Setting of digital outputs of the device
  - Transfer of various states of the device
  - Transfer of states of the digital inputs

For more information see “Communication via CAN_{Lust}”

6 Selection of supplementary components

6.1 Line choke

Function	Effect
Use of the line choke reduces the voltage distortion in the system. The limit values to be observed for variable-speed electric drives are laid down in the standards EN61800-3 and IEC1800-3. Of course, the line choke also offers protection against transient system voltage peaks.	Reduction of voltage distortion (THD)[1] Reduction of commutation notches Reduction of the amplitude of the line charging current Increase in service life of the DC-link capacitors Attenuation of transient voltage peaks from contaminated systems

1) THD = Total Harmonic Distortion

6.1.1 Effect of the line choke

Based on the example of a 4 kW inverter CDA34.010

A line impedance of 0.6 mH was assumed for the calculation. This value results from IEC1800-3 para. 6.1.2 (short-circuit current of system = 250 times fundamental current of load).

A line impedance of 6 mH was assumed for the calculation. This value results from IEC1800-3 para. 6.1.2 and from the use of a line choke with 4 % short-circuit voltage (U_K).

Harmonics load

Harmonic	Percentage without line choke	Percentage with line choke	Amplitude without line choke	Amplitude with line choke
1 (fundamental)	100%	100%	8.58 A	8.31 A
5	76%	30%	6.4 A	2.55 A
7	57%	8.9%	4.9 A	0.74 A
11	21%	6%	1.85 A	0.5 A
13 to 41	36%	10.9%	3.15 A	0.91 A

Table 6.1 Percentage shares of currents due to harmonics based on the example of a 4 kW inverter CDA34.010

System load

	Without line choke	With line choke	Change
	4 kW inverter, line impedance 0.6 mH	4 kW inverter, line impedance 0.6 mH	**Without line choke to with line choke**
Voltage distortion (THD)	99 %	33 %	-67 %
Mains current amplitude	18.9 A	9.7 A	-48 %
Mains current effective	8.5 A	6,23 A	-27 %
Commutation notches referred to the mains voltage	28 V	8 V	-70%
Life of the DC-link capacitors	Nominal life	2 to 3 times nominal life	+200 to 300 %

Table 6.2 Change in system load resulting from insertion of a line choke with 4 % short-circuit voltage based on the example of a 4 kW inverter CDA34.010

The total voltage distortion THD is calculated from the individual harmonics according to the following formula:

$$\mathrm{TDH} = \sqrt{U_5^2 + U_7^2 \ldots U_{41}^2} \qquad U_n \text{ as \% of } U_{\mathrm{fundamental}}$$

Mains voltage asymmetry

	Without line choke			With line choke		
	4 kW inverter, line impedance 0.6 mH			4 kW inverter, line impedance 0.6 mH		
Mains voltage asymmetry	0 %	+3 %	-3 %	0 %	+3 %	-3 %
Mains current amplitude	18.9 A	25.4 A	25.1 A	9.7 A	10.7 A	11 A
Mains current effective	8.5 A	10.5 A	10,2 A	6,2 A	6.7 A	6.8 A

Table 6.3 Effect of the line choke with asymmetrical mains voltage based on the example of a 4 kW inverter CDA34.010

According to IEC1000-2-4 the mains voltage asymmetry may be only 2%.

In summary: The example shows that the benefit of a line choke with 4 % short-circuit voltage is wide-ranging, and so it should not be omitted from any machine or system.

Procedure in practise

In order to establish whether your application conforms to the EN61800-3/ IEC1800-3 standard or another standard, you must ascertain the equivalent inverter referred to your line transformer. Based on the equivalent inverter and the line impedance, you then calculate the voltage distortion THD. You need to weight the result relative to the overall system ratios.

Theoretical calculation of the system ratios can only serve as a guide. If the theoretical calculation reveals that you are at the limits specified in the standards, you should always carry out a system analysis by means of systems analysts (measurement duration typically seven days). Only in this way is a practise-oriented assessment of your power supply system possible.

6.1.2 Operation with reactive current compensation system

Estimation of the resonance point

Capacitors in systems with inverters cause oscillations which additionally distort the mains voltage. The frequency of those oscillations depends on a number of different system parameters. Reactive current compensation systems may under certain circumstances impair the quality of the voltage waveform.

The compensation system forms an anti-resonant circuit together with the transformer inductance, which in the worst case may enter into resonance with a harmonic frequency generated by the inverter. As a result the capacitor battery draws the corresponding harmonic from the system, possibly leading to overloading of the capacitor battery.

.

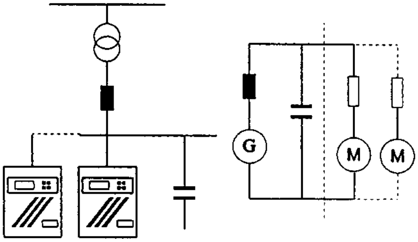


Figure 6.1 Anti-resonant circuit

The influence of the lowest system resonance can be estimated with an acceptable margin of error as follows:

$$n_{res} = \sqrt{S_k / Q_C}$$

S_k = short-circuit power
Q_C = power of capacitor battery
n_{res} = harmonic number at which resonance occurs

Example: Calculation of system resonance

S_{Tr} = 1600 kVA
U_k = 6 %
Q_C = 120 kVA

$S_k = S_{Tr} / U_k$ = 1600 kVA / 6 % = 266 kVA

$$n_{res} = \sqrt{S_k / Q_C} = \sqrt{(266kVA)/(120kVA)} = 1, 3$$

f = n_{res} x 50 Hz = 1.3 x 50 Hz = 65 Hz

Result:

The lowest resonance point is at the harmonic number 1.3 - corresponding to 65 Hz.

This calculation is used to estimate the lowest resonance point under ideal system conditions.

If the calculated resonance point is not in the vicinity of the harmonic numbers generated by the inverter of 5, 7, 9, 11, 13 etc., it can be assumed that no resonance problems will occur.

It should be mentioned that additional motor loads shift the resonance points toward higher values and the ohmic resistance component in the system brings about an attenuation of the resonant circuit. In complex system layouts in particular, pre-calculation of any possible resonance points is very difficult, so in such cases too it is advisable to perform measurements only after installation of a harmonics generator. Appropriate remedial measured should be initiated accordingly.

6.1.3 Technical data of line chokes LR3x.xxx

Ambient conditions	LR 32. xxx	LR 34. xxx
Rated voltage	1 x 230 V, -20 % +15 %, 50/60 Hz1)	3 x 460 V, -25 % +10 %, 50/60 Hz1)
Overload factor	1.8 x I_N for 40 s	1.8 x I_N for 40 s up to rated current 32 A 1.5 x I_N for 60 s above rated current 45 A
Ambient temperature	typically -25° C to +45° C, with power reduction to 60° C	
Mounting height	1000 m, with power reduction to 4000 m	
Relative air humidity	15 ... 95 %, condensation not permitted	
Storage temperature	-25° C to +70° C	
Protection	IP00, terminals VBG4	
Short-circuit voltage	UK 4 % at 230 V = 9.2 V	UK 4 % at 400 V = 9.24 V
Permissible contamination	P2 to EN 61558-1	P2 to EN 61558-1
Thermal configuration	$I_{eff} < I_N$	
Material	Only UL-listed materials are used	

Table 6.4 General technical data of line chokes LR3x.xxx

If several inverter modules are connected to one line choke, it must be ensured that the sum of the inverter rated currents does not exceed the rated current of the line choke.

$$\Sigma I_{Inverter} \leq I_{NLinechoke}$$

6.1.4 Assignment of line choke to inverter module

Line chokes for inverter modules with mains connection 1 x 230 V -20 %, +15 %

Tech. data Order ref.	Suitable for inverter module	Rated current [A]	Power loss tot. [W]	Inductance [mH]	Weight [kg]	Connection [mm]
LR32.8	CDA32.003 CDA32.004	8	10	3.66	0.8	4
LR32.14	CDA32.006 CDA32.008	14	16	2.1	1.5	4

Figure 6.2 Assignment of line choke to inverter module

Line chokes for inverter modules with mains connection 3 x 460 V -25 %, +10 %

Inverter module	**Inverter rated power**	**Line choke with 4% U_K**			
		Type	**Rated current**	**Power loss [W]**	**Dimensions HxWxD [mm]**
CDA34.003	0.75 kW	LR34.4	4,2 A	**20**	120x100x70
CDA34.005	1.5 kW	LR34.6	6 A	26.1	140x125x65
CDA34.006	2.2 kW	LR34.6	6 A	26.1	140x125x65
CDA34.008	3.0 kW	LR34.8	8 A	29	140x125x65
CDA34.010	4.0 kW	LR34.10	10 A	33	140x125x75
CDA34.014	5.5 kW	LR34.14	14 A	45	160x155x80
CDA34.017	7.5 kW	LR34.17	17 A	**45**	160x155x80
CDA34.024	11 kW	LR34.24	24 A	50	160x155x95
CDA34.032	15 kW	LR34.32	32 A	67	195x190x85
CDA34.045	22 kW	LR34.45	45 A	73	195x190x95
CDA34.060	30 kW	LR34.60	60 A	85	195x190x105
CDA34.072	37 kW	LR34.72	72 A	111	275x230x125
CDA34.090	45 kW	LR34.90	90 A	135	280x230x150
CDA34.110	55 kW	LR34.110	110 A	126	280x230x150
CDA34.143	75 kW	LR34.143	143 A	168	330x265x145
CDA34.170	90 kW	LR34.170	170 A	218	360x300x155

Table 6.5 Technical data

6.2 Motor choke

Function	**Effect**
• Insertion of the motor choke between the inverter module and the standard three-phase AC motor improves the operating conditions and reduces leakage currents and faults.	• Reduction of leakage currents • Reduction of rate of rise of voltage du/dt at the motor terminals • Suppression of faults caused by switching in the motor cable • Increase in motor cable length

6.2.1 Technical data of the motor chokes

Characteristic	**Motor choke MR32.xxx [3x230 V]**	**Motor choke MR34.xxx [3x400/460 V]**
	Not available at time of going to press.	

Table 6.6 Technical data of the motor chokes

Inverter module	**Inverter rated power**	**Line choke with 4% U_K**			
		Type	**Rated current**	**Power loss**	**Dimensions HxWxD [mm]**
CDA34.003					
CDA34.004		Not available at time of going to press.			
CDA34.005					
CDA34.006					
CDA34.008					
CDA34.010					

Table 6.7 Technical data of line choke with 4% UK

Inverter module	Inverter rated power	Line choke with 4% U_K			
		Type	Rated current	Power loss	Dimensions HxWxD [mm]
CDA34.014					
CDA34.017		Not available at time of going to press.			
CDA34.024					
CDA34.034					
CDA34.045					
CDA34.060					
CDA34.072					
CDA34.090					
CDA34.110					
CDA34.143					
CDA34.170					

Table 6.7 Technical data of line choke with 4% UK

6.2.2 Assignment to the inverter modules

Motor choke for inverter module with mains connection 1x230 V -20%, +15%

Inverter module	Rec. 4-pole standard motor	Motor choke		du/dt 1) without motor choke	du/dt 1) with motor choke	Motor cable length 2) without motor choke	Motor cable length 2) with motor choke
		Type	Rated current				
CDA32.003							
CDA32.004							
CDA32.006							
CDA32.008							
CDA32.008							

Not available
at time of going to press.

1) Rate of rise of voltage in V/µs
2) Maximum motor cable (shielded) without current reduction

Table 6.8 Technical data of motor choke for inverter modules

Motor choke for inverter modules with mains connection 3x460 V -25%, +10%

Inverter module	Rec. 4-pole standard motor	Motor choke		du/dt 1) without motor choke	du/dt 1) with motor choke	Motor cable length 2) without motor choke	Motor cable length 2) with motor choke
		Type	Rated current				
CDA32.003							
CDA32.004							
CDA32.006							
CDA32.008							
CDA32.008							

Not available
at time of going to press.

1) Rate of rise of voltage in V/µs
2) Maximum motor cable (shielded) without current reduction

Table 6.9 Technical data of motor choke for inverter modules

In multi-motor operation ensure that the total motor cable length is the sum of all individual motor cables. The permissible total length of the motor cable must not be exceeded.

6.3 Braking resistors

Function	Effect
• Use of braking resistors in the braking chopper electronics integrated as standard in the inverter module permits two and four-quadrant operation (braking and driving).	• When the motor is braked electrical energy is fed to the inverter module. To prevent the DC-link voltage of the inverter from reaching impermissible values in such cases, the braking energy in the braking resistor is converted into heat.

6.3.1 Technical data of series BRxxx, xx-xx

Technical data	BR-270.02, xx0 BR-160.02, xx0	BR-270.03, xx1 BR-160.03, xx1 BR-090.03, xx1	BR-090.10, xx1 to BR-010.80,xx1
Surface temperature	> 200° C	< 80° C	< 80° C
Touch protection	no	yes (< 80° C)	yes (< 80° C)
Voltage	max. 800 V	max. 800 V	max. 800 V
High-voltage strength	4000 V	4000 V	1800 V
Temperature monitoring	yes	yes	yes
Acceptance tests	CE		
Connection	1 m long PTFE-insulated litz wire	Ceramic terminals	Ceramic terminals

Table 6.10 Technical data of braking resistors

The sampling time T must be <150 sec.

$$P_{eff} = \sqrt{\frac{P_S^{2} \cdot t_{ST} \cdots}{T}}$$

6.3.2 Assignment to inverter modules CDA3000

Braking resistor for inverter module

Tech.data / Order ref.	Resistance [Ω ±10 %]	Cont. braking power [W]	Peak braking power [W]		Protection
			390 VDC[1)]	750 VDC[2)]	
BR-270.02, 540	270	150	560	2080	IP54
BR-270.03, 541	270	300	560	2080	IP54
BR-160.02, 540	160	150	950	3500	IP54
BR-160.03, 541	160	300	950	3500	IP54
BR-090.03, 541	90	300	1690	6250	IP54
BR-090.10, 201	90	1000	1690	6250	IP20
BR-090.10, 541	90	1000	1690	6250	IP54
BR-042.20, 201	42	2000	-	13390	IP20
BR-042.20, 541	42	2000	-	13390	IP54
BR-015.60, 541	15	6000	-	37500	IP20
BR-010.80, 541	10	8000	-	37500	IP54

1) 1 x 230 V mains connection -20%, +15%
2) 3 x 460 V mains connection -25%, +10%

Table 6.11 Technical data

For more detailed information on the dimensioning of the braking resistors See section 3.3.8.

6.4 Radio interference suppression filter

Function	Effect
• The insertion of radio interference suppression filters (RFI filters) between the inverter module and the system reduces the line-borne interference down to the permissible level.	• Protection against line-borne interference emission to EN 55011 (A) and EN 55022 (B).

6.4.1 Technical data of RFI filters EMC34.xxx

Characteristic	RFI filter EMC34.xxx

Not available at time of going to press.

Table 6.12 Technical data

RFI filter	Rated current	Power loss	Dimensions H x W x D [mm]

Not available at time of going to press.

Table 6.13 Technical data

6.4.2 Permissible motor cable length with internal RFI filter

		[A]		[B]		[C]		[D]		[E]		[F]	
		4 kHz power stage clock frequency				8 kHz 8 kHz power stage contact frequency				16 kHz power stage contact frequency			
Inverter module	Rec. 4-pole standard motor [kW]	With integral mains filter		With **[A]** and line choke U_K =4%		With integral mains filter		With **[C]** and line choke U_K =4%		With integral mains filter		With **[E]** and line choke U_K =4%	
		Class A [m]1)	Class B [m]1)	Class A [m]1)	Class B [m]1)	Class A [m]1)	Class B [m]1)	Class A [m]1)	Class B [m]1)	Class A [m]1)	Class B [m]1)	Class A [m]1)	Class B [m]1)
CDA32.003	0.375 kW	25	10	25	10	25	10	25	10	25	-	25	-
CDA32.004	0.75 kW	25	10	25	10	25	10	25	10	25	-	25	-
CDA32.006	1.1 kW	15	10	15	10	25	15	25	15	25	-	25	-
CDA32.008	1.5 kW	15	15	15	15	25	15	25	15	25	-	25	-
CDA34.003	0.75 kW	15	15	**25**	15	25	10	25	**15**	25	-	25	-
CDA34.004	1.1 kW	15	15	**25**	15	25	10	25	**15**	25	-	25	-
CDA34.005	1.5 kW	15	15	**25**	15	25	10	25	**15**	25	-	25	-
CDA34.006	2.2 kW	15	15	**25**	15	25	10	25	**10**	25	-	**25**	-
CDA34.008	3.0 kW	25	10	25	**15**	25	-	25	**10**	25	-	25	-
CDA34.010	4.0 kW	25	10	25	**15**	25	-	25	**10**	25	-	25	-
CDA34.014	5.5 kW	25	10	25	**15**	25	10	25	**25**	15	-	**25**	**15**
CDA34.017	7.5 kW	25	10	25	15	25	10	25	25	15	-	25	15

1) Maximum permissible motor cable length at which the standard is maintained

Table 6.14 Permissible motor cable length with integral mains filter dependent on standard EN 55011 A/B

6.4.3 Permissible motor cable length with internal and external RFI filter

Not available at time of going to press.

6.4.4 Permissible motor cable length with external RFI filter

			[A]		[B]		[C]		[D]		[E]		[F]	
			4 kHz power stage clock frequency				8 kHz power stage contact frequency				16 kHz power stage contact frequency			
Inverter module	Rec. 4-pole standard motor [kW]	External mains filter	With external mains filter		With **[A]** and line choke U_K =4%		With external mains filter		With **[C]** and line choke U_K =4%		With external mains filter		With **[C]** and line choke U_K =4%	
			Class A [m]1)	Class B [m]1)	Class A [m]1)	Class B [m]1)	Class A [m]1)	Class B [m]1)	Class A [m]1)	Class B [m]1)	Class A [m]1)	Class B [m]1)	Class A [m]1)	Class B [m]1)
CDA34.024		EMC34.024												
CDA34.034		EMC34. xxx												
CDA34.045		EMC34. xxx												
CDA34.060		EMC34. xxx												
CDA34.072		EMC34. xxx												
CDA34.090		EMC34. xxx												
CDA34.110		EMC34. xxx												
CDA34.143		EMC34. xxx												
CDA34.170		EMC3x. xxx												

1) Maximum permissible motor cable length at which the standard is maintained

Table 6.15 Permissible motor cable length with external mains filter dependent on standards EN 55011 (A) and EN 55022 (B)

7 System installation

7.1 Heat discharge from the switch cabinet

7.1.1 Basic terms for calculation

A number of calculations must be carried out in order to be able to dimension the air-conditioning components correctly. The following variables are key to the calculations:

Basic terms	Explanations
Q_V [Watt]	Power loss (heat output) of the electrical components installed in the switch cabinet.
Q_S [Watt]	Heat output introduced or emitted via the effective switch cabinet surface (to VDE 0660 Part 500). If the interior temperature of the cabinet is higher than the ambient temperature ($T_i > T_u$), heat is emitted from the cabinet ($Q_S>0$). If the ambient temperature is higher than the interior temperature ($T_i<T_u$), heat is radiated into the cabinet ($Q_s < 0$).
Q_E [Watt]	Necessary cooling power of an air-conditioning component; this refers to the heat output which the device must discharge from the switch cabinet.
Q_H [Watt]	Necessary heat output of a switch cabinet heater.
T_i [°C]	Maximum permissible cabinet interior temperature specified by the manufacturers of the electrical components. As a rule it is between +35°C and +45°C.
T_u [°C]	Maximum ambient temperature at which fault-free functioning of all electronic components in the switch cabinet or electronics housing must still be guaranteed.
V [m³/h]	Necessary volumetric flow of a filter fan.
A {m²]	Effective switch cabinet surface calculated according to DIN 57 660 Part 500 / VDE 0660 Part 500.
k [W/m²K]	Heat transfer coefficient of the switch cabinet. It is defined by the following equation: $\mathbf{k} = \frac{\mathbf{l}}{\frac{\mathbf{l}}{\alpha_{\mathbf{i}}} + \frac{\mathbf{s}}{\lambda} + \frac{\mathbf{l}}{\alpha_{\mathbf{a}}}}$

α_ι and α_α designate the heat transfer coefficients for the inner and outer wall respectively; λ designates the heat transfer coefficient of the wall material and s the wall thickness.

$$R = \frac{1}{k}\left[\frac{m^2K}{W}\right]$$

Heat transfer resistance of the switch cabinet.

7.1.2 Effective switch cabinet surface

Of the variables cited above, the effective switch cabinet surface A requires a special note of explanation: The heat output emitted from the switch cabinet is not only dependent on its actual surface area; the mode of installation of the cabinet is also decisive. A housing standing free and open on all sides can emit more heat than one mounted on a wall or in a niche. For that reason there are precise regulations as to how the effective switch cabinet surface is to be calculated dependent on the mode of installation. The formulae to calculate A are laid down in DIN 57660 Part 500 / VDE 0660 DIN 500 (See Figure 7.1).

Enclosure installation type to VDE 0660 Part 500

Installation type to VDE 0660/500	Formula for calculation of A [m^2]
☐	A = 1.8 x H x (W+D) + 1.4 x W x D
⬒	A = 1.4 x B x (H+D) + 1.8 x D x H
◨	A = 1.4 x T x (H+W) + 1.8 x W x H
◳	A = 1.4 x H x (W+D) + 1.4 x W x D
◫	A = 1.8 x W x H + 1.4 x W x D + D x H
◙	A = 1.4 x W x (H+D) + D x H
▣	A = 1.4 x W x H + 0.7 x W x D + D x H

- ☐ Single enclosure, all-round, freestanding
- ⬒ Single enclosure for wall mounting
- ◨ Start or end enclosure, freestanding
- ◳ Start or end enclosure for wall mounting
- ◫ Middle enclosure, freestanding
- ◙ Middle enclosure for wall mounting,
- ▣ Middle enclosure for wall mounting, covered roof areas

W = Cabinet width [m]
H = Cabinet height [m]
D = Cabinet depth [m]

Figure 7.1 Calculation of the effective emitting switch cabinet surface

Radiated power of a switch cabinet surface

If the effective switch cabinet surface A and the heat transfer coefficient k are known, the radiated power Q_S at maximum cabinet interior temperature T_i and maximum outside temperature T_u can be calculated as follows:

$$Q_S = k \cdot A \cdot (T_i - T_u) \qquad (1)$$

There are also diagrams from which the radiated power can be read directly, without calculation (See Figure 7.2).

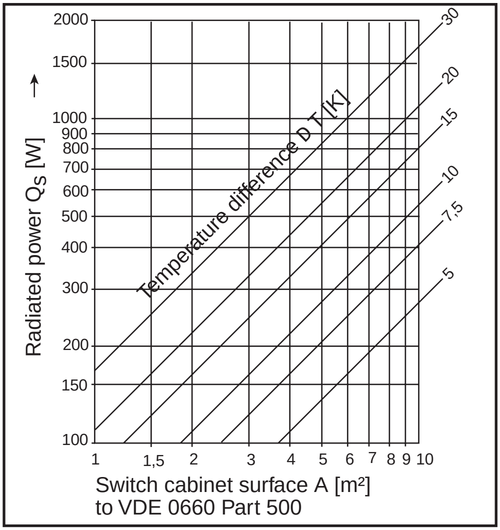


Figure 7.2 Radiated power of a switch cabinet surface

7.1.3 Calculation of filter fans

The necessary volumetric flow of a filter fan depends on the power loss of the components installed in the switch cabinet and on the difference between the maximum permissible interior and exterior temperatures:

Necessary volumetric flow

$$V = f \cdot \frac{Q_v}{T_i - T_u} \qquad (2)$$

The factor f [m³K/Wh] is dependent on the altitude above sea level at which the fan is operated (see Tabelle 7.1). This takes into account the fact that the air pressure - and thus the air density - decreases as the altitude increases and the fan consequently discharges less and less heat to the outside while the volumetric flow remains constant.

Altitude above sea level [m]	f m³K/Wh)
0 - 100	3.1
100 - 250	3.2
250 - 500	3.3
500 - 750	3.4
750 - 1000	3.5

Tabelle 7.1 Calculation factor “f” for filter fans dependent on altitude above sea level

Example: The fan is to be installed in a switch cabinet at an altitude of 80 m above sea level, having a power loss of 600 Watts. The temperature values are T_i = +40° and T_u = +20°C. Application of these values in formula (2) produces:

$$V = 3,1 \cdot \frac{600}{20}\frac{m^3}{h}$$

Therefore a filter fan with a delivery rate of at least 93 m/h is required.

The filter fans should generally be selected somewhat larger than calculated, since the operational side of the filter mat becomes increasingly clogged with dirt and the heat discharge is thereby impaired. For this reason the heat emission via the switch cabinet surface should also be ignored when calculating the necessary volumetric flow of the fan.

7.1.4 Calculation of heat exchangers

In contrast to the filter fans, the heat discharge via the switch cabinet surface certainly does need to be taken into account in design of the heat exchangers. The necessary cooling power QE which a heat exchanger must deliver is calculated from the difference between the power loss and the radiated power of the switch cabinet.

QE = QV - QS (3)

Example: A fully exposed sheet-steel switch cabinet is 60 cm wide, 2 m high and 50 cm deep. The power loss in the cabinet is 900 Watts.

The maximum ambient temperature is +25°C, the temperature in the cabinet should not rise above +35°C.

The radiated power of the switch cabinet surface is calculated according to formula (1) as:

$$Q_S = k \cdot A \cdot (T_i - T_u)$$

k designates the heat transfer coefficient and A the effective switch cabinet surface.

The heat transfer coefficient for sheet-steel is 5.5 W/m²K.

The effective switch cabinet surface is calculated to DIN 57 660 Part 500 / VDE 0660 Part 500 (see Tabelle 7.1):

$A = 1.8 \cdot H (W + D) + 1.4 \cdot B \cdot T$

H, W and D indicate the height, width and depth of the cabinet in meters. Thus in our example:

$A = (1.8 \cdot 2 \cdot (0.6+0.5) + 1.4 \cdot 0.6 \cdot 0.5)\ m^2 = 4.38\ m^2$

Applying the approximation 4.4 m for A, formula (1) produces

$:Q_S = k \cdot A \cdot (T_i - T_u) = 5.5 \cdot 4.4 \cdot 10\ W = 242\ W$

Therefore the necessary cooling power of the heat exchanger according to formula (3) is:

$Q_E = Q_V - Q_S = 900\ W - 242\ W = 658\ W$

Then a number of other variables need to be considered, depending on whether an air-to-air or air-to-water heat exchanger is to be used.

If you want to know more about this subject, we can recommend the book entitled “Schaltschrank-Klimatisierung” ("Switch cabinet air conditioning" - German) published by the “moderne industrie” publishing company; see bibliography.

7.2 Heat transfer by heat conductance

When a constant flow of heat P flows through a flat wall, the temperatures ϑ_1 and ϑ_2 are produced on the two surfaces (Figure 7.3). The relationship is described in the equation

$$P = \lambda \frac{A}{d}(\vartheta_1 - \vartheta_2) \quad (1)$$

P:	Heat flow	W
λ:	Thermal conductivity	$\frac{W}{m \cdot K}$
A:	Area of wall	m^2
d:	Thickness of wall	m
ϑ_1, ϑ_2:	Surface temperatures	°C or K

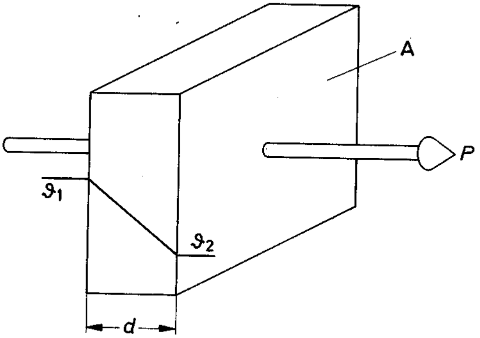


Figure 7.3 Stationary heat conductance through a wall

The thermal conductivity λ is a temperature-dependent material property. In electronic devices it can be considered as constant for most applications. Tabelle 7.2 summarizes λ values for a number of key materials. Depending on the task at hand - provision of good heat conductance or high insulation - materials with the corresponding thermal conductivity are selected.

The thermal resistance in heat conductance, the temperature lag R_{thL}, is produced from:

$$R_{thL} = \frac{d}{\lambda \cdot A} \qquad (2)$$

R_{thL}:	Temperature lag	$\frac{K}{W}$
d:	Wall thickness	m
λ:	Thermal conductivity	$\frac{W}{m \cdot K}$
A.	Wall area	m²

Thus equation (1) can be reformulated:

$$\Delta\vartheta = \vartheta_1 - \vartheta_2 = P \cdot R_{thL}$$

If a wall comprises more than one layer, the resultant temperature lag is equal to the sum of the temperature lags of the individual layers.

Good heat conductors Material	λ
Aluminum, pure	**230**
Cast iron	**58**
V2A steel	**15**
Sheet-steel	**59**

Tabelle 7.2 Thermal conductivity of some materials at $\vartheta = 20°$

The specific thermal contact resistance (Υ in $\frac{Cm^2 \cdot K}{W}$) of metal on metal is halved when heat transfer compound is used between two metal surfaces.

Appendix A Formula bank

A.1 Mathematical symbols

Appendix

Equality and inequality			
~	proportional	<	less than
≈	about, approximately	>	greater than
=	equal to	≥	greater than or equal to
≙	corresponding to	≤	less than or equal to
≡	identically equal	«	very small against
≢	not identically equal	»	very large against
≠	not equal, unequal		

Geometric symbols			
||	parallel	≅	congruent
≢	not parallel	∢	angle
↑↑	equivalent to parallel	$\overline{AB}$	distance AB
↑↓	opposite to parallel	$\overset{\frown}{AB}$	arc AB
⊥	rectangular to, perpendicular to	~	similar
Δ	triangle		

Table 7.3 Geometric symbols

A.1.1 SI units

Variable	Formula symbol	Units		Formula (A cross-sectional area)
		Name	Abbreviation	
Voltage	U	Volt	V	$U = I \bullet R$
Current rating	I	Ampere	A	$I = U/R$
Resistance	R	Ohm	Ω	$R = U/I$
Conductivity, elec.	G	Siemens	S, 1/Ω	$G = 1/R$
Specif. el. resistance	ρ	Ohm/m	Ωm; Vm/A	$\rho = 1/\sigma$
El. conductivity	σ, χ	Siemens/m	S/m; A/Vm	$\sigma = 1/\rho$
Note: For vector values many formula symbols are designated by German letters.				

Table 1.1 SI units

Variable	Formula symbol	Units		Formula (A cross-sectional area)
		Name	Abbreviation	
Frequency (c speed of light)	f	Hertz	Hz, (kHz)	f = c/λ
Wavelength	λ	Meter	m, (cm)	λ = c/f
Electrical charge	Q	Coulomb	C, As	Q = I · t
Capacitance	C	Farad	F	C = Q/U
Inductance	L	Henry	H; Vs/A	
Power output	P	Watt, Joule/s	W; VA, J/s	P = U · I
Work	W, A	Joule	J; Ws	W = P · t
Force, (weight)	F, (G)	Joule/m	J/m; Ws/m	F = W/1
El. field strength	E	Volt/m	V/m; N/C	E = U/1
Dielectric const.	ε	Farad/m	F/m; C/Vm	ε = c · 1/A
El. field constant, var.	εo	Farad/m	F/m; C/Vm	$\varepsilon = \varepsilon_0 . \varepsilon_r$
Dielectric constant	ερ	-	-	$\varepsilon_r = \varepsilon/\varepsilon_0$
El. displacement flux	ψ	Coulomb	C, As	
El. displacement density	D	Coulomb/m^2	C/m^2	D = Q/A
El. current density	S, (i)	Ampere/m^2	A/m^2	S = I/A
El. loading	θ	Ampere	A; J/Wb	θ = H · l
Magnetic flux	Φ	Weber, Maxwell	Wb; Vs; M	Φ = B · A
Magn. voltage	V	Ampere	A; J/Wb	V = H · s
Magn. field strength	H	Amp./m; Oerstedt	A/m; N/Wb, (Ö)	H = B/μ = I · w/l
Magn. inductance (flux density)	B	Tesla; Weber/ m^2 (Gauß)	T; Wb/m^2 (G)	B = μ · H
Magn. field constant	μ_0	Henry/m	H/m; Wb/Am	$\mu_0 = 4\pi/10^7$
Permeability, absolute	μ	Henry/m	H/m; Wb/Am	μ = B/H
Permeability coefficient	μ_t	-	-	$\mu_t = \mu/\mu_0$
Magn. polarization	J	Tesla; Weber/ m	T; Wb/m²	$J=B-\mu_0$
Note: For vector values many formula symbols are designated by German letters.				

Table 1.1 SI units

Variable	Formula symbol	Units		Formula (A cross-sectional area)
		Name	Abbreviation	
Magnetization intensity	M	Webermeter	Wbm; Vsm	$M = J/\mu_0 \cdot H$
Magn. conductivity	Λ	Henry	H	$\Lambda = 1/R_m$
Magn. resistance	R	10^8/Henry	10^8/H	$R_m = 1/A \cdot \mu$
El. susceptibility	χ	-	-	$= 4\pi\,\chi'$
Magn. susceptibility	χ	-	-	$=M/H = \mu_r-1$
Note: For vector values many formula symbols are designated by German letters.				

Table 1.1 SI units

A.1.2 Important units

Important units
Force
$1\text{N} = 1\dfrac{\text{kg}\cdot\text{m}}{\text{s}^2}$
Force
1 kp = 9.80665 N
Power output
$1\text{PS} = 75\dfrac{\text{kp}\cdot\text{m}}{\text{s}} = 0,7355\text{kW} = 735,5\dfrac{\text{kg}\cdot\text{m}^2}{\text{s}^3} = 735,5\dfrac{\text{Nm}}{\text{s}}$
Work, energy
$1\text{Ws} = 1\text{Nm} = 1\text{J} = 1\dfrac{\text{kg}\cdot\text{m}^2}{\text{s}^2}$
Moment of inertia
$1\text{kg}\cdot\text{m}^2 = 1\text{W}\cdot\text{s}^3 = 1\text{Nm}\cdot\text{s}^2$
Acceleration due to gravity
$g = 9,80665\dfrac{\text{m}}{\text{s}^2}$

Table 1.2 Important units

A.2 Drive engineering equations

A.2.1 Basic physical equations

Translation	Rotation
Travel/angle	
$s = v \cdot t$	$\varphi = \omega \cdot t$
Velocity	
$v = \frac{s}{t}$	$v = \omega \cdot r = \frac{\pi \cdot n}{60} \cdot d$
Angular velocity	
	$\omega = \dot{\varphi} = \frac{2 \cdot \pi \cdot n}{60} = \frac{\varphi}{t}$
Acceleration	
$a = \frac{v}{t}$	$\dot{\omega} = \ddot{\varphi} = \frac{\omega}{t}$
Force	
$F = m \cdot a$	$F = m \cdot r \cdot \omega^2$
Torque	
$M = F \cdot r$	$M = J \cdot \dot{\omega}$
Power output	
$P = F \cdot v$	$P = M \cdot \omega$
Energy	
$W = F \cdot s$	$W = M \cdot \varphi$
Energy	
$W = \frac{1}{2} \cdot m \cdot v^2$	$W = \frac{1}{2} \cdot J \cdot \omega^2$

Table 7.4 Basic physical equations

A.2.2 Power

Rotational power	Rotational acceleration
$P = \frac{M \cdot n}{9,55}$	$P = \frac{J \cdot n^2}{91,2 \cdot t_{BE}}$
Translation/friction power	Translation/friction power with rise
$P = \frac{F \cdot v}{\eta} = \frac{m \cdot g \cdot \mu \cdot v}{\eta}$	$P = \frac{m \cdot g \cdot v}{\eta} \cdot (\mu \cdot \cos\alpha + \sin\alpha)$
Translation with acceleration	Lift
$P = \frac{m \cdot a \cdot v}{\eta}$	$P = \frac{m \cdot g \cdot v}{\eta}$

Table 7.5 General drive capacity

a	Acceleration	m/s²
F	Force	N
m	Mass	kg
M	Torque	Nm
n	Speed	rpm
P	Power	W
v	Velocity	m/s
η	Efficiency	
α	Angle of inclination	deg.
μ	Coefficient of friction	

Work output for metal-working machinery

Basic equation
$P_s = \frac{F_H \cdot v_s}{60000}$
Turning
$P_s = \frac{F_H \cdot n_P \cdot 2 \cdot \pi \cdot r}{60000}$
Milling
$P_s = \frac{z_E \cdot F_m}{60000} \cdot v_s = \frac{z_E \cdot F_m}{60000} \cdot \frac{d \cdot \pi \cdot n_F}{1000}$
Shearing and cutting
$P_s = \frac{K_s \cdot l_s \cdot s \cdot v_s}{60000}$
Drilling
$P_s = \frac{z_E \cdot (d_1 - d_2) \cdot s_Z \cdot K_s}{60000} \cdot v_s$
Cutting speed during drilling
$v_s = \frac{d_1 + d_2}{2} \cdot \frac{n_B \cdot \pi}{1000}$
Pressing
$P_P = \frac{F_{St} \cdot v_{St}}{60000}$

Table 7.6 Work output for metalworking machinery

b	Face width	mm
d	Cutter diameter	mm
d_1	Drill diameter	mm
d_2	Predrill diameter	mm
f	Advance per revolution	mm
F_H	Main cutting force	N
F_m	Mean cutting force in milling	N
F_{St}	Plunger force in pressing	N
K_S	Special cutting force (general)	N/mm²
k_C	Specific cutting force for various cutting thicknesses	N/mm²
k_{C11}	Specific cutting force for face cross-section 1 mm x 1 mm	N/mm²
l_S	Length of cut line	mm
n_B	Drill speed	rpm
n_F	Cutter speed	rpm

n_P	Face plate speed	rpm
P_S	Cutting power	kW
P_P	Drive capacity of a press	kW
r	Turn radius	m
s	Sheet thickness	mm
s_Z	Advance per cutting edge	mm
v_S	Cutting speed	m/min
v_{St}	Plunger speed	m/min
z_E	Number of active cutting edges	
κ	Setting angle	deg.

Specific cutting forces of various metals

Material	Tensile strength in N/mm² and hardness	kC_{11} in N/mm	k_C in N/mm² at h in mm $h = f \bullet \sin\kappa$				
			0.063	0.1	0.16	0.25	0.4
St 34, St 37, St 44	500	1780	2820	2600	2400	2240	2060
St 50, C 35	520	1990	4200	3610	3190	2830	2500
St 60	620	2110	3310	3080	2830	2620	2440
St 70	720	2260	5120	4500	3920	3410	2990
C 45, Ck 45	670	2220	3240	3040	2840	2660	2500
C60, Ck60	770	2130	3430	3150	2920	2700	2490
16 Mn Cr 5	770	2100	4350	3830	3400	3020	2660
18 Cr Ni 6	630	2260	5140	4510	3920	3410	3000
42 Cr Mo 4	730	2500	5000	4500	4000	3550	3150
34 Cr Mo 4	600	2240	4000	3610	3200	3000	2750
50 Cr V 4	600	2220	4620	4100	3610	3290	2820
15 Cr Mo 5	590	2290	3660	3390	3130	2890	2680
55 Ni Cr Mo 6-G	940	1740	3470	3070	2720	2390	2170
55 Ni Cr Mo 6-V	1220	1920	3470	3310	2950	2860	2380
100 Cr 6-G	620	1730	3680	3320	2900	2560	2240
Mn, Cr Ni steels	850...1000	2350	4200	3800	3450	3150	2850
Cr, Mo & other alloy steels	1000...1400	2600	4450	4050	3700	3350	3100
Stainless steels	600...700	2550	4200	3850	3530	3250	3000
Mn hard steels		3300	6100	5500	4980	4500	4080
X 12 Cr Ni 18 8	HB 160	1600	3810	3480	2880	2500	2140
X 6 Cr Ni Mo 18 10	HB 163	1500	3930	3520	2960	2510	2110
GG 25	HB 200...250	1160	2360	2110	1870	1660	1470
GS 45	300...500	1600	2560	2360	2180	2000	1860
GTW 40, GTS 35	HB 220	1180	2240	2000	1800	1600	1460
Brass	HB 80...120	780	1300	1200	1100	1000	920
Cast bronze		1780	2870	2600	2400	2240	2060
Red cast		640	1250	1120	1000	900	800
Cast aluminum	300...420	640	1250	1120	1000	900	800

Table 7.7 Specific cutting forces of various metals

k_{C11}	Specific basic cutting force for face cross-section 1 mm x 1 mm
k_C	Specific cutting force for various face thicknesses h

Drive capacities in process engineering

Drive capacities in process engineering
Fan
$P = \frac{Q_F \cdot p}{\eta}$
Pump
$P = \frac{Q_F \cdot p}{\eta}$
Extruder
$P = V \cdot \Upsilon$

Table 7.8 Drive capacities in process engineering

p	Total pressure	N/m²
P	Drive capacity	kW
Q_F	Delivery	m³/s
V	Specified throughput	kg/h
γ	Specific drive power	kWh/kg
η	Fan efficiency/pump efficiency	

For fans:

$\eta \approx 0.3$ at 1 kW
$\eta \approx 0.5$ at 10 kW
$\eta \approx 0.65$ at 100 kW

The following table shows the specific drive power for various thermoplasts:

Thermoplast	Specific drive power in kWh/kg
ABS	0,2 to 0.3
CAB	0.1 to 0,2

Table 7.9 Specific drive power for various thermoplasts

Thermoplast	Specific drive power in kWh/kg
PA 6 and PA 66	0.2 to 0.4
PE - LD	0.2 to 0.25
PE - HD	0.25 to 0.3
PP	0.25 to 0.3
PVC	0.15 to 0.2

Table 7.9 Specific drive power for various thermoplasts

A.2.3 Torques

Torques
Torque to produce translational movement
$M = \frac{F \cdot r}{1000} = 9,55 \cdot \frac{P}{n}$
Acceleration torque
$M_{BE} = J \cdot \dot{\omega} = J \cdot \frac{\dot{n}}{9,55} = J \cdot \frac{\Delta n}{9,55 \cdot t_{BE}}$
Acceleration time
$t_{BE} = J \cdot \frac{\Delta n}{9,55 \cdot (M - M_L)} = J \cdot \frac{(\Delta n)^2}{91,2 \cdot (P - P_L)}$

Table 7.10 Torques

F	Circumferential force	N
J	Overall mass moment of inertia	kg · m²
M	Motor torque	Nm
M_L	Load torque	Nm
n	Speed	rpm
P	Motor power	W
P_L	Power output of load	W
r	Radius of drive roller	mm
t_{BE}	Acceleration time	s
Δv	Differential speed	rpm
ω	Angular velocity	1/s

A.2.4 Work

Work of friction force
$W = F_R \cdot s = m \cdot g \cdot \mu_1 \cdot \cos\alpha \cdot s$
Work of acceleration force
$W = m \cdot \left(\frac{v_2^2}{2} - \frac{v_1^2}{2} \right)$
Work of gravity
$W = m \cdot g \cdot (h_2 - h_1)$
Work of spring force
$W = c \cdot \left(\frac{x_2^2}{2} - \frac{x_1^2}{2} \right)$
Work of friction torque
$W = M \cdot \mu_r \cdot \varphi$
Work of acceleration torque
$W = J \cdot \left(\frac{\dot{\varphi}_2^2}{2} - \frac{\dot{\varphi}_1^2}{2} \right) = J \cdot \left(\frac{\omega_2^2}{2} - \frac{\omega_1^2}{2} \right)$

Table 7.11 Work

From these general equations, with $\omega_2 = \omega$ and $\omega_1 = 0$, with $v_2 = v$ and v1 = 0, with $h_2 = h$ and $h_1 = 0$ and with $x_2 = x$ and $x_1 = 0$ the following results are produced:

Kinetic energy of the translational movement

$$W = \frac{1}{2} \cdot m \cdot v^2$$

Kinetic energy of the rotational movement

$$W = \frac{1}{2} \cdot J \cdot \omega^2$$

Potential energy of the position

$$W = m \cdot g \cdot h$$

Potential energy of the fields

$$W = \frac{1}{2} \cdot c \cdot x^2$$

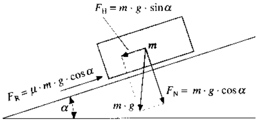
Table 7.12 Energy

c	Spring rigidity	Nm
F_R	Friction force	N
g	Acceleration due to gravity	m/s²
h	Lift height	m
h_1	Lift height at time $t=t_1$	m
h_2	Lift height at time $t=t_2$	m
J	Mass moment of inertia	kg · m²
m	Mass	kg
M	Torque	Nm
M_R	Friction torque	Nm
s	Effective travel of friction force	m
v	Velocity	m/s
v_1	Velocity at time $t=t_1$	m/s
v_2	Velocity at time $t=t_2$	m/s
W	Work	Nm
x	Spring travel	m
x_1	Spring travel at time $t=t_1$	m
x_2	Spring travel at time $t=t_2$	m
α	Angle of inclination of inclined plane	deg
μ_1	Coefficient of friction for longitudinal movement	
μ_r	Coefficient of friction for rotational movement	
φ_1	Angle of revolution at time $t=t_1$	rad
φ_2	Angle of revolution at time $t=t_2$	rad
ω	Angular velocity	1/s
ω_1	Angular velocity at time $t=t_1$	1/s
ω_2	Angular velocity at time $t=t_2$	1/s

A.2.5 Friction

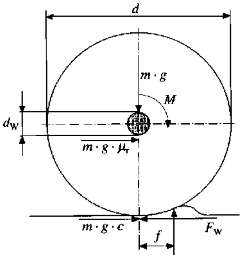
Friction force of Coulomb friction (dry friction)

$$F_R = F_N \cdot \mu_l = m \cdot g \cdot \mu_l \cdot \cos\alpha$$



Tractive resistance to rolling friction

$$F_W = m \cdot g \cdot \left[\frac{2}{d} \cdot \left(\frac{d_W}{2} \cdot \mu_r + f\right) + c\right]$$



Friction torque in thread

$$M_R = F \cdot \frac{d_m}{2} \cdot \tan\rho$$

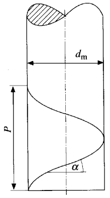


Table 7.13 Friction

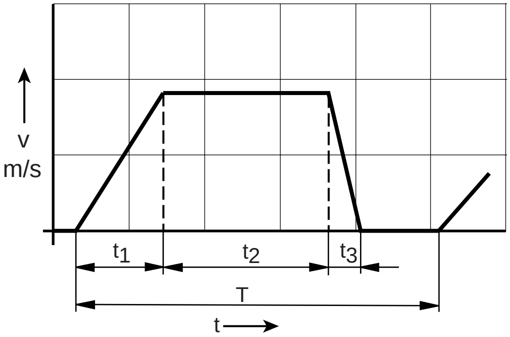
c	Rim friction	
d	Wheel diameter	m
d_m	Mean thread diameter	m
d_W	Axle/shaft diameter	m
F	Longitudinal force in screw/ threaded spindle N	
F_N	Normal force	N
F_R	Friction force with Coulomb friction	N
F_W	Tractive resistance to rolling friction	N
f	Lever arm of rolling friction	m
g	Acceleration due to gravity	m/s²
m	Mass	kg
M_R	Friction torque	Nm
α	Angle of inclination of inclined plane	deg.
μ_l	Coefficient of friction in longitudinal movement	
μ_r	Coefficient of friction in rotational movement	
ρ	Friction angle in threaded spindles	deg.

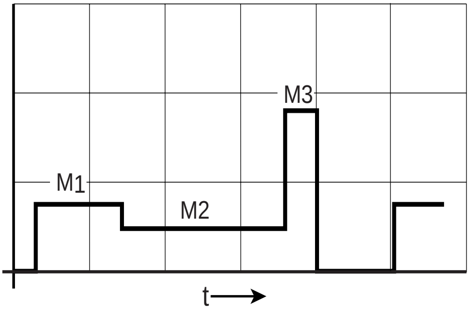
A.2.6 Effective motor torque/power output

$M_{eff} = \sqrt{\frac{1}{T} \cdot \Sigma_{i=1}^{n} M_i^2 \cdot t_i}$
$M_{eff} = \sqrt{\frac{M_1^2 \cdot t_1 + M_2^2 \cdot t_2 \cdot M_3^2 \cdot t_3}{T}}$
$P_{eff} = \sqrt{\frac{1}{T} \cdot \Sigma_{i=1}^{n} P_i^2 \cdot t_i}$
$P_{eff} = \sqrt{\frac{P_1^2 \cdot t_1 + P_2^2 \cdot t_2 + P_3^2 \cdot t_3}{T}}$

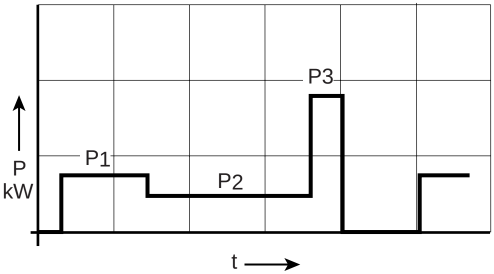
Table 7.14 Effective motor torque/power output

The following diagrams relating to a working example illustrate the meanings of the formula symbols used.





The motor is defined at $M_N \geq M_{eff}$.



The motor is defined at $P_N \geq P_{eff}$.

A.2.7 Choice of max. acceleration

Slip of a conveyed item

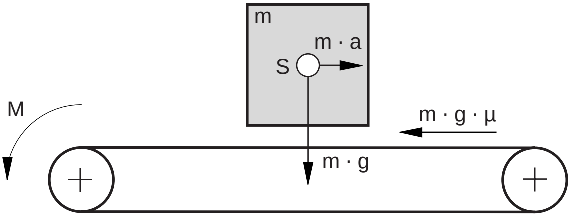


Figure 8.1 Conveyor belt with unsecured object during acceleration

Maximum acceleration: $a = g \cdot \mu$

a	Belt acceleration in m/s²
g	Acceleration due to gravity in m/s²
µ	Coefficient of friction

Tip limit of a conveyed item

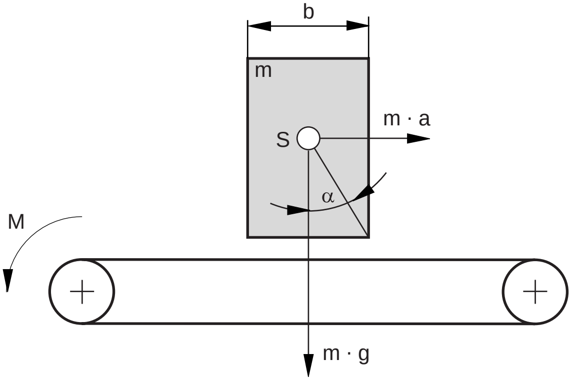


Figure 8.2 Conveyor belt with a high body and small standing area

Maximum acceleration: $a \leq \frac{b}{h} \cdot g$

a	Belt acceleration in m/s²
b	Width of body in m
g	Acceleration due to gravity in m/s²
h	Height of body in m

1
2
3
4
5
6
7
A
DE
EN

Overswill of a liquid

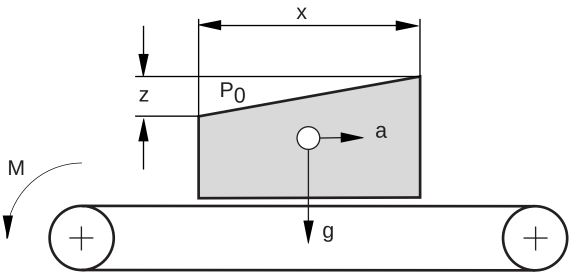


Figure 8.3 Conveyor belt in acceleration phase with a vessel filled with liquid

Height difference during acceleration: $z = \frac{a}{g} \cdot x$

The value z indicates the height difference of the liquid level in a vessel of length x accelerated at speed a. At the point of the lowest liquid level z is always 0.

a	Belt acceleration in m/s²
g	Acceleration due to gravity in m/s²
x	Coordinates in horizontal direction in m
z	Coordinates in vertical direction in m

Pendulum of a suspended load

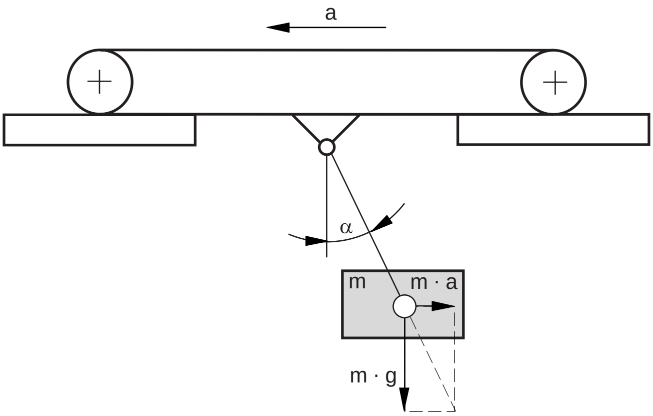


Figure 8.4 Schematic view of a crane with suspended load

Maximum acceleration: $a = g \cdot \tan\alpha$

a	Belt acceleration in m/s²
g	Acceleration due to gravity in m/s²
α	Angle of deflection of cable in degrees

In most applications the angle α should not exceed a value of 3°. With this value the result for the acceleration is:

A.2.8 Mass moments of inertia

Mass moments of inertia of bodies

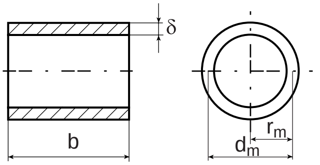
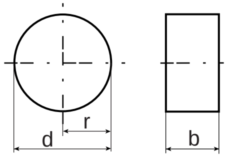
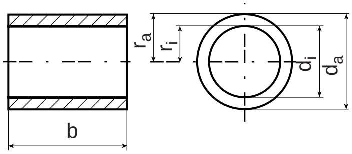
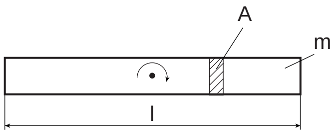
Thin-walled hollow cylinder $J = m \cdot \frac{d_m}{4} = \frac{d^3{}_m}{4} \cdot \pi \cdot b \cdot \rho \cdot \delta$	
Cylinder with full circular cross-section $J = \frac{m}{2} \cdot \left(\frac{d}{2}\right)^2 = \frac{\pi \cdot b \cdot \rho}{2} \cdot \left(\frac{d}{2}\right)^4$	
Thick-walled hollow cylinder $J = \frac{m}{2}\left[\left(\frac{d_a}{2}\right)^2 + \left(\frac{d_i}{2}\right)^2\right]$	
Long, thin bar with pivot point at center of gravity $J = \frac{m}{12} \cdot l^2 = \frac{A \cdot \rho}{12} \cdot l^3$	

Table 7.15 Mass moments of inertia of bodies

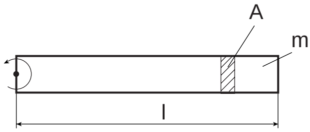
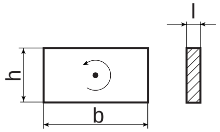
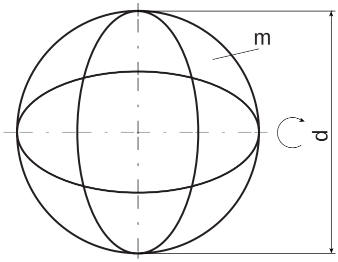
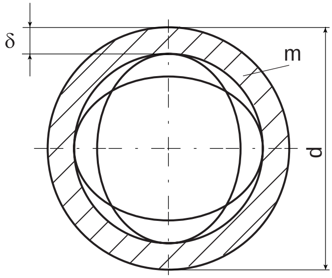
Long, thin bar with pivot point at end of bar $J = \frac{m}{3} \cdot l^2 = \frac{A \cdot \rho}{3} \cdot l^3$	
Rectangular plate with pivot point at center of gravity $J = \frac{m}{12} \cdot (h^2 + b^2)$	
Solid ball with rotary axis through center of gravity $J = \frac{2 \cdot m}{5} \cdot \left(\frac{d}{2}\right)^2 = \frac{\pi \cdot \rho \cdot d^5}{60}$	
Thin-walled ball shell with rotary axis through center of gravity $J = \frac{2 \cdot m}{3} \cdot \left(\frac{d}{2}\right)^2 = \frac{\pi \cdot \rho \cdot \delta \cdot d^4}{6}$	

Table 7.15 Mass moments of inertia of bodies

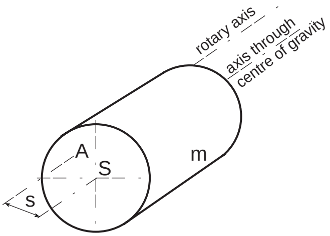
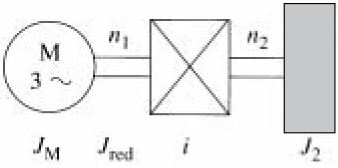
Steiner’s set $J_A = J_S + m \cdot s^2$	

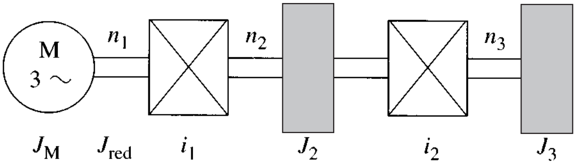
Table 7.15 Mass moments of inertia of bodies

Reduction via a gear



$$J_{red} = \frac{J_2}{(i)^2} = \frac{J_2}{(n_1 / n_2)^2}$$

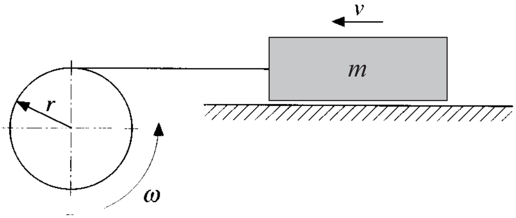
Reduction via two gears



$$J_{red} = \frac{J_2 + \frac{J_3}{(i_2)^2}}{(i_1)^2} = \frac{J_2 + \frac{J_1}{(n_2 / n_3)^2}}{(n_1 / n_2)^2}$$

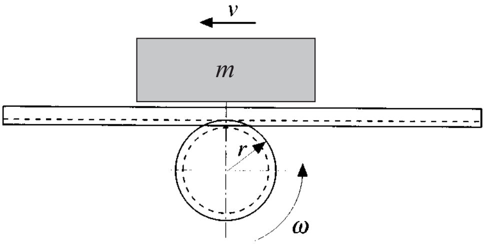
$$J_{tot} = J_M + J_{red}$$

Movement by conveyor roller



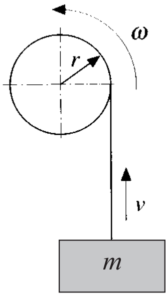
$$J = m \cdot r^2 = m \cdot \left(\frac{v}{\omega}\right)^2 = m \cdot \left(\frac{60 \cdot v}{2 \cdot \pi \cdot n}\right)^2$$

Movement by rack



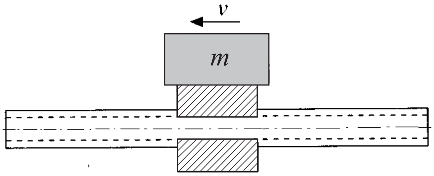
$$J = \sum m \cdot r^2 = \sum m \cdot \left(\frac{v}{\omega}\right)^2 = \sum m \cdot \left(\frac{60 \cdot v}{2 \cdot \pi \cdot n}\right)^2$$

Movement by cable reel



$$J = \sum m \cdot r^2 = \sum m \cdot \left(\frac{v}{\omega}\right)^2 = \sum m \cdot \left(\frac{60 \cdot v}{2 \cdot \pi \cdot n}\right)^2$$

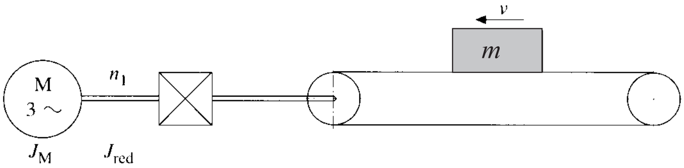
Movement by spindle



$$J = m \cdot \left(\frac{P}{2 \cdot \pi}\right)^2$$

P Lead in thread

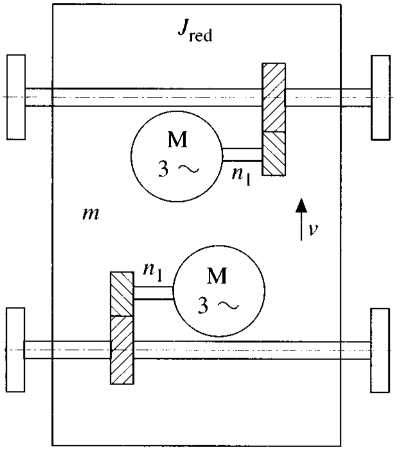
Conversion from translation into rotation



$$J_{red} = 91,2 \cdot \sum m \cdot \left(\frac{v}{n_1}\right)^2$$

$$J_{tot} = J_M + J_{red}$$

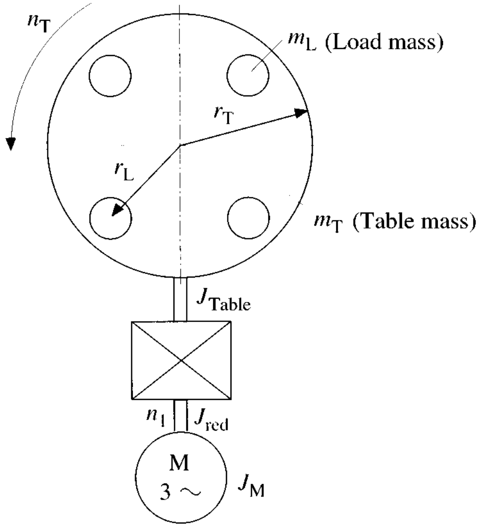
Conversion from translation into rotation with several motors



$$J_{red} = \frac{1}{k_A} \cdot 91,2 \cdot m \cdot \left(\frac{v}{n_1}\right)^2$$

k_A Number of drives

Indexing table with eccentric loads



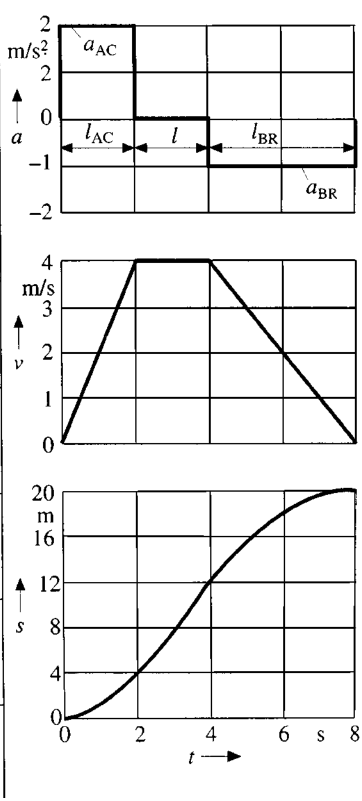
$$J_{Table} = \frac{1}{2} \cdot m_T \cdot r_T + m_L \cdot r_L$$

$$J_{red} = J_{Table} \cdot \left(\frac{n_T}{n_1} \right)^2$$

$$J_{tot} = J_M + J_{red}$$

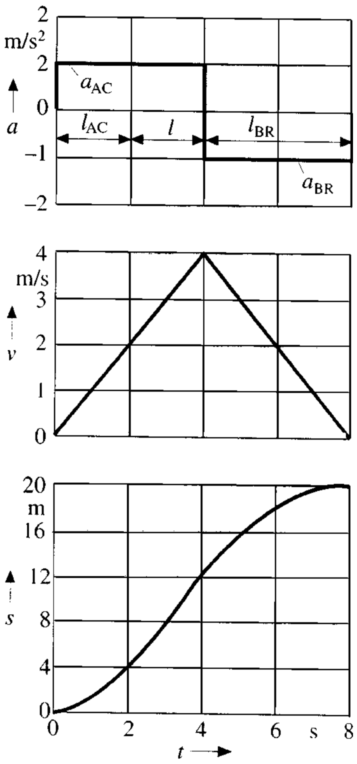
A.2.9 V/t diagram

Acceleration time	$t_{AC} = \frac{v}{a_{AC}}$
Acceleration travel	$s_{AC} = \frac{1}{2} \cdot v \cdot t_{AC} = \frac{1}{2} \cdot a_{AC} \cdot t_{AC}^2$
Braking time	$t_{BR} = \frac{v}{a_{BR}}$
Braking travel	$s_{BR} = \frac{1}{2} \cdot v \cdot t_{BR} = \frac{1}{2} \cdot a_{BR} \cdot t_{BR}^2$
Travel with v=const.	$s = v \cdot t$
Time for v=const.	$t = \frac{s}{v}$
Total travel	$s_{tot} = s_{AC} + s_{BR} + s$
Total time	$t_{tot} = t_{AC} + t_{BR} + t$



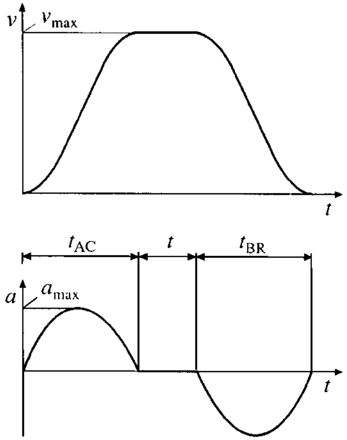
v/t diagram for minimum torque

Acceleration time	$t_{AC} = \frac{v}{a_{AC}}$
Acceleration travel	$s_{AC} = \frac{1}{2} \cdot v \cdot t_{AC} = \frac{1}{2} \cdot a_{AC} \cdot t_{AC}^2$
Braking time	$t_{BR} = \frac{v}{a_{BR}}$
Braking travel	$s_{BR} = \frac{1}{2} \cdot v \cdot t_{BR} = \frac{1}{2} \cdot a_{BR} \cdot t_{BR}^2$
Total travel	$s_{tot} = s_{AC} + s_{BR}$
Total time	$t_{tot} = t_{AC} + t_{BR}$



v/t diagram with sinusoidal characteristic

Period	$T = 2 \cdot \pi \cdot \frac{v_{\max}}{a_{\max}}$
Acceleration time	$t_{AC} = \frac{T}{4}$
Acceleration travel	$s_{AC} = v_{\max} \cdot \frac{T}{8}$
Braking time	$t_{BR} = \frac{T}{4}$
Braking travel	$s_{BR} = v_{\max} \cdot \frac{T}{8}$
Acceleration	$a_{\max} = \frac{2 \cdot \pi \cdot v_{\max}}{T} = \frac{1,57 \cdot v_{\max}}{t_{AC}}$



A.2.10 Efficiencies, coefficients of friction and density

Efficiencies of transmission elements

Transmission element	Characteristic	Efficiency
Wire cable	Each complete wrap of the cable reel (friction or roller bearing supported)	$\eta = 0.91 - 0.95$
V-belt	Each complete wrap of the V-belt pulley (normal belt tension)	$\eta = 0.88 - 0.93$
Plastic belts	Each complete wrap; rollers on roller bearings (normal belt tension)	$\eta = 0.81 - 0.85$
Rubber belts	Each complete wrap; rollers on roller bearings (normal belt tension)	$\eta = 0.81 - 0.85$
Chains	Each complete wrap; chains on roller bearings (depending on chain size)	$\eta = 0.90 - 0.96$
Spindles	Trapezoidal threaded spindle Recirculating ball spindle	$\eta = 0.30 - 0.70$ $\eta = 0.70 - 0.95$

Table 7.16 Efficiencies of transmission elements

Coefficients of friction for bearing friction

Bearing type	Coefficient of friction
Roller bearing	μ = 0.001 to 0.005
Friction bearing	μ = 0.08 -0.1

Table 7.17 Coefficients of friction for bearing friction

Coefficients of friction for roller bearing friction

Roller bearing	Coefficient of friction
Axial groove ball bearing	0.0013
Radial self-aligning ball bearing	0.0010
Radial self-aligning roller bearing	0.0018
Radial groove ball bearing	0.0015
Radial taper roller bearing	0.0018
Radial cylinder roller bearing	0.0011
Radial needle bearing	0.0045

Table 7.18 Coefficients of friction for roller bearing friction

Coefficients of friction for spindles

Spindle type	Coefficient of friction
Trapezoidal threaded spindle	μ = 0.05 - 0.08 (greased) μ = 0.1 - 0.18 (dry)
Recirculating ball spindle	μ = 0.005 -0.05

Table 7.19 Coefficients of friction for spindles

Coefficients for rim and side friction

Wheel type	Coefficients for rim and side friction
Roller bearing supported wheels	c=0.003
Friction bearing supported wheels	c=0.005
Side guide rollers	c=0.002

Table 7.20 Coefficients for rim and side friction

Coefficients of friction of various material pairings

Friction pairing	Friction type	Coefficient of friction
Steel on steel	Static friction (dry) Sliding friction (dry) Static friction (greased) Sliding friction (greased)	μ_0=0.12-0.60 μ =0.08-0.50 μ_0=0.12-0.35 μ =0.04-0.25
Wood on steel	Static friction (dry) Sliding friction (dry)	μ_0=0.45-0.75 μ =0.30-0.60
Wood on wood	Static friction (dry) Sliding friction (dry)	μ_0=0.40-0.75 μ =0.30-0.50
Plastic belt on steel	Static friction (dry) Sliding friction (dry)	μ_0=0.25-0.45 μ =0,25
Steel on plastic	Static friction (dry) Sliding friction (dry)	μ_0=0.20-0.45 μ =0.18-0.35

Table 7.21 Coefficients of friction of various material pairings

Lever arm of rolling friction for various material pairings

Material pairing	Lever arm of rolling friction
Steel on steel	f=0.5 mm
Wood on steel (roller conveyor)	f=1,2 mm
Plastic on steel	f=2.0 mm
Hard rubber on steel	f=7.0 mm
Plastic on concrete	f=5.0 mm
Hard rubber on concrete	f=10 mm - 20 mm
Medium-hard rubber on concrete	f=15 mm - 35 mm

Table 7.22 Leverarmofrollingfrictionforvariousmaterialpairings

Density ρ of various materials

Aluminum	2700	kg/m³
Gray-cast	7600	kg/m³
Copper	8960	kg/m³
Brass	8400-8900	kg/m³
Steel	7860	kg/m³
Zinc	7130	kg/m³

Table 7.23 Density of various materials

Tin	7290	kg/m³
Epoxy resin	1200	kg/m³
Rubber	920-990	kg/m³
Phenol resin, type 31	1400	kg/m³
Polyethylene	900-950	kg/m³
PVC	1300-1400	kg/m³

Table 7.23 Density of various materials

Transversal forces

The expected transversal forces must be calculated in order to determine the correct size of motor and gearing.

Transmission elements	Comments	Supplement fz
Cogwheels	≥ 17 cogs < 17 cogs	1 1.15
Chain wheels	≥ 20 cogs < 20 cogs < 13 cogs	1 1.25 1.4
Narrow V-belt pulley	dependent on pre-tension	1.5-2
Flat belt with tension roller	dependent on pre-tension	2-2.5
Flat belt without tension roller	dependent on pre-tension	2.3-3

Table 7.24 Transversal forces

$F_Q=(M/r) \cdot f_z$

M	Torque
r	Radius
f_z	Supplement for radial force calculation

A.2.11 Motor lists

Three-phase AC motors with squirrel-cage rotor to DIN VDE 0530, 3000 rpm, 50 Hz, IP54 protection, internally cooled

Standard 3-phase AC motor 3000 rpm, 50 Hz

Size	Power P in kW	Efficiency η in %	Nominal torque M_n in Nm	Mass moment of inertia J in kgm²	Rated current at 230/400 V
56S/2	0.09	50	0.31	0.000130	0.80/0.5
56L/2	0.12	49	0.41	0.000160	0.96/0.6
63S/2	0.18	57	0.63	0.000141	1,22/0.75
63L/2	0.25	59	0.86	0.000188	1.5/0.91
71S/2	0.37	69	1,25	0.00035	1.83/1.1
71L/2	0.55	75	1.87	0.000455	2.45/1.45
80S/2	0.75	72	2.58	0.000678	3.25/1.93
80L/2	1.1	78	3.73	0.000904	4.6/2.7
90S/2	1.5	78	5.1	0.00137	5.8/3.4
90L/2	2.2	82	7.4	0.00183	8.4/4.9
100S/2	3.0	73	10.0	0.00282	12.5/7.3
112M/2	4.0	80	13.3	0.00556	14.8/8.6
132S/2	5.5	85	18.3	0.00837	21.1/12.1
132S/2a	7.5	84	24.9	0.012	27.1/15.7
160M/2	11.0	87	36.0	0.033	37.3/21.6
160M/2a	15.0	88	49.0	0.045	48.1/28.1
160L/2	18.5	92	60.0	0.054	59.1/34.1
180M/2	22.0	91	71.0	0.073	74.1/43.1
200L/2	30.0	90	97.0	0.12	96.1/56.1
200L/2a	37.0	92	119.0	0.15	114.1/66.1
225M/2	45.0	93	145.0	0.22	148.1/81.1
250M/2	55.0	95	177.0	0.36	170.1/98.1
280S/2	75.0	93	241.0	0.61	-/135.1
280M/2	90.0	92	289.0	0.70	-/165.1
315S/2	110.0	93	353.0	1.46	-/202.1
315M/2	132.0	92	424.0	1.70	-/244.1
315M/2a	160.0	93	514.0	2.00	-/289.1
315M/2b	200.0	87	641.0	2.20	-/385.1
The data given represent mean values which may vary slightly depending on manufacturer.					

Table 7.25 Standard 3-phase AC motor, 3000 rpm, 50 Hz

Standard 3-phase AC motor, 1500 rpm, 50 Hz

Three-phase AC motors with squirrel-cage rotor to DIN VDE 0530, 1500 rpm, 50 Hz, IP54 protection, internally cooled

Size	Power P in kW	Efficiency η in %	Nominal torque M_n in Nm	Mass moment of inertia J in kgm^2	Rated current at 230/400 V
56S/4	0.06	42	0.42	0.000130	0.62/0.4
56L/4	0.09	39	0.63	0.000160	0.97/0.6
63S/4	0.12	49	0.85	0.000210	0.97/0.6
63L/4	0.18	63	1.26	0.000280	1.1/0.7
71S/4	0.25	61	1.72	0.000560	1.5/0.9
71L/4	0.37	65	2.56	0.000730	2.0/1.2
80S/4	0.55	73	3.8	0.00128	2.7/1.6
80L/4	0.75	80	5.1	0.00165	3.4/2.0
90S/4	1.1	72	7.5	0.00235	5.1/3.0
90L/4	1.5	77	10.2	0.00313	6.5/3.8
90L/4a	2.2	76	15.0	0.00316	9.6/5.6
100L/4	2.2	76	14.9	0.00450	9.5/5.5
100L/4a	3.0	77	20.3	0.00600	12.9/7.5
112M/4	4.0	83	27.0	0.0199	15.7/9.1
132S/4	5.5	85	36.0	0.0233	20.0/11.6
132M/4	7.5	87	49.0	0.0317	28.1/16.3
132M/4a	9.2	87	60.0	0.0354	35.1/20.1
160M/4	11.0	89	72.0	0.062	39.4/23.1
160L/4	15.0	89	98.0	0.083	54.1/31.1
180M/4	18.5	91	121.0	0.127	66.1/38.1
180L/4	22.0	94	143.0	0.153	80.1/44.1
200L/4	30.0	89	195.0	0.249	99.1/57.1
225S/4	37.0	91	240.0	0.392	124.1/70.1
225M/4	45.0	95	290.0	0.474	152.1/85.1
250M/4	55.0	93	355.0	0.736	176.1/98.1
280S/4	75.0	94	484.0	1.22	-/140.1

The data given represent mean values which may vary slightly depending on manufacturer.

Table 7.26 Standard 3-phase AC motor, 1500 rpm, 50 Hz

Size	Power P in kW	Efficiency η in %	Nominal torque M_n in Nm	Mass moment of inertia J in kgm²	Rated current at 230/400 V
280M/4	90.0	95	581.0	1.46	-/168.1
315S/4	110.0	94	707.0	2.12	-/210.1
315M/4	132.0	96	849.0	2.54	-/240.1
315M/4a	160.0	96	1029.0	2.97	-/285.1
315M/4b	200.0	93	1286.0	3.25	-/370.1
The data given represent mean values which may vary slightly depending on manufacturer.					

Table 7.26 Standard 3-phase AC motor, 1500 rpm, 50 Hz

Standard 3-phase AC motor, 1000 rpm, 50 Hz

Three-phase AC motors with squirrel-cage rotor to DIN VDE 0530, 1000 rpm, 50 Hz, IP54 protection, internally cooled

Size	Power P in kW	Efficiency η in %	Nominal torque M_n in Nm	Mass moment of inertia J in kgm²	Rated current at 230/400 V
63S/6	0.09	47	0.97	0.00031	0.88/0.55
63L/6	0.12	41	1.29	0.00042	1.2/0.74
71S/6	0.18	58	1.89	0.00091	1.23/0.75
71M/6	0.25	64	2.58	0.0012	1.66/1.0
80S/6	0.37	57	3.84	0.0022	2.5/1.5
80L/6	0.55	69	5.71	0.0028	3.0/1.78
90S/6	0.75	69	7.83	0.0037	4.1/2.3
90L/6	1.1	68	11.5	0.0050	5.6/3.4
100L/6	1.5	73	15.1	0.010	7.2/4.2
112M/6	2.2	81	22.1	0.018	9.85/5.75
132S/6	3.0	82	29.8	0.031	13.5/7.9
132M/6	4.0	84	39.8	0.038	16.8/9.8
132M/6a	5.5	81	55.8	0.045	23.3/13.5
160M/6	7.5	85	74.0	0.093	28.6/16.6
160L/6	11.0	86	109.0	0.127	42.1/24.1
180M/6	13.0	85	130.0	0.168	49.1/28.1
180L/6	15.0	85	148.0	0.192	55.1/32.1
200LK/6	20.0	88	196.0	0.281	73.1/42.1
200L/6	22.0	91	215.0	0.324	78.1/45.1
225M/6	30.0	89	290.0	0.736	103.1/60.1
250M/6	37.0	93	360.0	1.01	123.1/71.1
280S/6	45.0	92	436.0	1.48	156.1/90.1
280M/6	55.0	92	533.0	1.78	190.1/110.1
315S/6	75.0	92	727.0	2.63	-/143.1
The data given represent mean values which may vary slightly depending on manufacturer.					

Table 7.27 Standard 3-phase AC motor, 1000 rpm, 50 Hz

Size	Power P in kW	Efficiency η in %	Nominal torque M_n in Nm	Mass moment of inertia J in kgm²	Rated current at 230/400 V
315M/6	90.0	93	878.0	3.08	-/170.1
315M/6a	110.0	95	1061.0	3.63	-/205.1
315M/6b	132.0	93	1273.0	4.17	-/250.1
355S/6	160.0	95	1543.0	10.7	-/290.1
355S/6a	200.0	95	19,29.0	12.7	-/365.1
The data given represent mean values which may vary slightly depending on manufacturer.					

Table 7.27 Standard 3-phase AC motor, 1000 rpm, 50 Hz

Asynchronous servomotors

Asynchronous servomotors with squirrel-cage rotors to DIN 42 950, self-cooling, IP 65 protection

Size	Power P in kW	Efficiency η in %	Nominal torque M_n in Nm	Mass moment of inertia J in kgm²	Nominal speed n in rpm	Rated current in A
ASM(H)31	2.1	83.0	13.0	0.0070	1500	5.2
ASM(H)32	2.7	85.0	17.0	0.0090	1500	6.8
ASM(H)33	3.6	85.0	23.0	0.0130	1500	8.7
ASM(H)34	5.5	87.0	35.0	0.0209	1500	12.6
ASM(H)24	2.1	84.0	10.0	0.00298	2000	5.3
ASM(H)25	2.7	85.0	13.0	0.00384	2000	6.6
ASM(H)11	0.41	76.0	1.3	0.00028	3000	1.4
ASM(H)12	0.54	77.0	1.7	0.00037	3000	1.8
ASM(H)13	0.72	79.0	2.3	0.00047	3000	2.3
ASM(H)14	1.1	80.0	3.5	0.00065	3000	3.3
ASM(H)15	1.5	82.0	4.7	0.00089	3000	4.5
ASM(H)21	1.1	82.0	3.5	0.00109	3000	3.0
ASM(H)22	1.5	83.0	4.7	0.00144	3000	3.9
ASM(H)23	2.2	84.0	7.0	0.00215	3000	5.6
The data given represent mean values which may vary slightly depending on manufacturer.						

Table 7.28 Asynchronous servomotors, self cooling

Asynchronous servomotors with squirrel-cage rotors to DIN 42 950, forced cooling, IP 65 protection

Size	Power P in kW	Efficiency η in %	Nominal torque M_n in Nm	Mass moment of inertia J in kgm²	Nominal speed n in rpm	Rated current in A
ASF(V)3 1	2.8	80.0	18.0	0.0070	1500	7.0
ASF(V)3 2	3.6	83.0	23.0	0.0090	1500	8.9
ASF(V)3 3	5.0	85.0	32.0	0.0130	1500	11.6
ASF(V)3 4	7.4	87.0	47.0	0.0209	1500	15.4
ASF(V)2 4	2.7	83.0	13.0	0.00298	2000	6.7
ASF(V)2 5	3.4	85.0	16.5	0.00384	2000	8.2
ASF(V)1 1	0.54	76.0	1.7	0.00028	3000	1.8
ASF(V)1 2	0.72	78.0	2.3	0.00037	3000	2.4
ASF(V)1 3	0.94	79.0	3.0	0.00047	3000	2.9
ASF(V)1 4	1.5	81.0	4.7	0.00065	3000	4.3
ASF(V)1 5	2.0	82.0	6.5	0.00089	3000	6.2
ASF(V)2 1	1.5	82.0	4.7	0.00109	3000	3.9
ASF(V)2 2	2.0	83.0	6.5	0.00144	3000	5.0
ASF(V)2 3	3.1	85.0	10.0	0.00215	3000	7.4
The data given represent mean values which may vary slightly depending on manufacturer.						

Table 7.29 Asynchronous servomotors, forced cooling

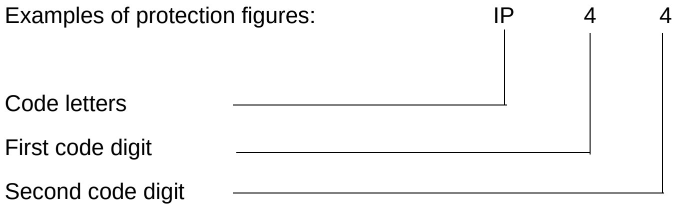
A.3 Protection

A.3.1 Protection to IEC/EN

Protection against touch and foreign body contact

First code digit	Scope of protection	
	Designation	Explanation
0	No protection	No special protection of personnel against random touch contact with live or moving parts. No protection of equipment against intrusion of solid foreign bodies.
1	Protection against foreign bodies ≥ 50 mm	Protection against random large-area touch contact with live parts and internal moving parts, e.g. with back of hand, but no protection against intentional accessing of said parts. Protected against solid foreign bodies with a diameter of 50 mm and larger.
2	Protection against foreign bodies ≥ 50 mm	Protection against touch contact by fingers with live parts or internal moving parts. Protected against solid foreign bodies with a diameter of 12.5 mm and larger.
3	Protection against foreign bodies ≥ 2.5 mm	Protection against touch contact with live parts or internal moving parts by tools, wires or similar items of a thickness of 2.5 mm and thicker. Protected against solid foreign bodies with a diameter of 2.5 mm and larger.
4	Protection against foreign bodies ≥ 1 mm	Protection against touch contact with live parts or internal moving parts by tools, wires or similar items of a thickness of 1 mm and thicker. Protected against solid foreign bodies with a diameter of 1 mm and larger.
5	Protection against dust deposits	Complete protection against touch contact with live parts or internal moving parts. Protection against damaging dust deposits. The intrusion of dust is not entirely prevented, but the dust must not penetrate to the extent that operation or safety is impaired.
6	Protection against dust intrusion Dust-proof	Complete protection against touch contact with live parts or internal moving parts. Protection against intrusion of dust.

Table 1.3 Protection against touch and foreign body contact



For water protection

First code digit	Scope of protection	
	Designation	**Explanation**
0	No protection	No special protection
1	Protection against vertically falling dripping water	Water dripping vertically must not have any damaging effect.
2	Protection against dripping water with housing at a tilt of up to 15°	Water dripping vertically must not have any damaging effect when the housing is at a tilt angle of 15° to either side of the vertical.
3	Protection against splashing water	Water splashing at any angle up to 60° on either side of the vertical must not have any damaging effect.
4	Protection against splashing water	Water splashing onto the housing from any direction must not have any damaging effect.
5	Protection against water jet spray	A water jet from a nozzle directed from any direction onto the equipment must not have any damaging effect.

Table 1.4 For water protection

First code digit	Scope of protection	
	Designation	**Explanation**
6	Protection against powerful water jet spray	A powerful water jet directed from any direction onto the housing must not have any damaging effect.
7	Protection in case of temporary immersion	Water must not intrude in damaging quantities when the equipment is immersed in water under standardized pressure and time conditions.
8	Protection in case of permanent immersion	Water must not intrude in damaging quantities when the equipment is permanently immersed in water under conditions which must be agreed between the manufacturer and the user. The conditions must be more severe than those for code digit 7.
9K*	Protection in case of high-pressure/ steam jet cleaning	Water directed from any direction under very high pressure onto the housing must not have any damaging effect. Water pressure 100 bar Water temperature 80°C
* This code digit originates from the standard DIN 40050 Part 9.		

Table 1.4 For water protection

A.3.2 Protection to EEMAC and Nema

Types of protection of electrical equipment for USA and Canada conforming to IEC 529/EN 60529, VDE 0470 Part 1

The IP protection types quoted represent a rough comparison. A detailed comparison is not possible, because protection tests and assessment criteria differ.

Marking of the housing and the protection type		**Marking of the housing and the protection type to CSA-C22.1 (Canadian Electrical Code) CSA-C22.2 No. 94**	**Comparable IP protection to IEC 529 / DIN 40050**
to NEC NFPA 70 (National Electrical Code) to UL 508 to NEMA No. 250-1985	**to NEMA ICS6-19831) to EEMAC E 14-22)**		
Housing type 1	Housing type 1 General use	Housing 1 Housing for general use	IP 20
Housing type 2 Drip-tight	Housing type 2 Drip-proof	Housing 2 Drip-proof housing	IP 22
Housing type 3 dust-tight, rain-tight	Housing type 3 Dust-tight, rain-tight, resistant to sleet and ice	Housing 3 Weather-proof housing	IP 54
Housing type 3 R Rain-proof	Housing type 3 R Rain-proof, resistant to sleet and ice		
Housing type 3 S Dust-tight, rain-tight	Housing type 3 S Dust-tight, rain-tight, resistant to sleet and ice		
Housing type 4 Rain-tight, water-tight	Housing type 4 Dust-tight, water-tight	Housing 4 Water-tight housing	IP 65
Housing type 4 X Rain-tight, water-tight, corrosion-resistant	Housing type 4 X Dust-tight, water-tight, corrosion-resistant		
Housing type 6 Rain-tight	Housing type 6 Dust-tight, water-tight, submersible, resistant to sleet and ice		

Table 7.30 Protection types of electrical equipment for USA and Canada

Marking of the housing and the protection type		Marking of the housing and the protection type to CSA-C22.1 (Canadian Electrical Code) CSA-C22.2 No. 94	Comparable IP protection to IEC 529 / DIN 40050
to NEC NFPA 70 (National Electrical Code) to UL 508 to NEMA No. 250-1985	**to NEMA ICS6-19831) to EEMAC E 14-22)**		
Housing type 6 P Rain-tight, corrosion-proof			
Housing type 11 Drip-tight, corrosion-proof	Housing type 11 Drip-proof, corrosion-resistant, oil-immersed		
Housing type 12 Dust-tight, drip-tight	Housing type 12 Use in industry, drip-tight, dust-tight	Housing 5 Dust-tight housing	IP 54
Housing Type 12 K (as for type 12)			
Housing type 13 Dust-tight, drip-tight	Housing type 13 Dust-tight, oil-tight		

Table 7.30 Protection types of electrical equipment for USA and Canada

1) NEMA=	National Electrical Manufacturers Association
2) EEMAC=	Electrical and Electronic Manufacturers Association of Canada

Terms in German/English:

allgemeine Verwendung:	general purpose
tropfdicht:	drip-tight
staubdicht:	dust-tight
regendicht:	rain-tight
regensicher:	rain-proof
wettersicher:	weather-proof
wasserdicht:	water-tight
eintauchbar:	submersible
eisbeständig:	ice resistant
hagelbeständig:	sleet resistant
korrosionsbeständig:	corrosion resistant
öldicht:	oil-tight

Appendix B Practical working aids for the project engineer

Recording of movement task

Project name: ____________________

Company: ____________________

____

____

Name/Function: ____________________

____

____

Industry/Application: ____________________

Goal: ____________________

____

____

Special background conditions: ____________________

____

____

____

Comments: ____________________

____

____

____

Author: ____________________ Date: ____________________ Sheet ..... of .....

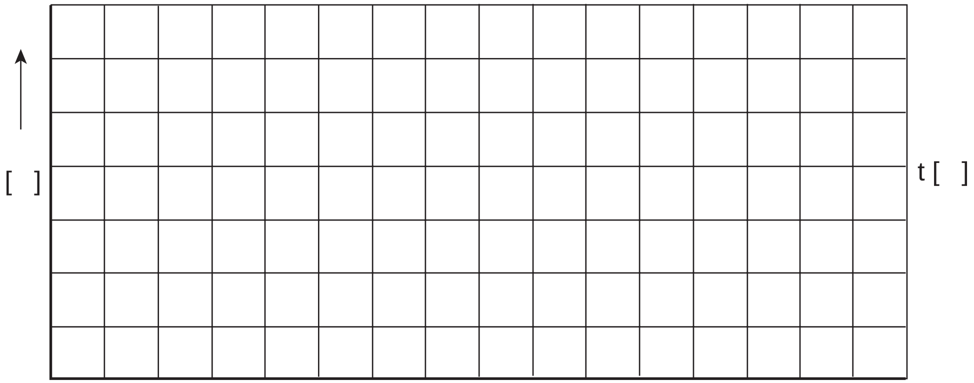
Movement requirement for processing

Project name: ____________________

☐ Continuous material flow

☐ Discontinuous batch process

☐ Discontinuous unit process



☐ Rotational movement [n=f(t)]

☐ Translational movement [v=f(t)]

Radius of drive shaft by which the movement is generated: _______ mm

Comments: ____

____

____

Author: ____________________ Date: ____________________ Sheet ..... of .....

Movement requirement for processing

Project name: ____________

Moment of inertia: ______ [kgm²] or Mass: ____________ [kg]

Mode of movement: ____________

Speed manipulating range: ____________

Static speed accuracy: ____________ [rpm]

Dynamic speed accuracy: ____________ [rpm]

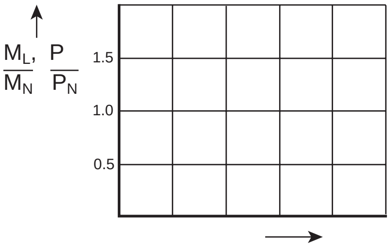
Torque rise time: ____________ [ms]

Positioning accuracy: ____________ [ms]

Comments: ____________

Load torque of processing process

☐ M_L~ 1/n, P=constant
☐ M_L=constant, P~n
☐ M_L=f(n), P=f(n)
☐ M_L~n², P~n³
☐ M_L=f(n)
☐ M_L=f(s)
☐ M_L=f(α)
☐ M_L=f(t)



Author: ____________ Date: ____________ Sheet ..... of .....

Additional environmental data

Project name: ____________________

Automation process: ____________________

____

____

____

Environmental and installation conditions: ____________________

____

____

____

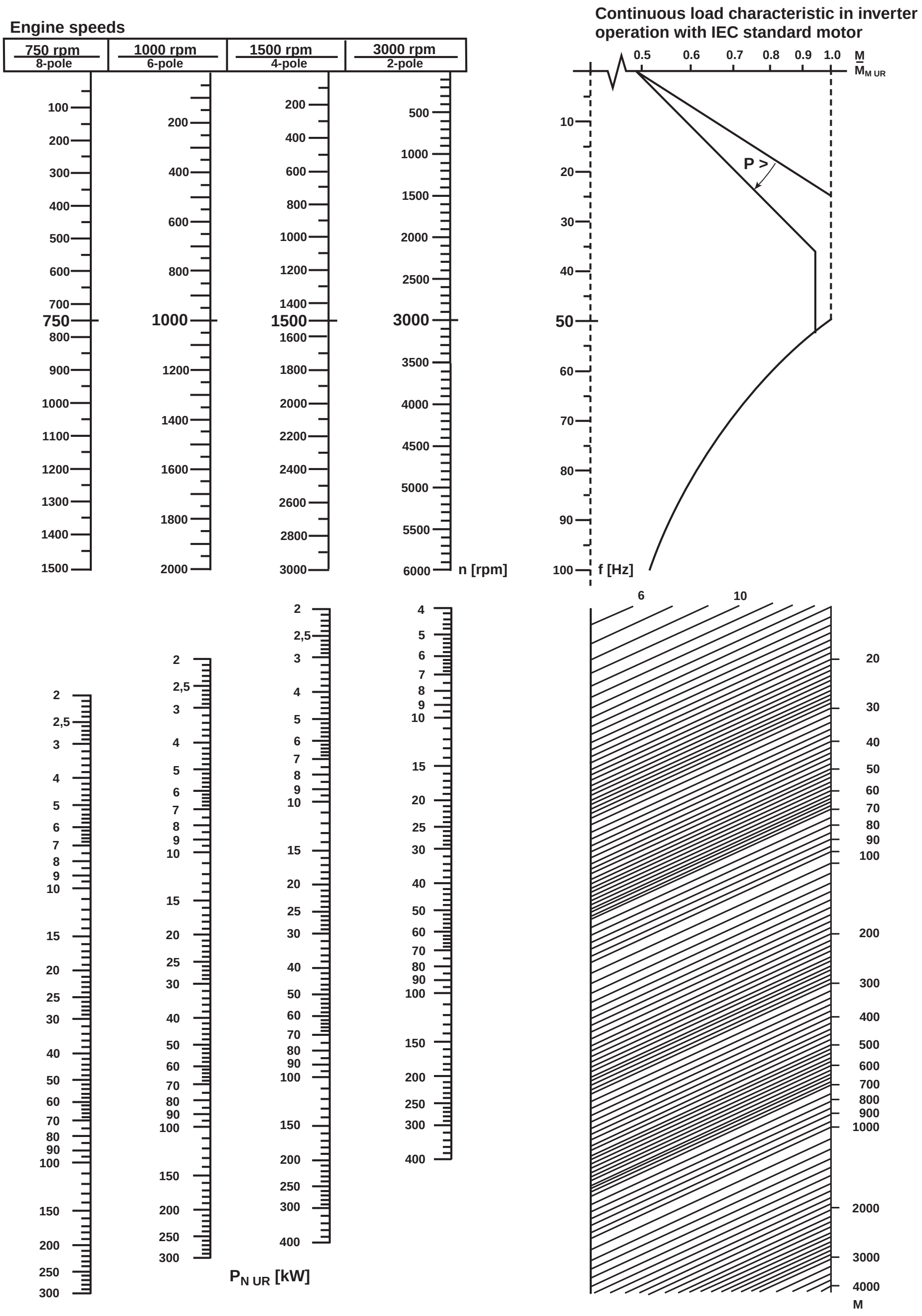
Standards, regulations and safety: ____________________

____

____

____

Author: ____________________ Date: ____________________ Sheet ..... of .....


Engine speeds

Continuous load characteristic in inverter operation with IEC standard motor

Rated power, inverter and motor

Load torque

Appendix C Bibliography and source reference

Das 1x1 der Antriebstechnik
Friedrich Wilhelm Garbrecht - Joachim Schäfer
ISBN 3-8007-2005-1
VDE Publishing

Maschinenbau Lexikon
Prof. Dr.-Ing. habil. Heinz M. Hiersig
ISBN 3-18-401372-3
VDE Publishing

Feldschwächung bei Umrichterantrieben bietet viele Vorteile
Joachim Schäfer
Specialist article in “Antriebstechnik” 36 (1997) no. 4

Projektmanagement
J. Boy - C. Dudek - S. Kuschel
ISBN 3-930799-01-4
Gabal

Taschenbuch der Technik
T. Krist
ISBN 3-87807-124-8
Technik - Tabellen Publishing

Der Drehstrommotor
Karl Falk
ISBN 3-8007-2078-7
VDE Publishing

Elektrische Antriebstechnik
Heinz Stüben
ISBN 3-7736-0839-x
W. Girardet Publishing

Grundlagen der elektrischen Antriebstechnik mit Berechnungsbeispielen
Johannes Vogel
ISBN 3-7785-1547-0
VEB Technical Publishing

Moderne Stromrichterantriebe
Peter F. Bosch
ISBN 3-8023-0241-9
Vogel Publishing

Feldbussysteme im Vergleich
Robert Busse
ISBN 3-7905-0722-9
Pflaum Publishing

Dynamische Eigenschaften von Drehstrom-Motoren
Joachim Schäfer
Specialist article in AGT 1994, no. 2

Positionieren mit Frequenzumrichtern durch Echtzeitverarbeitung, Teil 1
Joachim Schäfer
Specialist article in “Antriebstechnik” 1991, no. 3

Positionieren mit Frequenzumrichtern durch Echtzeitverarbeitung, Teil 2
Joachim Schäfer
Specialist article in “Antriebstechnik” 1991, no. 5

Klöckner Moeller Schaltungsbuch
Klöckner Moeller, Bonn

Oberschwingungen
Albert Kloss
ISBN 0175-9965
VDE Publishing

Absicherung von Maschinen vor gefahrbringenden Bewegungen
Elan Corporation in D-35435 Wettenberg

Schutztechnik mit Isolationsüberwachung
Wolfgang Hofheinz
ISBN 3-8007-2215-1
VDE Publishing

ZVEI research report “Elektrische Belastung und Ausfallverhalten der Wickelisolierung von Asynchronmaschinen mit Umrichterbetrieb”.
Berth, Eberhardt, Kaufhold, Speck, Auinger
Elektrie, H.8/9 (1995) p. 336

Frequenzumformer
Dr. Ing. P. F. Brosch
ISBN 3-478-93036-7
Moderne Industrie Publishing

Schaltschrank Klimatisierung
Heinrich Styppa
ISBN 3-478-93080-4
Moderne Industrie Publishing

Elektronische Gerätetechnik
Prof. Dipl.-Ing. Hans Brümmer
ISBN 3-8023-0610-4
Vogel Publishing

Appendix D Index

LUST
ANTRIEBSTECHNIK

Lust Antriebstechnik GmbH
Gewerbestrasse 5-9 • D-35631 Lahnau
Tel. 0 64 41 / 9 66-0 • Fax 0 64 41 / 9 66-137
Internet: http://www.lust-tec.de • e-mail: lust@lust-tec.de

ID no.: 0840.25B.1-00 • Date: 12/99
We reserve the right to make technical changes.