Introduction to Motion Control

TM400

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Requirements

Training modules:	No prerequisites
Software	No prerequisites
Hardware	No prerequisites

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1 INTRODUCTION

Nearly every machine or system component today involves positioning tasks of varying complexity, with the trend clearly moving in the direction of mechatronic drive solutions.

Movement sequences that used to be carried out using mechanical constructions that were sometimes quite elaborate can now be carried out with the highest degree of flexibility and efficiency using the latest motion control technologies.

The basics of drive technology

A drive solution that is uniform and can be used across different systems plays a major role these days. The more the individual components can be coordinated with one another, the stronger the technology will be. The mechatronic drive network can be integrated into the process as a closed functional unit.

This makes it possible for developers to focus primarily on optimizing the higher-level process.

This document will describe the fundamental concepts and procedures in a clear and understandable manner.

1.1 Training module objectives

In this training module, you will receive...

- An overview of the components that make up a mechatronic drive solution.
- A solid understanding of how different technologies function and where they are typically used.
- Insight into the properties of various drive mechanisms.
- A general idea of B&R drive components and how they are integrated into different topologies.
- Information regarding important criteria for setting up a drive configuration.

2 THE MECHATRONIC DRIVE SOLUTION

Electrical drive systems, power transmission systems, drive solutions, drive configurations, servo drives, etc.

These or similar expressions are used frequently to describe the range of components in a positioning system. Defining all of this into one single term is tough to do – but why?

Assessment

There is a wide range of different electrical drive system types. In addition, there are generally multiple designs of a single component, each with its own specific strengths and weaknesses.

For example, a servo-driven linear motor with high-precision position determination is required for one type of application, whereas an induction motor powered by a frequency inverter is sufficient for handling another application.

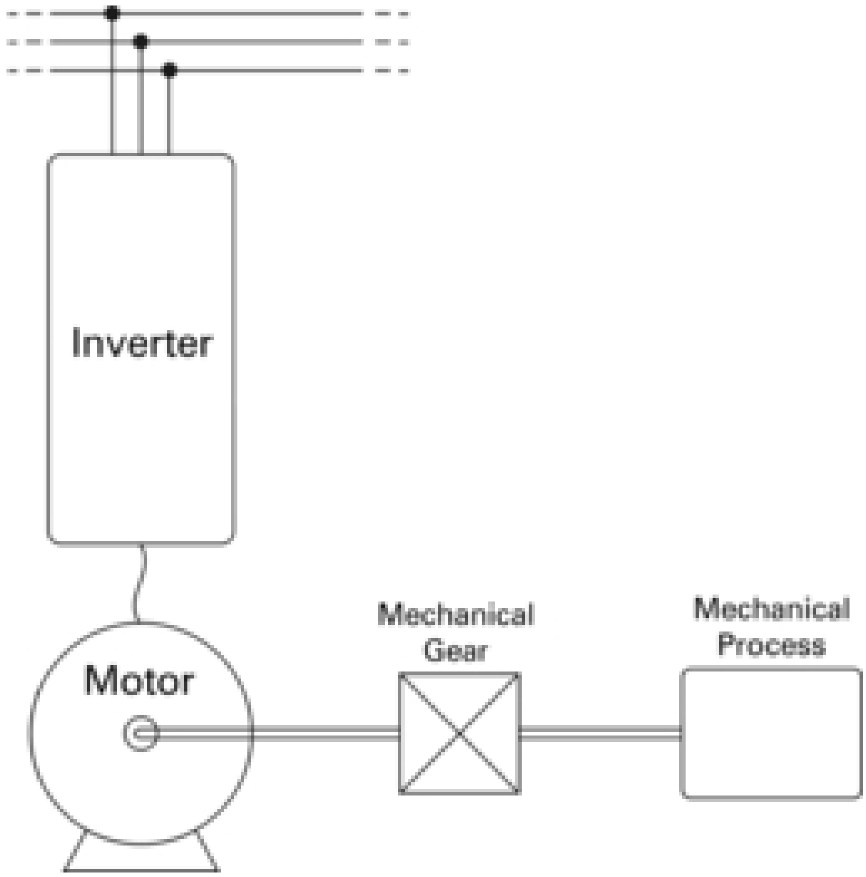
Orientation

As a result, there are a few fundamental questions:

- What components actually make up a drive or positioning system?
- What are the differences between existing technologies or variations thereof?
- What are the separate technologies used for specifically?

These questions can be cleared up through a simple illustration of the components involved:

The following diagram generally applies to electrical drive systems across the board:



Basic components of an electric drive system

The following components are used:

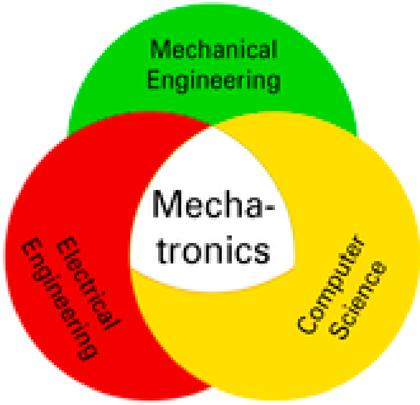
- Inverter or energy converter
- Electric motor
- Mechanical gear (gearboxes and couplings)
- Mechanical process (machine or mechanical system)

The inverter takes electrical energy from the mains and turns it into a suitable form that can be used by the electric motor. The motor then converts electrical energy into kinetic energy, thereby putting the mechanical system into motion (via a gearbox if necessary).

We will add to this basic scheme step-by-step as we work through the following sections. The focus will remain on how the individual components work as well as their characteristics within the complete system.

Before that, however, it is necessary to deal with a topic that comprises all aspects of modern drive technology. We are talking, of course, about mechatronics.

2.1 The core aspects of mechatronics

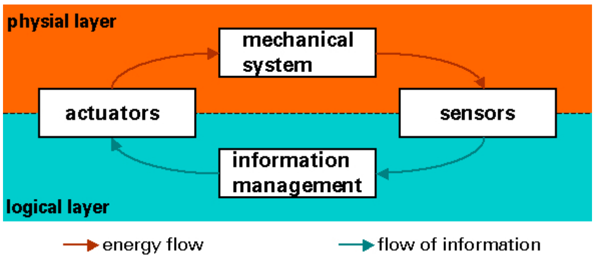


Mechatronics

The area of mechatronics deals with the interaction of mechanic, electronic and information-related systems.

In mechatronics, the boundaries between the areas of mechanics, electricity, electronics and information technology is put aside. Instead, the system is viewed as a single functional unit.

The key objective is the preparation and processing of all information for usage across all of these areas.



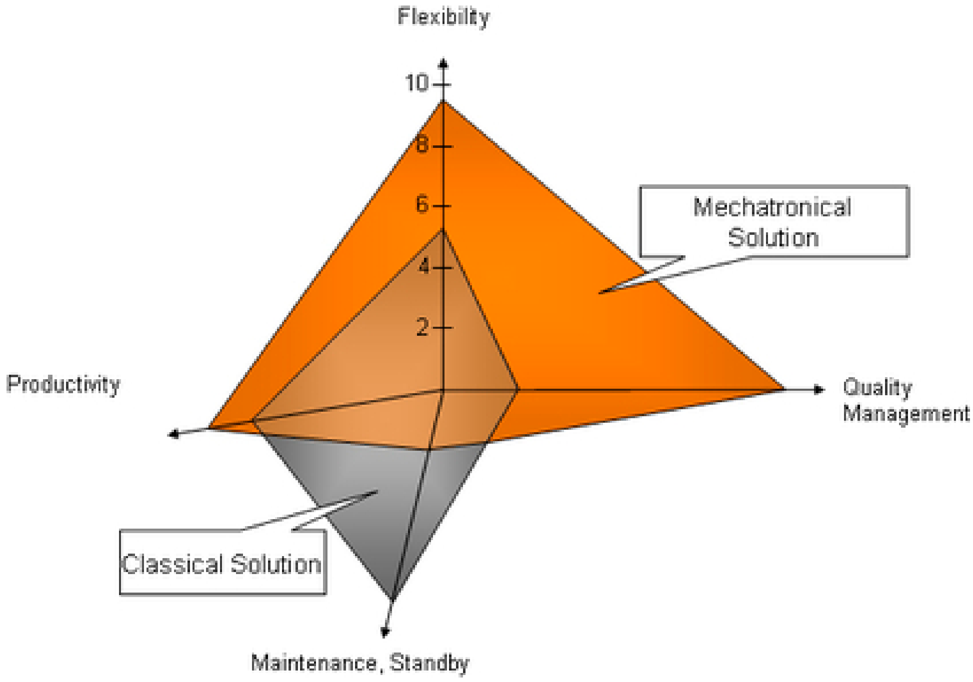
Communication throughout the entire system

Even the design and development of these technologies is carried out in close coordination with process demands, in our case the mechanical system.

This integrated approach to mechatronics provides clear advantages:

- Optimal adaptation of the basic system to the process requirements
- Creation of compact functional units (automation objects) and improved possibilities for standardization since the different process routines can be developed modularly and therefore easily reused
- Ease of use through standardized user interfaces and detailed diagnostics
- All of the resulting advantages of process optimization, efficiency and quality management (process monitoring)

The practical benefits of a mechatronic drive solution are clear:



Advantages of a mechatronic solution

2.2 The basic requirements of a drive system

What properties characterize a drive system?

This type of system needs to be highly dynamic and provide an exceptional degree of repeatability. The word "dynamics" is a general term that encompasses force, propulsion, or force that enacts or responds to change. This brings up the topic of how force changes over time.

Basic requirements

Practical considerations often require the following:

- Quickly reaching a certain speed
- Quickly reaching an exact position
- Being able to maintain a certain speed over time
- Maintaining a predetermined torque

As a result, a drive system must be able to position the connected mechanical system exactly according to specifications – while applying the greatest amount of force – without "going out of whack".

This characteristic flows directly into the productivity of the machine. In many applications, it's the positioning precision that determines whether or not a drive system is a suitable solution. In addition to its dynamic properties, a drive must also be able to be take in precise positions and "defend" them with an appropriate amount of force.

Selecting the electric motor is not the only decisive factor, however. Sophisticated measuring equipment and control algorithms also play a major role in handling these tasks.

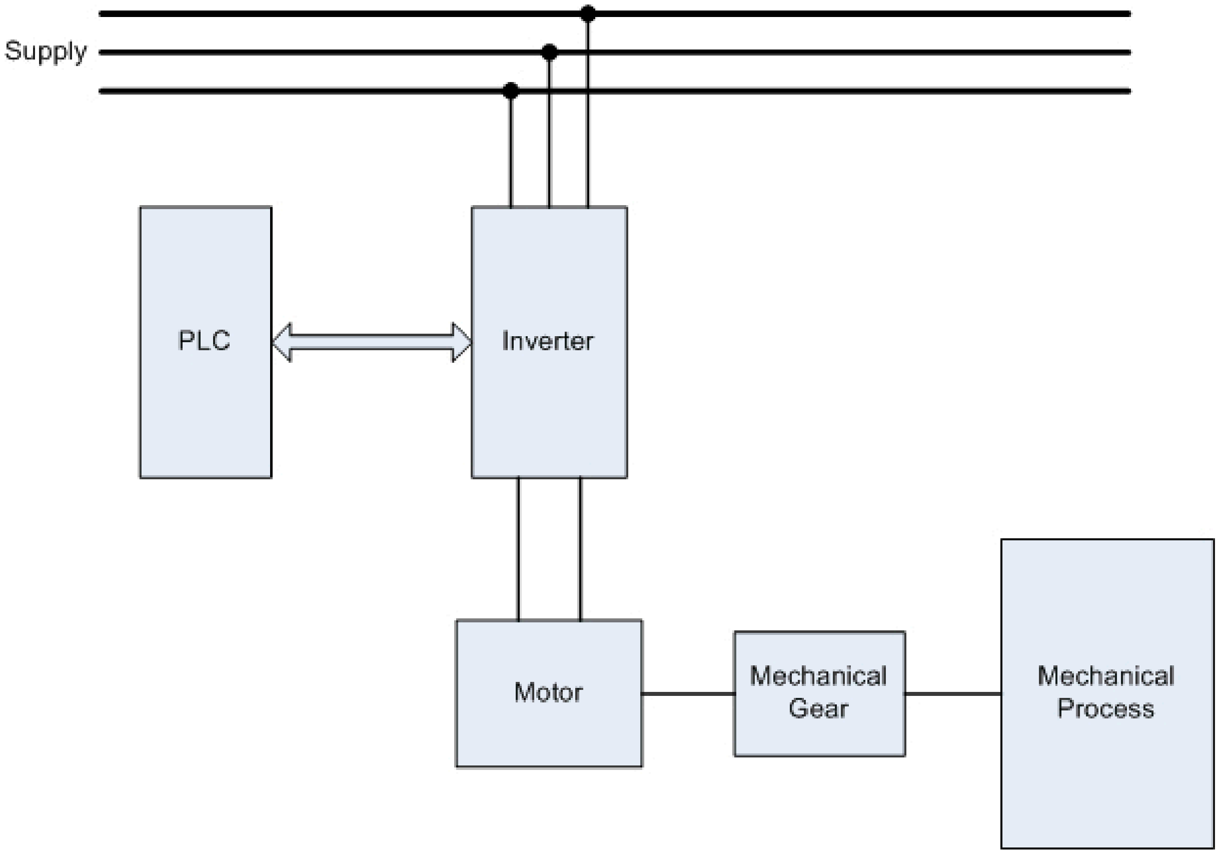
High demands can only be met when all of the components in a system are interacting seamlessly.

Because of this, selecting the proper drive and motor technology makes it possible to match technical requirements to a cost-efficient solution.

3 THE COMPONENTS OF A DRIVE SYSTEM

A drive system refers to a physical structure that is able to move a machine through the transformation of energy.

The process itself begins at the machine It is usually driven by an electric motor. A gearbox can sometimes be used to connect these two seperate units All of this is tied into how rotation and torque are adapted



Schematic illustration of an electric drive system

An electric motor converts electrical energy into mechanical energy. This results in various levels of torque and force. In order to control these values as needed, an inverter is required. Its main task is to prepare the electrical energy that will be supplied to the motor.

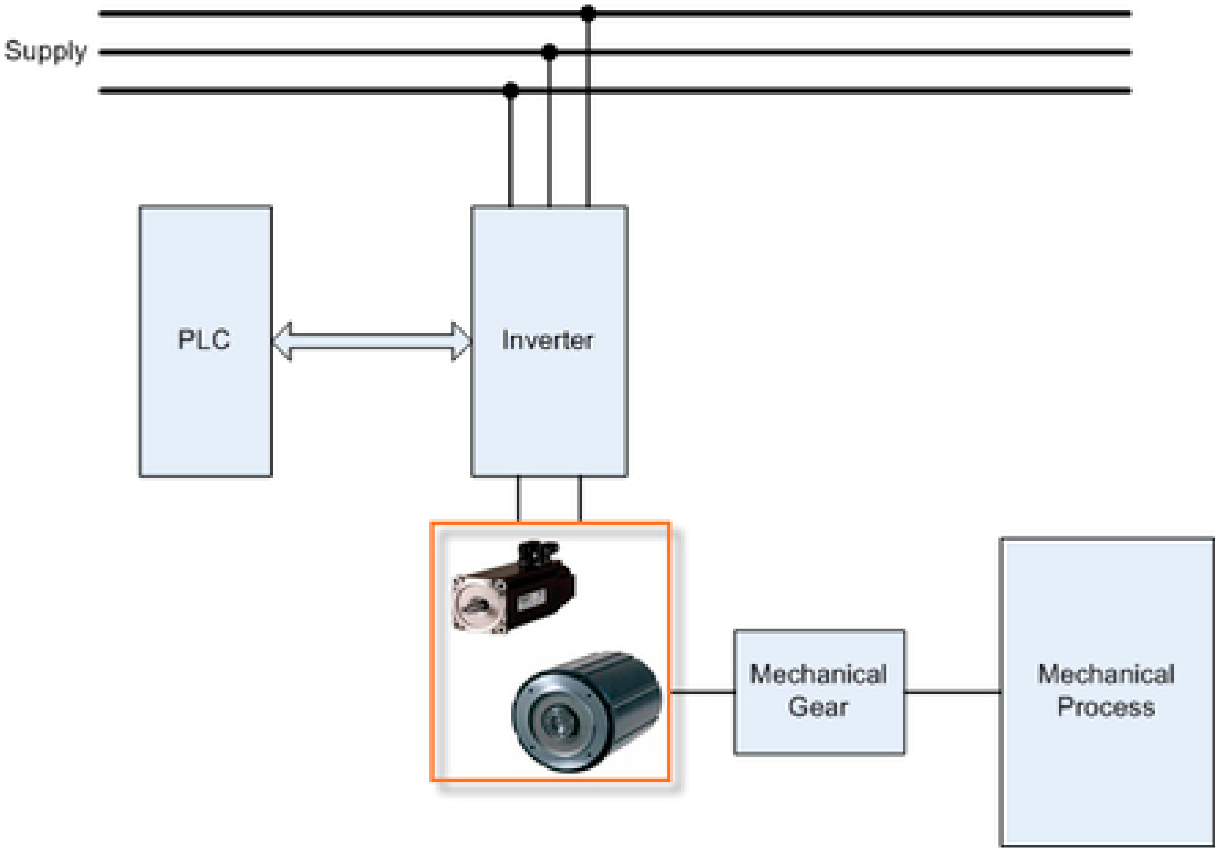
For positioning tasks, it is important to know the current position of the drive. In these cases, a position encoder is used; it is usually mounted directly on the motor.

The inverter receives its positioning commands from a PLC. This is where the application program that contains the necessary motion sequences is stored.

3.1 Electric motors

The history of the electromechanical machine - in particular the development of motors - starts at the beginning of the 19th century. Over time, many different types have emerged that vary in their construction as well as their basic characteristics.

All of the variations that were developed were designed to be used for particular tasks, which further highlighted their strengths.



The motor in an electric drive system

The following three motor types are the most conventional:

- DC motors
- Synchronous motors
- Induction motors

In turn, they form the basis for additional variants:

- Linear motors
- Torque motors
- Stepper motors
- Others

The next section will deal with the properties of motors in general. It will shed some light on their design, how they work and where each particular motor type is used.

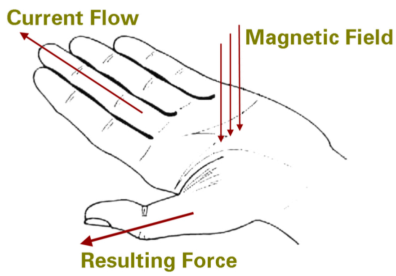
3.1.1 The basic principle of electric motors

The basic principle of electric drives can be explained by **Lorentz force**:

If current is applied to an electrical conductor in a magnetic field, the conductor will be acted upon by a force.

This force's direction of action depends on the direction of the two initiating values: the flow of current and the magnetic field.

The "left hand rule" illustrates these relationships.



"Left hand rule"

Mathematically speaking, it looks like this:

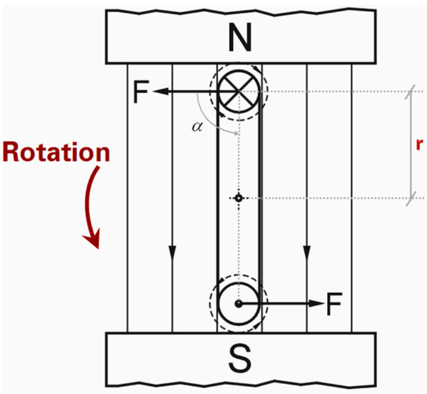
Value	Description
F	Force vector
B	Magnetic field vector
l	Length vector of the conductor in the field
I	Current

The following formula can be used to determine the resulting force:

$F = I * l * B * \sin(\alpha)$

Where **α** is the angle between the direction of the magnetic field and the direction the current is flowing.

For electric motors, this angle is almost always 90°, as can be seen in the following diagrams.



Current applied to a coil in the magnetic field

The force on the conductor depends on the intensity of the magnetic field, the strength of the current and the length of the conductor inside the magnetic field.

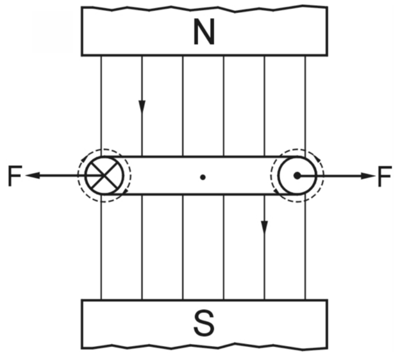
The following diagrams illustrate how this force is transformed into rotational motion.

A current-conducting, rotatable coil is located in a magnetic field. A flow of current in the conductor creates mechanical force in the coil sections perpendicular to the direction of the magnetic field; these sections are perpendicular to the image plane in the diagram.

These forces act on the rotational circumference of the coil. The torque for the resulting rotation is represented as follows:

$M = 2 * F * r * \sin(\alpha)$

Starting from this position, the system would come to rest after a certain amount of time:



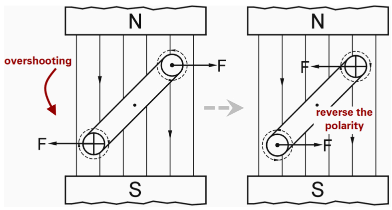
Rotatable coil at rest

There are two ways to sustain rotational motion:

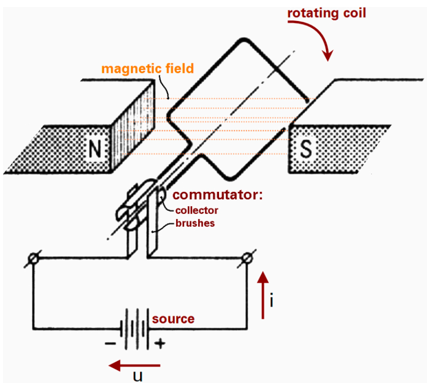
- Reversing the direction of the current flow
- Reversing the magnetic field polarity

Reversing the direction of the current flow

The coil rotates past the rest position as a result of its mechanical inertia. At this point, the flow of current is reversed, thereby inverting the coil forces' direction of action. The rotational movement thus continues.



Reversing the direction of the current flow



Rotation caused by reversing the direction of current

Reversing the magnetic field polarity

Electric motors are made up of a moving part (the rotor) and a fixed part (the stator). In our example, the rotating coil corresponds to the rotor. The magnetic field is generated by the stator.

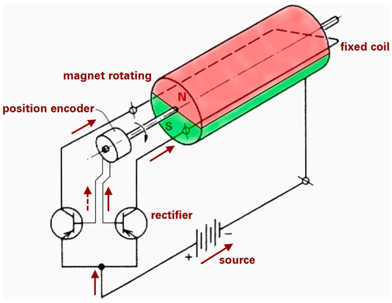
The information above will make it easier to understand how electric motors work.

"Commutation" ensures that a current-conducting winding is always in the exciter field in the correct position (0° to the field).

On a DC motor, this is achieved using a collector and brushes to establish contact, as shown in the image above. In this context, this is referred to as mechanical commutation.

Wear on the mechanical elements in the commutator (collector, carbon brushes) and the resulting required maintenance are disadvantages of the collector motor.

The exciter field (stator) can be changed electronically using power transistors. In this case, the rotor corresponds to a magnet.



Rotation caused by reversing the magnetic field

The exciter field is inverted by reversing the direction of the current flow in the exciter winding. The flow of current is controlled by electronic switching elements (power transistors), thereby eliminating mechanical parts that are subject to wear.

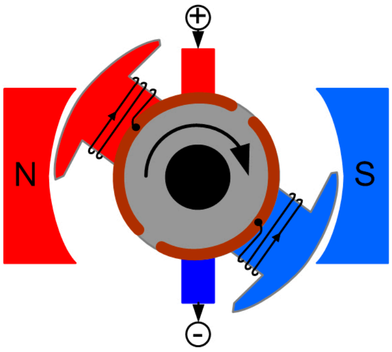
3.1.2 Direct current (DC) motors

A direct current motor is also known as a DC motor.

How a DC motor operates was touched on in the last section.

The DC motor is designed with multiple windings on the rotor that, when positioned ideally, are supplied with current via static carbon brushes on the collector.

The stator field can be divided into several poles as well for larger motors. How it works remains principally the same. Several carbon brushes ensure targeted current supply for the rotor windings.



DC motor design (*haade / de.wikipedia.org*)

Before the development of industrial power electronics, the DC motor was considered more beneficial than the three-phase motor due to its ease of use (easy speed adjustment by changing the supply voltage).

The possibilities that have emerged from modern drive technology for three-phase motors began pushing the DC motor more and more out of the picture when it came to positioning applications.

Areas of use:

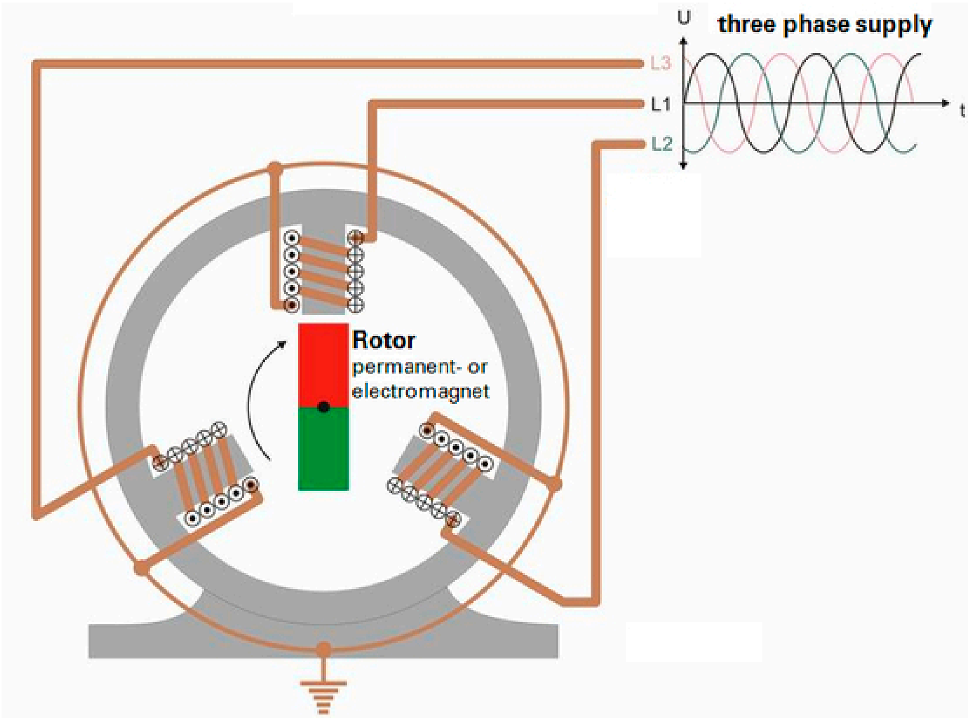
- Automotive technology (e.g. windshield wiper motors, motors in power windows, etc.)
- Consumer electronics (e.g. vibrate function on mobile phones)
- Actuators
- Household appliances (e.g. vacuum cleaners)

3.1.3 Induction motors (AC motors)

Developments in the area of electronics and materials have led to a shift from DC motors to AC motors in drive systems. Even in servo systems, which used to be nearly universally designed for DC technology, there has been a strong tendency to move towards synchronous AC motors.

AC motors operate according to variations in the stator field. The field generated by the stator coils where the rotor is located is changed over time in such a way that a rotating magnetic field results (→ rotating field).

The required voltage feed to the stator windings is best described using the voltage characteristics of the three-phase mains power supply:



How an AC motor works

The sinusoidal supply voltage of the individual phases reach their respective peak values one after the other in periodic intervals with an electrical offset of 120°. The windings are also equally distributed on the stator.

The rotor can be set up as a permanent magnet or an electromagnet (→ current-conducting coil). Therefore, we can look at the rotor as a magnet that aligns itself in accordance with the field it is in.

The maximum supply voltage - and therefore the maximum of the stator field influence - moves around the circumference of the stator. The magnetic field vector made up of the individual coil fields rotates in the stator.

The rotor is essentially "passed" between the individual stator windings.

Specially designed AC motors become more and more common. For example, direct drives are steadily becoming more popular because of their special characteristics for automated positioning.

The following two types of electric motors differ in how the magnetic field occurs:

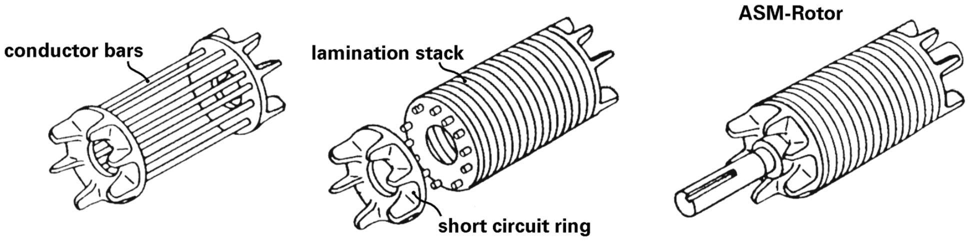
- Induction motors (IM)
- Synchronous motors (SM)

A description of how the different types of induction machines can be controlled can be found in the Inverters section.

3.1.4 Induction motors (IM)

The stator of an induction motor corresponds to a rotating field motor with a three-phase winding.

Unlike a synchronous motor, the rotor is not permanently excited. Conduction bars are connected in the rotor via a short-circuit ring (squirrel-cage motor). This results in a system of conductor loops.



IM squirrel-cage motors

Because the rotor is located in a changing magnetic field, voltage is induced in the conductor loops (Lenz's law). This voltage generates a current flow in the conductor bars.

A force (Lorentz force) caused by the stator field acts upon the active conductors, which gets the rotor moving.

After starting, the rotor turns at a speed slightly less than that of the rotating field. This speed difference, known as "slip", is necessary to induce enough current in the rotor to overcome friction, air resistance and load torque.

The rotor can never reach the speed of the rotating field; as a result, the movement is asynchronous, which is why induction motors are also referred to as asynchronous motors.

The mechanical and electrical properties of induction motors determine where they are typically used. Induction motors are usually operated at the rated speed. They are rarely at a standstill since the cooling of the motor is mostly dependent on speed. On some motors, for example, cooling is handled by a paddle wheel mounted on the rotor that directs the flow of air through cooling fins. For fans and pumps, it's often sufficient to start the motor slowly and get it up to between 30% and 100% of the rated speed. Cycle times are usually within just a few seconds.

Possible applications for induction motors:

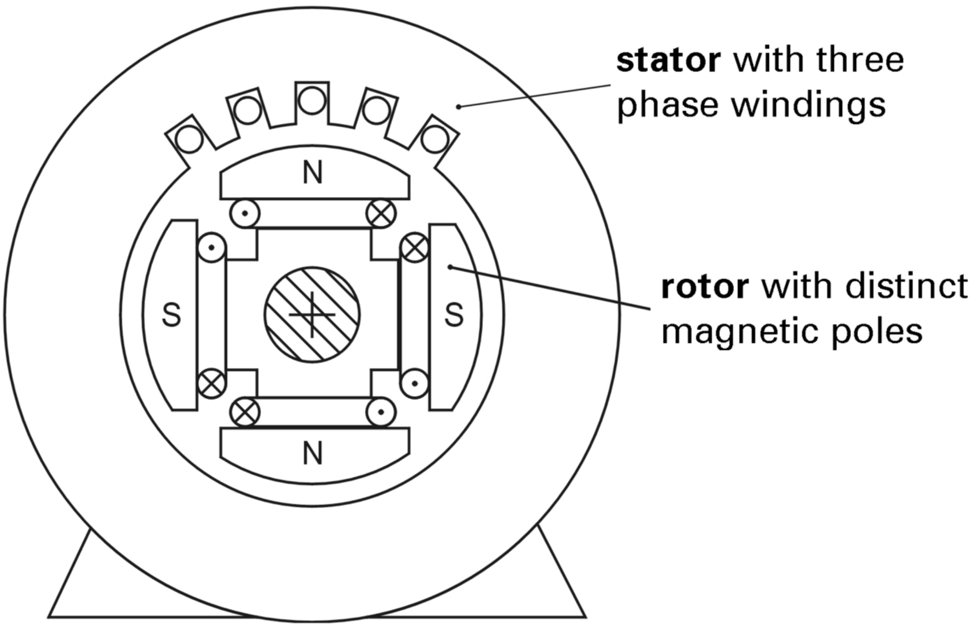
- Pumps
- Compressors
- Fans
- Conveyors
- Presses, mixers, stirrers
- Centrifuges

This motor type is well-suited for operation with a frequency inverter (rotating field specification without reference to rotor position) and is typically used in this way.

3.1.5 Synchronous motors (SM)

The laminated stator is connected to the star-formed three-phase winding (U, V and W designs). Connecting to three-phase mains causes the stator winding to generate a rotating field.

The rotor in a synchronous motor has either an electromagnet (current-conducting winding arrangement) or a permanent magnet. In this way, the rotor field is generated "actively".



Schematic diagram of a synchronous motor

The rotor is aligned with no "slip" in the rotating field, hence the term "synchronous motor". These properties make synchronous motors a good choice for positioning tasks. Speed is linked by the number of pole pairs with the frequency of the alternating current.

The high energy density of new, extremely powerful permanent magnets increases the motor's performance while simultaneously reducing its mass. This results in increased drive dynamics and smaller motor sizes. Optimized concentricity enables high-precision positioning.

The mechanical and electrical properties of synchronous motors allows them to be operated well at standstill as well as at their rated and maximum speed on the motor characteristic curve. Surface cooling enables the motor to maintain a specific torque value during standstill, then approach a new position and exert its holding torque. Movement cycles and dynamics in the ms range are common.

Possible applications:

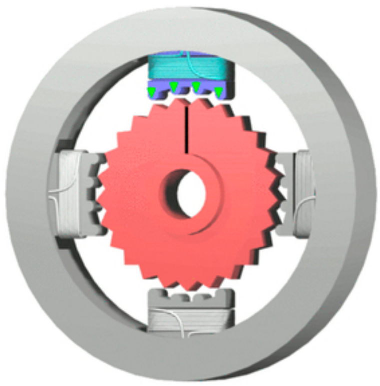
- The same as described in Induction motors (IM) but also...
- High-precision actuators and positioning drives
- Machine tools, CNC
- Robots

> The following sections contain descriptions of widely used special designs of permanent-magnet synchronous motors. These are often used as direct drives.

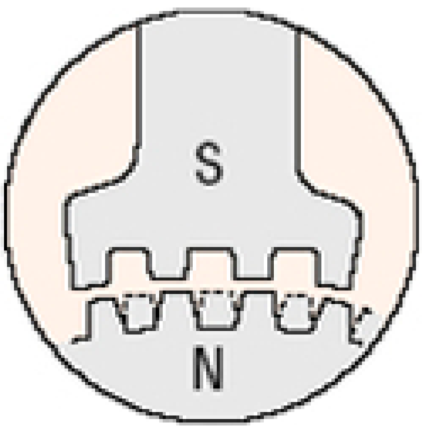
3.1.6 Stepper motors

The stepper motor belongs to the family of synchronous motors. How it works is very simple. The rotor moves by a minimal degree in a series of steps. This is done by controlling the rotating electromagnetic field in the stator coil.

A stepper motor usually has a significantly higher number of pole pairs than a synchronous motor.



Stepper motor design (*Teravolt / en.wikipedia.org*)



Teeth on the rotor, division into steps

If the motor is operated with an unsuitable load, too much torque or at a speed that is too high, then the rotor will fall out of sync.

This is referred to as "losing steps" and can be prevented by properly dimensioning the drive.

Intelligent stepper motor controllers are able to detect when steps are lost. It is also possible to combine them with a position encoder.

In addition, the rotor can be positioned in smaller steps within a full step (microstep mode). Extremely precise positioning is possible if the drive is dimensioned properly.

Stepper motors are characterized by their long service life, high torque and low cost. Speeds up to 1000 rpm are common. Stepper motors are typically controlled and positioned without encoder feedback.

Possible applications:

- Infeed axes
- Positioning units
- Peristaltic pumps
- Slew drives
- Weaving machines
- CNC units
- Dot matrix and ink jet printers

3.1.7 Direct drive motors

A direct drive motor is unique in that the motor is connected directly to the machine. This type of system places high demands on proper dimensioning since the speed of the motor is the same as that of the machine. This configuration totally eliminates the need for a gearbox. Additional information about drive mechanics can be found here: Drive mechanics and power transmission

In this context, special emphasis is placed on the physical size in relation to high speeds. The reason for this is not just the omission of a gearbox, but also the reduced mass of the motor itself.

This can be attributed to the specified power output since this increases when speed is increased at the same torque.

Speed = Torque x Power

Due to their varying speeds, direct drive motors are often divided into the following classes:

- Low-speed motors
- High-speed motors

Low-speed motors

With low-speed motors, speed is reduced due to the high number of poles. For example, a 30-pole motor may have a rated speed of 200 rpm. One typical application involves generators at hydroelectric power plants that may have a speed of 65.2 rpm and 92 poles.

Motors that have a large number pole pairs are called "high-pole motors". These types of motors have a lower speed and deliver higher torque.

The motor can even deliver additional torque at the same power output.

$$Torque = \frac{Speed}{Power}$$

High-speed motors

High-speed motors are significantly faster than conventional motors. They can reach speeds well over 100,000 rpm. This is possible through the use of frequency inverters and a supply frequency from several hundred Hz to over 1000 Hz. Physically, these motors are smaller than conventional engines but have the same power output. High demands are placed on the rotating parts as they must sometimes counteract considerable radial acceleration (centrifugal force). Typical applications for high-speed motors include turbo-molecular pumps (vacuum pumps) and electric turbochargers that run at approximately 130,000 rpm.

The achievable output power of a motor is determined by its mass and size.

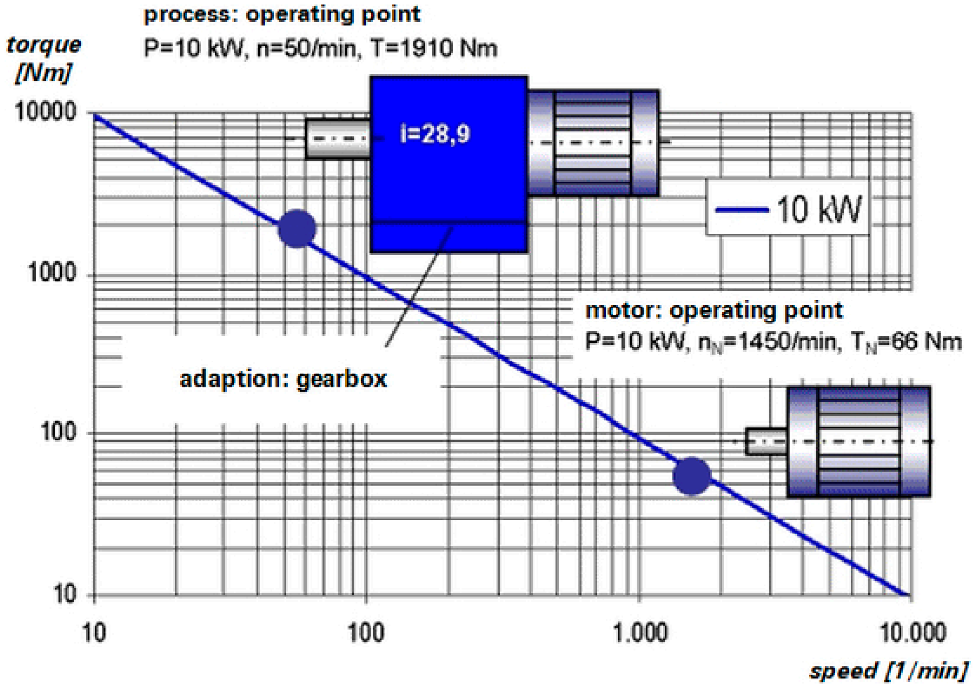
Specific types of direct drive motors include:

- Torque / Sector motors – high torque
- Linear motors – high thrust

Advantages of direct drive motors in detail

The primary task is to use suitable drives to provide the force, torque and movements required for carrying out processes such as conveying, mixing or separating.

Drive dimensioning therefore requires that the machine's operating point be adjusted to the load process's operating point (torque, speed). Generally, this adjustment to the process is made using a gearbox that adapts the torque and speed accordingly:



Adaptation using mechanical gearboxes

A gearbox is not necessary when the operating point of the process coincides with that of the machine. The motor – in this case the electric motor – becomes a direct drive motor.

A direct drive motor has no reductions because gearbox or ball screw mechanisms are not used.

System values such as current, force/torque and speed/rotations can be determined directly and integrated into a control concept. In addition to improving positioning accuracy, this also makes it easier to control the drive.

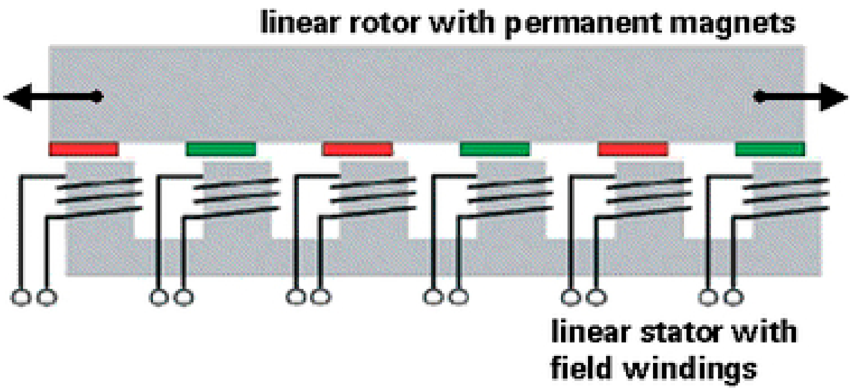
General characteristics of direct drive motors:

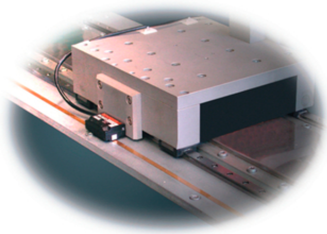
- Low inertia
- Precision (no backlash) coupled with dynamics
- No use of mechanical parts that are subject to wear
- Small installation dimensions
- Large hollow shaft diameters possible

The high power density of direct drive motors means that they can become considerably warm. Because of this, they are often equipped with water or air cooling systems, which is not always necessary in comparable drives that use mechanical power conversion.

3.1.8 Linear motors

Translational direct drive motors use the functional principles of rotating motors ("translation" = straight movement). The principle of the permanently excited synchronous motor is the most common:





Linear motor

Linear motor design

Linear motors have the same components as AC motors (stator and rotor), but they are arranged linearly. The rotor slide is positioned linearly due to the three-phase current feed for the stator windings.

Areas of use:

- Machine tools
- Positioning systems
- Handling systems
- Shearing equipment
- Household electrical appliances

3.1.9 Torque motors

Torque motors are generally designed and manufactured as high-pole, permanently excited synchronous motors.

Torque motors are often built with a rotor molded into a hollow shaft. This makes possible the mechanical connection necessary for transferring high torque forces. Torque motors can be adapted optimally to the machine.

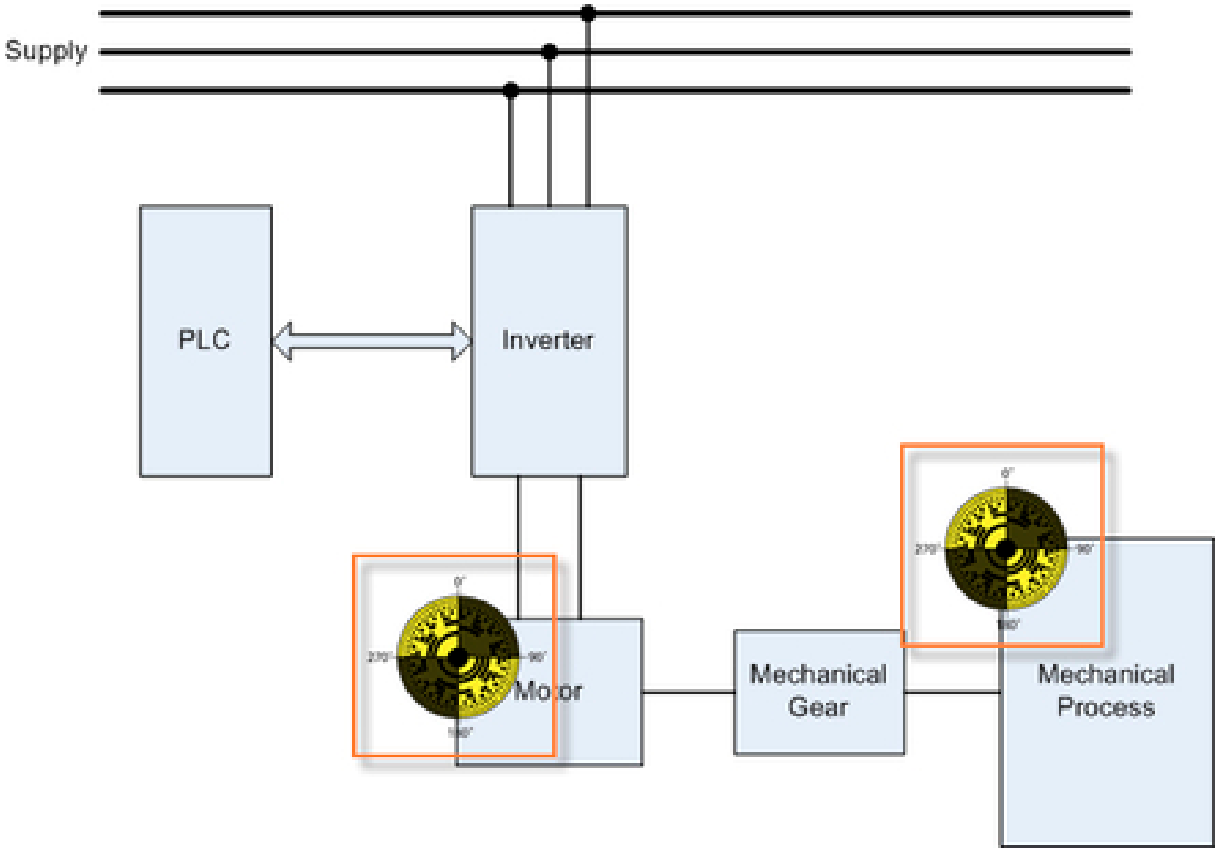

Torque motor

Possible applications:

- Gearless direct drive motors
- Pressure cylinder axes (precision, zero backlash, stiffness)
- Eccentric presses
- Image setters
- Film stretching machines
- Paper machines

3.2 Position encoder

A position encoder is an important part of many drive systems. It makes it possible to accurately determine the position and orientation of a mechanical element. The movement speed is then derived from this information. The measured positioning value frequently has a direct influence on the drive solution to be used.



Position measurement in a drive system

Encoder systems with varying resolution and modes of operation can be used. Often, the position encoder is part of the motor, but it's also possible to measure position at the load.

> Position feedback to the positioning controller may be necessary depending on the task at hand. Position feedback is often not required, however, if frequency inverters or stepper motors are being used. For one, this is often a cheaper solution; at the same time, precise positioning and speed can often be sufficiently achieved without an encoder.

Physical units

The exact position of a motor is the most important bit of information when controlling a positioning process.

Using unique physical units by...

- Defining the zero-point position
- Dividing motor revolutions into a certain number of positioning units

...makes it possible to "send" the motor system, and accordingly the mechanics of the machine, to a defined position:

"...Move to absolute position 3000"

"...Move 290 units to the right of the current position"

> Doing so allows the positioning application to use physical units when specifying the distance to be traveled. In this case, the path is not specified in terms of rotor rotations, but rather in tenths of a mm or degree.

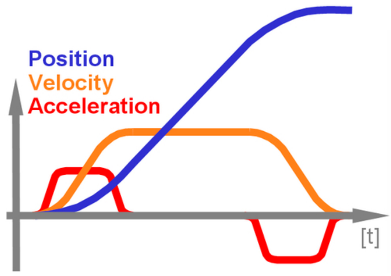
3.2.1 The position encoder as a measuring device

The position encoder is an important measuring device within a drive configuration.

In a positioning system, it is used as a measuring tool and takes on multiple roles:

- The position encoder provides the drive controller with information about the current position and speed of the motor. The stator field on the electric motor is systematically controlled by the servo drive (electronic commutation). This control makes it possible to put the motor's rotor in a defined position or to dynamically put it in motion.

- This allows the the drive controller to use internal control to react to deviations in the drive from the predefined positioning sequence (set position, set speed).
- A drive controller must also be able to accurately determine the current position of the motor's rotor within a rotation so that it can be activated at the correct position.



Positioning profile

That's why with servo motors (→ motors controlled by servo drives) the position encoder is usually connected directly to the drive shaft in the motor's housing.

Resolution is an important criteria when selecting an encoder type. It determines how accurately the position can be measured by the encoder within a single rotation.

Integrated position encoder

This resolution affects the measurability of very small distances and position fluctuations, i.e. the accuracy of the encoder, which is determined by the electronics used for evaluation. Both factors influence the overall quality of the controlled procedure.

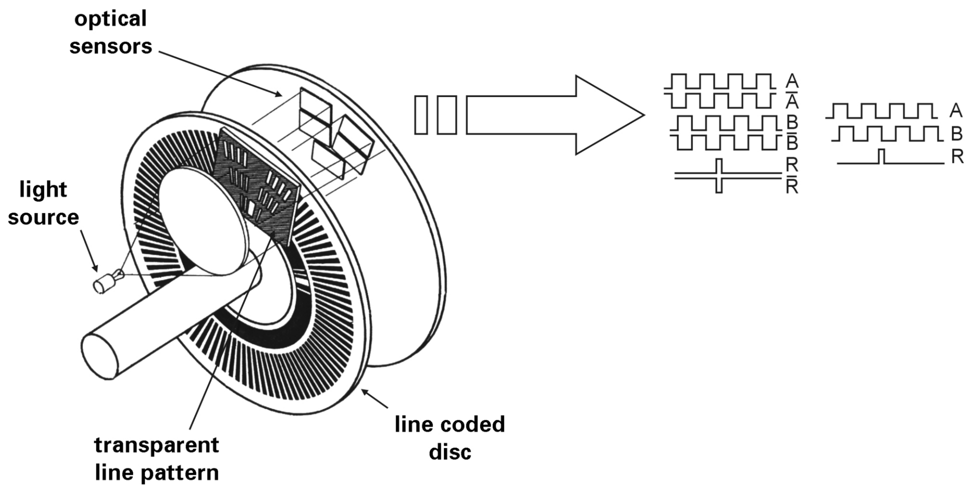
In the next few sections, we will take a closer look at the following encoder systems:

- Optical incremental encoder
- Inductive absolute encoder - Resolver
- Optical absolute encoder
- Optical absolute encoder - EnDat
- Optical absolute encoder - Functional safety
- Synchronous serial interface - SSI
- BISS interface (bidirectional / serial / synchronous)
- Motor feedback system - Hiperface

3.2.2 Optical incremental encoder

An optical incremental encoder has a transparent glass or plastic disc; when light passes through the disc, a light source and photo detector read the optical pattern that results.

The optical incremental encoder has lines on the glass that determine the code. This makes it possible for optical encoders to detect the direction of rotation, measure speed and determine the position at a high resolution. In order to determine the position, a homing procedure must always be carried out.

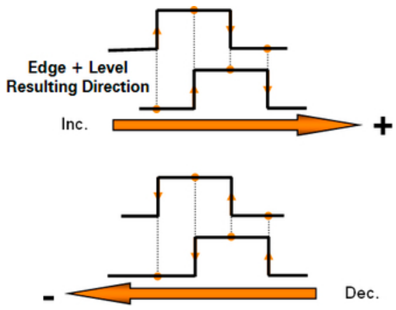


Optical incremental encoder

This superimposition results in the processing of a sine signal or a cosine signal shifted 90° to the rectangular encoder signals.

They are used by the processing logic in the subsequent system (electronics) to increment/decrement a position counter.

The direction of rotation can be detected by analyzing the sequence of falling and rising edges of the encoder tracks.



Signal analysis

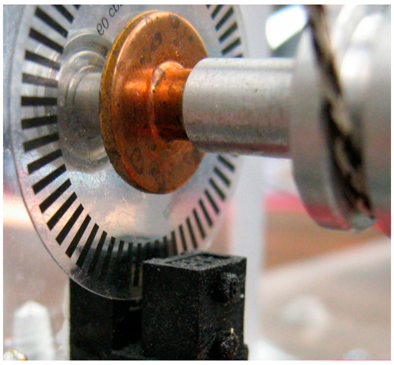
When using an incremental encoder, the position of the mechanics (→ encoder position) cannot be concluded right away as this is not covered by the encoder information. The only position information that is detected is whether an "increment" is taking place in the positive or negative direction. Because of this, the position of the encoder within a rotation cannot be determined.

An additional reference track that is executed provides an "improvised clue" to help determine the position within a rotation. A homing procedure also has to be carried out in order to create a relationship between the counter and the current position.

The resolution of the incremental encoder depends on the number of lines, the type of evaluation and the maximum input frequency of the processing logic.

The optical incremental encoder has a very high resolution (several million increments possible per rotation) and is distinguished by its ability to carry out high-speed evaluation.

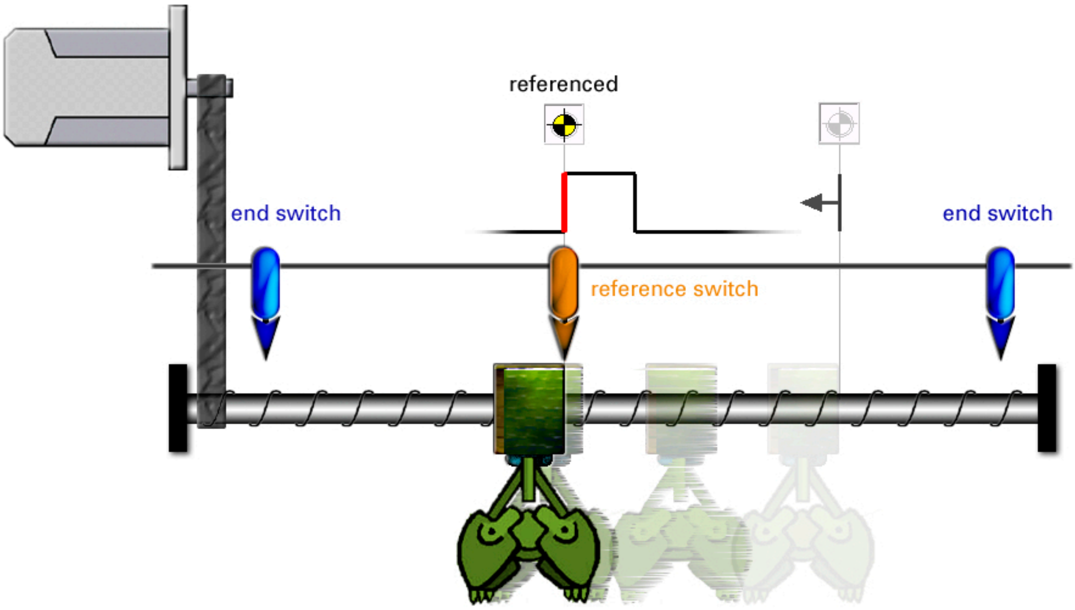
This is certainly an advantage for controlling the servo drive (speed, position, etc.). Deviations between current values and set values are quickly detected on the drive controller. This allows "responses" with a minimum of dead time.



An incremental encoder in the lab
(*Tycho / de.wikipedia.org*)

Before a positioning procedure can begin, a homing procedure must be performed to initialize the positioning system.

In most cases, the mechanical system is brought to a defined position, e.g. it approaches a fixed reference or end switch.



Homing procedure

The current position is then assigned a defined value (for software-based positioning). From this point on, the drive system effectively "knows" where the mechanics are located. Positioning can now be started.

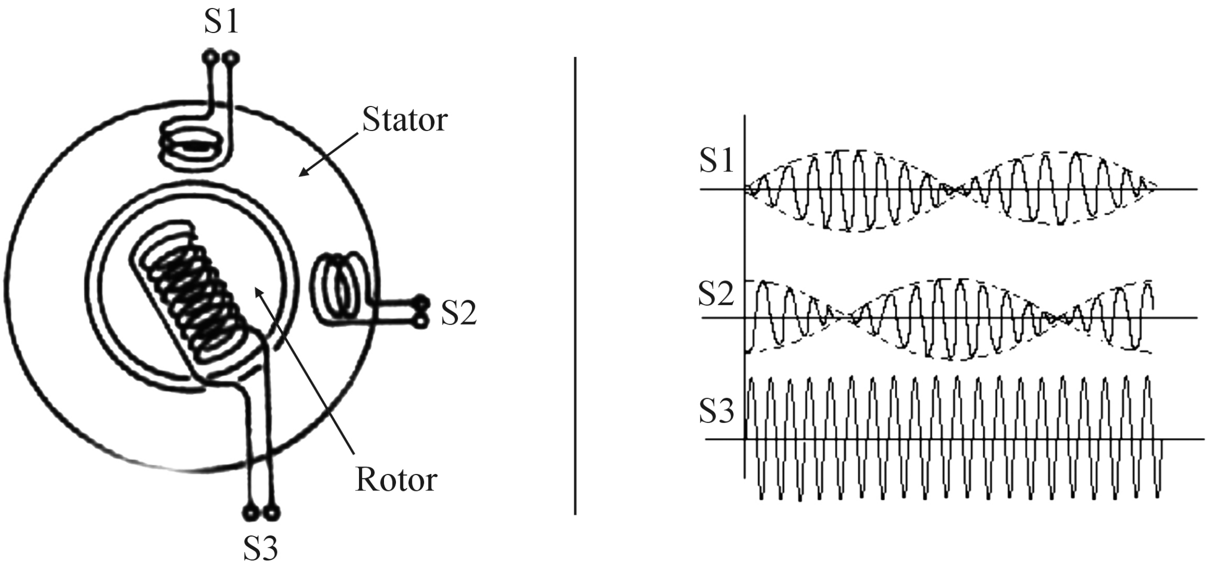
The homing procedure can be omitted if only the speed needs to be determined. This is because only the counted lines per unit of time are relevant.

3.2.3 Inductive absolute encoder - Resolver

Military technology paved the way for a very robust encoder with a simple construction. These characteristics correspond to those of the resolver.

The resolver works according to the principles of a rotary transformer. In a rotary transformer, the rotor consists of a coil (winding), which together with the stator winding makes up a transformer.

The resolver is essentially built the same way, with the difference that the stator is made up of two windings offset from each other by 90° instead of just one:



Resolver design and measurement signal

The signal is generated by feeding a sine signal with a constant frequency to the rotor coil (S3). This uses the basic principles of transformers to transfer the voltage signals S1 and S2 to the 90° offset stator coils.

The signal curve for S1 and S2 (shown above) results when the rotor is moving. The envelope curves for these signals depict two sine curves offset by 90°. The processing logic uses this information to determine the position.

If the movement range for the axis is within one encoder rotation, then a unique position can be related to each encoder value and homing is not necessary. This is what defines an absolute encoder.

Dismantled resolver

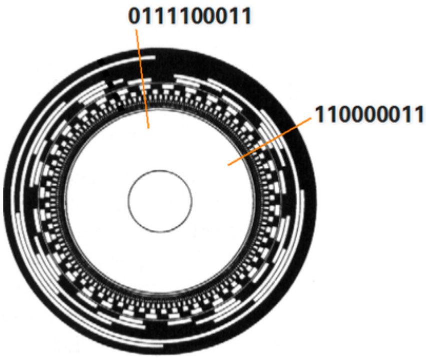
On a resolver, the position information is repeated with each new rotation. For example, if you were to disable the drive system and manually turn the motor shaft 360°, the analyzing system would not be able to detect this manipulation.

If the motor's movement range goes beyond this one particular rotation, then a homing procedure must be performed.

The resolution of the resolver depends on the processing logic and the frequency of the supply to the rotor coil (4,096/16,384 increments).

A certain amount of time passes before the processing logic sends the value corresponding to the current position. This means additional dead time for the control loop.

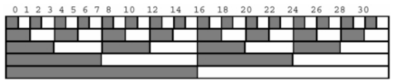
3.2.4 Optical absolute encoder



Binary-coded encoder disc

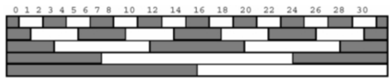
With absolute encoders, a unique value is assigned to each encoder position. The resolution of an encoder revolution is dictated by a bit-coded optical encoder disc:

Encoder discs are designed to work with either binary or Gray code.



Binary code

The position is specified as a bit combination, with each bit corresponding to a track on the disc. The signal is transferred to the processing logic via the SSI protocol (Synchronous Serial Interface - SSI).



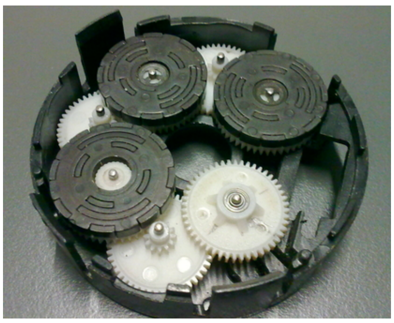
Gray code

An optical absolute encoder is similar to a resolver in that a full encoder rotation can be clearly resolved. In this case, we are speaking of a **"single-turn"** encoder.

A homing procedure is not necessary for this type of encoder as long as one motor rotation is not exceeded during positioning. After the system is started, the encoder displays an explicit value. This value can then be used to determine the position of the mechanical gear.

A **multi-turn encoder** is the expanded version of the single-turn encoder. This type of encoder includes a counter that records the number of rotations completed. This information is used to extend the explicitly defined position measurement range to a specific number of rotations (typically 4096).

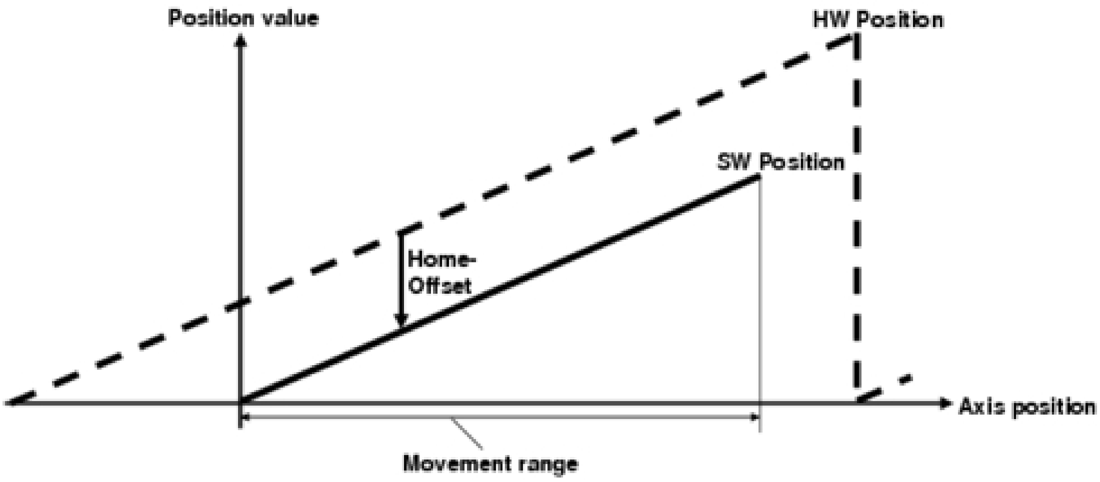
A homing procedure is not necessary when using a multi-turn encoder. As soon as the position offset has been determined once, it is possible to ascertain the current machine position.



Counter mechanism in a "multi-turn" encoder

The position offset is the difference between the actual internal encoder position and the machine position.

If the machine is in the zero position, for example, and the software position value is 56343, then the position should be referenced to the value zero. In this case, the position offset is 56343.



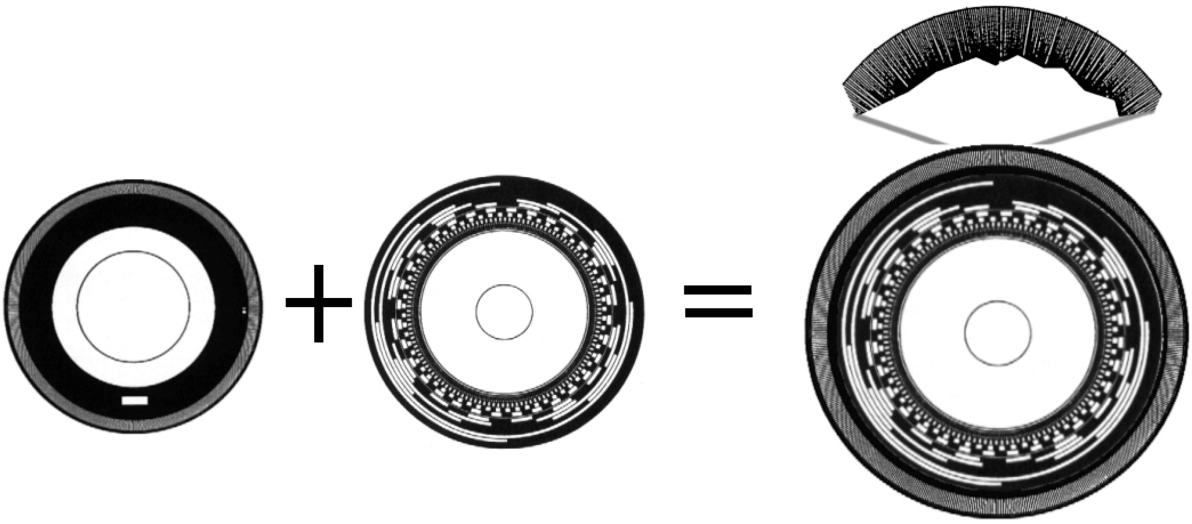
Encoder offset

This offset can be used from any position to determine the position of the machine.

The counting mechanism is implemented either with an additional mechanical transfer gearbox or electronic logic.

3.2.5 Absolute encoder - EnDat

The EnDat[1] position encoder **("En**coder **Dat**a") combines the two optical encoder types – incremental and absolute. This makes it possible to take advantage of both technologies.



EnDat design

[1] The EnDat interface from HEIDENHAIN is a digital, bidirectional interface for position encoders.

Advantages:

- **Incremental encoder:** The advantages of this type of encoder are high-speed signal transfers and extremely high resolution ("sine evaluation"). These characteristics represent the ideal conditions for drive control.
- **Absolute encoder:** There is a constant relationship (offset) between the encoder position and the machine position. The encoder position can be used to figure out the current position of the mechanics (→ "software position" for the control program). A homing procedure is not necessary. Of course, the valid movement range for the encoder must be taken into consideration ("single-turn" / "multi-turn").

Embedded parameter chip

The EnDat encoder system has nonvolatile, maintenance-free EEPROM data memory onboard. All data required to operate the drive is stored here. Values such as motor parameters and the characteristics of the encoder are pre-programmed in this memory. This data is automatically transferred to the servo drive via the SSI connection when the system is started.

3.2.6 Absolute encoder for functional safety

In today's motion applications, it is common to put the drive into a mode where speed is limited or safe torque is applied whenever the safety chain is breached, e.g. when a protective door is opened. These types of applications rely on a safe position encoder. For example, the EnDat 2.2 - FS (the FS stands for "functional safety") can be used to monitor safe positioning.

3.2.7 Synchronous Serial Interface - SSI

The Synchronous Serial Interface (SSI) is a way for absolute encoders to transmit data. Because transmission takes place serially, it is possible to receive absolute information concerning a position. Many different manufacturers use this interface.

Features:

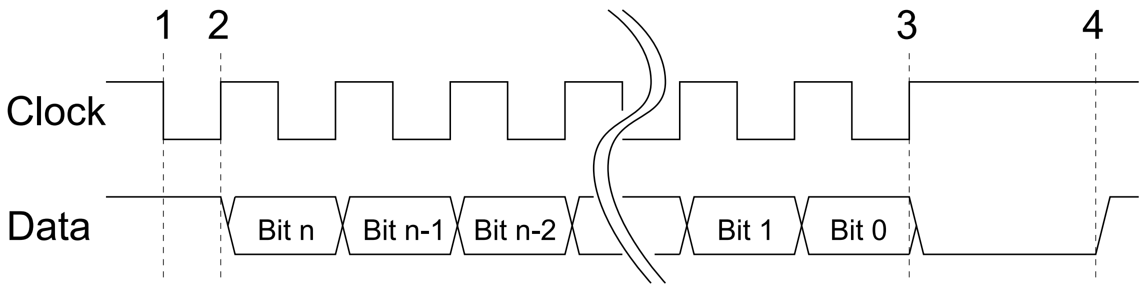
- **Synchronous:** Position data is sent based on a clock signal.
- **Serial:** Position data is sent consecutively using a certain baud rate.

This type of data transmission is very robust and easy to establish. The data itself is transferred over two wire pairs. Other advantages include reduced cabling complexity and expense as well as additional shielding against interference thanks to the twisted pair wiring.

The number of data bits can be configured, with data values being transferred as either binary or Gray code.

Data transfer

The measurement value is permanently read in the sensor. When a data value is read, a cycle sequence on the clock line is output. Each time the clock edge rises, a data bit is set on the data line. If the last bit has been sent, the sequence is stopped. Transmission takes place in connection with a defined delay time.



Transmission via SSI

3.2.8 BiSS interface

The BiSS interface (bidirectional / serial / synchronous) is an open source solution. It is based on a protocol for implementing real-time interfaces that can be used to exchange digital data between controllers, sensors and actuators.

The BiSS protocol can be used in industrial applications that require higher transfer speeds and safety.

3.2.9 Motor feedback system - Hiperface

Hiperface stands for "HIgh PERformance InterFACE" and is a standard interface for motor feedback systems from SICK STEGMANN. This interface was developed specifically to meet the needs of digital drive control and provides user with unified and simplified mechanical and electrical interfaces.

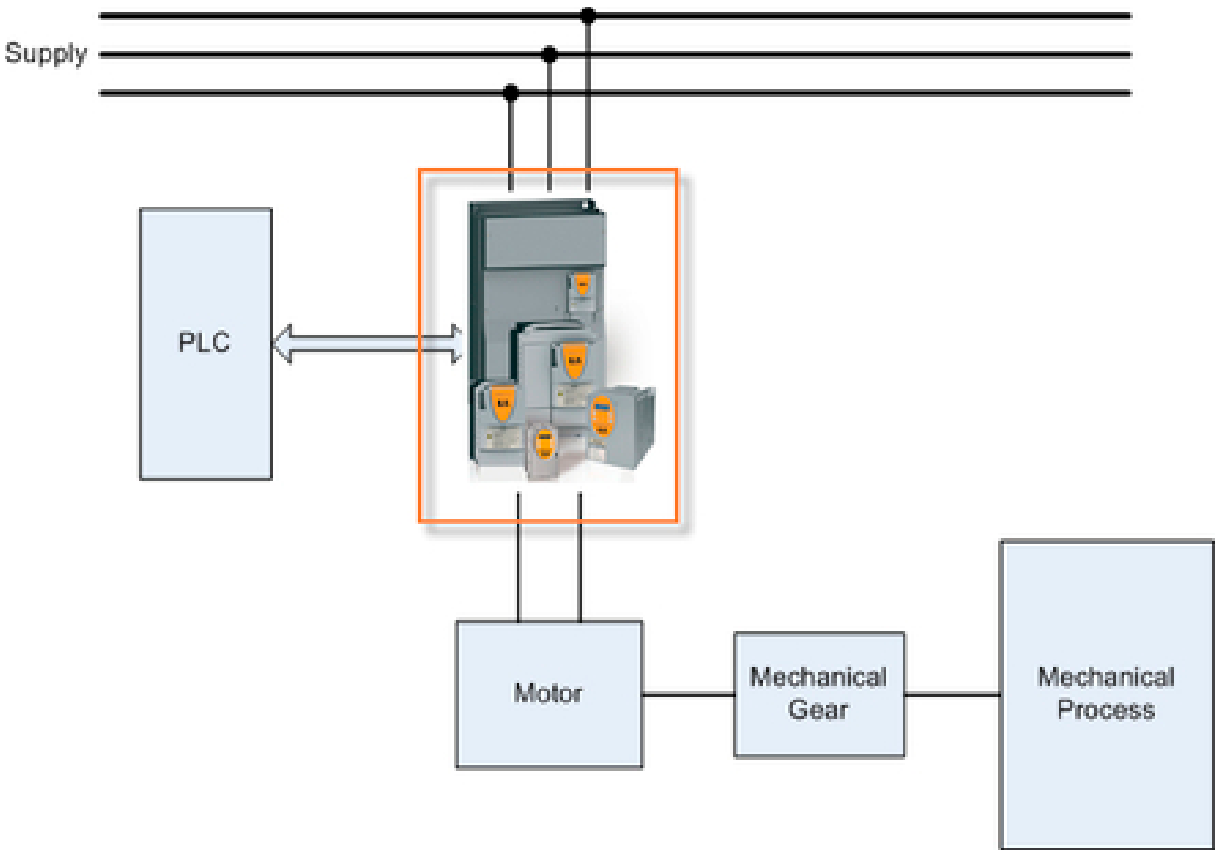
Basic features include the combination of incremental and absolute encoder, an embedded parameter chip and the option of mechanically-assisted multi-turn position determination.

3.3 Inverters

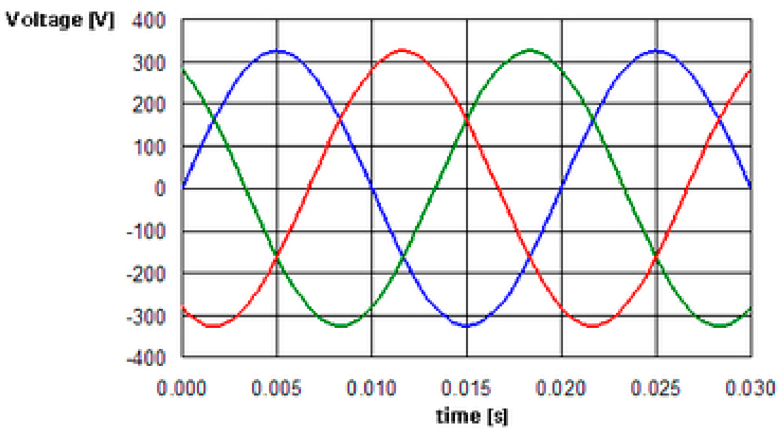
A power converter's job is to convert electrical energy from a mains power supply so that it can be used to operate electric motors.

Why is this conversion necessary?

For AC motors, the stator can be adjusted by changing the amount of power supplied to the stator windings. The alignment and intensity of the magnetic field in the stator result from the respective winding voltages. The speed and power of the motor can thus be influenced as needed.



The inverter in an electrical drive system



Phase shifts in a three-phase power system

The power mains provide single or multi-phase AC voltage, e.g. a 3-phase supply running at 50 Hz.

As you can see in the following image, sinusoidal voltages with a constant frequency and amplitude are supplied; this is referred to as three-phase alternating current.

An AC motor, and in some cases a synchronous motor, can be operated directly on this power grid. Here, the stator field of the motor rotates according to the frequency of the supply voltage.

> The actual speed of the rotor on an AC motor is set slightly below the synchronous frequency (slip speed of the motor). The synchronous motor would move exactly with the rotating field (at zero load).

An inverter is now needed to selectively control the characteristics of the stator voltages for positioning. The inverter can take electrical energy from the mains supply and pass on to the motor the voltage characteristics required for positioning.

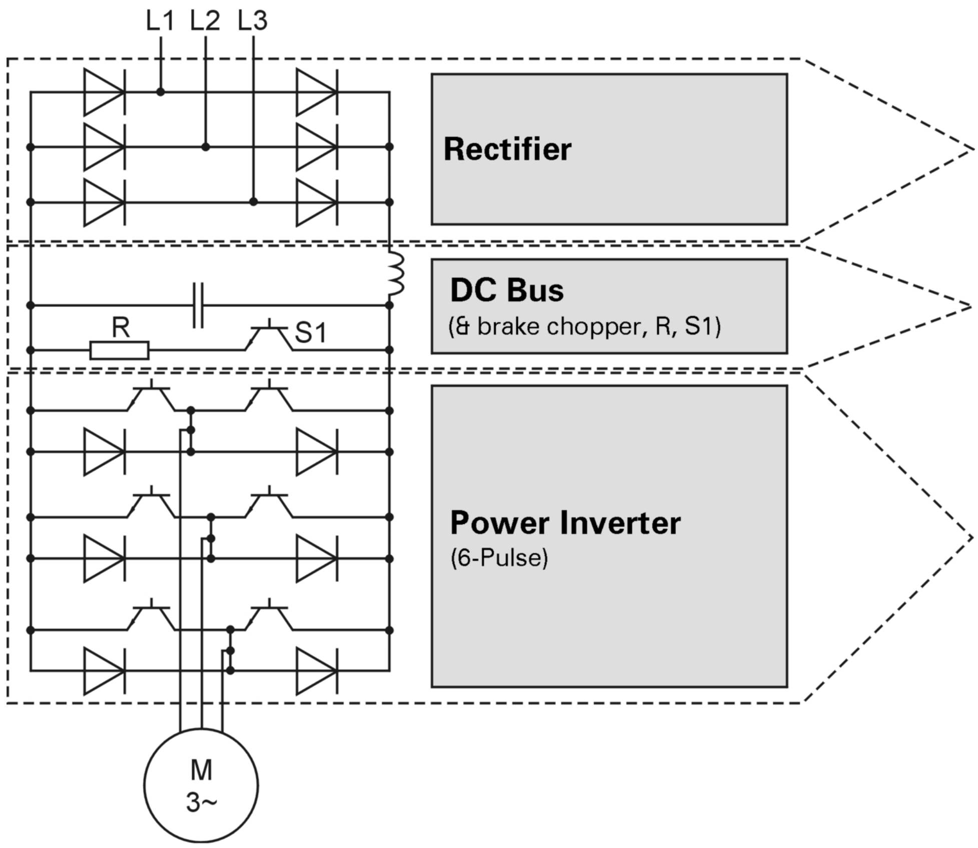
There are two main types:

- Variable frequency drives
- Servo drives

The following section will break down these inverters into their subparts and examine them more closely.

3.3.1 How they work

The power electronics are generally the same for variable frequency drives and servo drives.



Inverter principle, power electronics

The following components are shown in the diagram above:

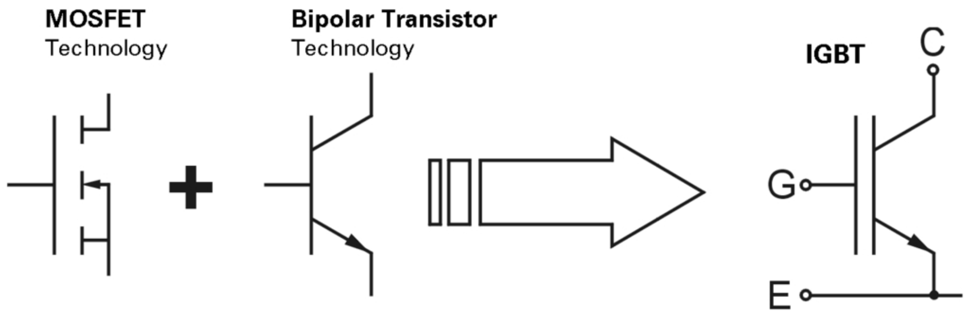
- Rectifier
- DC bus
- Power inverter

The bridge rectifier takes the sinusoidal AC voltage it receives from the power mains and turns it into DC voltage.

This DC voltage is stored in the DC bus. Here, the DC bus capacitor handles both the storage and the stabilization of the electrical energy. This turns the DC bus into a sort of "energy pool" from which the downstream power inverter can draw energy.

The voltage required to control the motor is clocked from the DC bus voltage. An important component of the inverter is the IGBT (insulated gate bipolar transistor).

As an electronic switching element, the IGBT combines the advantages of MOSFET and bipolar transistor technology:

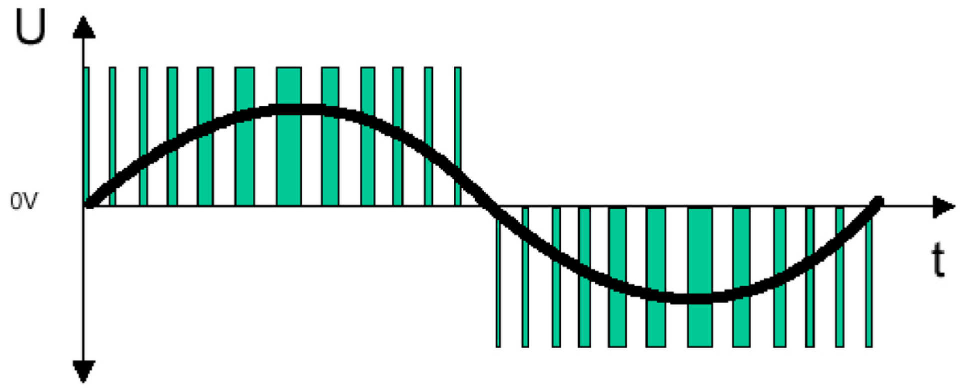


IGBT design

It features ease of control, good passband response and high dielectric strength. The IGBTs in a power inverter are controlled by the signal electronics of the inverter.

Pulse width modulation (PWM) can be used to generate a highly flexible and dynamic voltage characteristic.

With pulse width modulation, closing or opening the voltage valve within a constant period generates a specific effective value on the output. The longer the valve is open within a cycle, the larger the effective output value of this period.

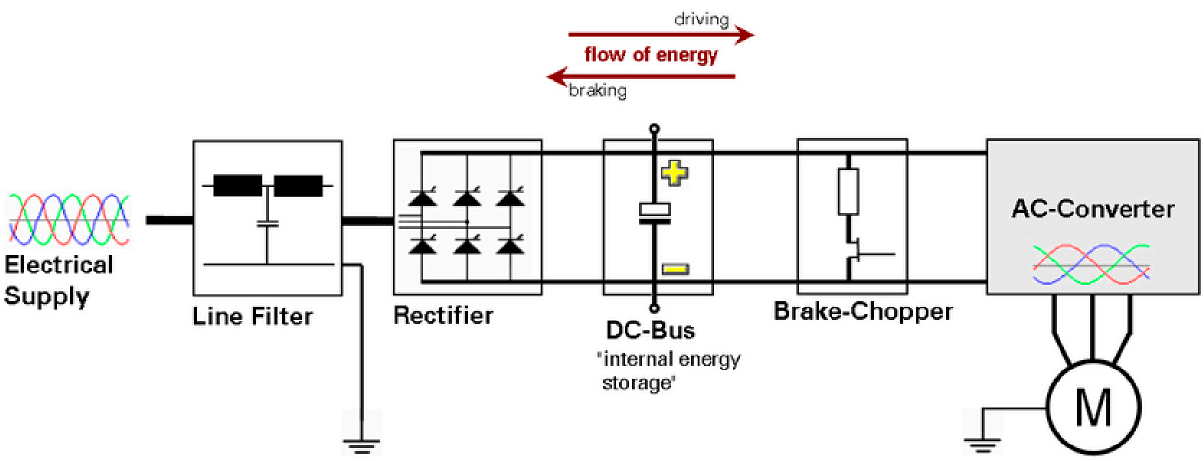


Pulse width modulation principle

The clock frequency is a decisive factor for the quality of the effective value generation.

Other components at a glance

On closer examination, there are additional functional units:



Inverter design

Line filter

In some operating conditions, the inverter can cause disturbance signals in the mains power supply (e.g. through the rectifier and power inverter). To prevent these disturbances on the mains supply while not influencing other equipment that is using it, it is a recommended to use a line filter.

Feeding energy back to the DC bus

When a motor is being braked, the inverter treats it as a generator. It is able to reconvert the kinetic energy from the mechanical system to electrical energy. This is then absorbed by the DC bus.

From there, this "energy surplus" can be used in the following ways:

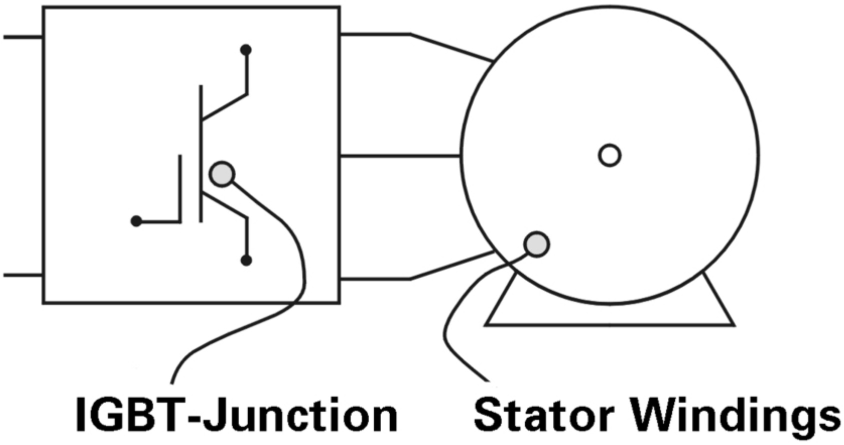
- **Linked to the DC bus**
  The DC bus voltage can be applied on the inverter module via a connector. This makes it pos-

sible for modules to be linked together electrically in parallel – essentially resulting in a common energy pool for connected drive modules.
A drive that has "leftover" energy from a braking procedure makes this energy available to the other components in the DC bus network. In this case, the energy in the system is used optimally as well.

- **Braking resistor / braking chopper**
  Here, excess energy that cannot be absorbed by the DC bus is converted to heat via a braking resistor.
  The braking chopper connects the DC bus voltage to the resistor. When the maximum braking energy is reached, it switches the power through completely.
- **Power regeneration**
  Excess energy in the DC bus can be fed back into the mains power supply. A power inverter operating in the opposite direction handles the corresponding regeneration of voltage to the mains power supply. This results in optimized energy consumption.

Temperature monitoring

Current thermal relationships within a system are important when operating an inverter. Certain elements become warm during operation but are not allowed to exceed critical temperatures.



Inverter, temperature monitoring

The **IGBT junction temperature** of these power transistors must be monitored. Since it is not possible to carry out measurements directly in the component, a sensor is used to gauge the temperature on the IGBT heat sink. The exact construction of the IGBTs is known (thermal transitions). With measurement value polled here, temperature modeling can be used to determine the actual junction temperature.

When a load is placed on the motor, **the stator windings are heated up**. It is possible to get this current value using sensors. In addition, temperature modeling is also used to calculate the winding temperature from the stator currents. This is a way the system can compensate for the delayed heating of the sensor ("thermal inertia"). Optimal protection for the motor is the result.

3.3.2 Frequency converter (FC)

Also called a frequency changer, this is the simplest of today's frequency converters. The converter regulates the motor voltage and frequency in a linear relationship. This results in very weak torque at low speeds.

The speed of the connected motor varies depending on its present load. Compensation can also be carried out without positioning feedback by using current measurement to determine the actual load (slip compensation). This method is sufficient for simple applications with little speed variation and without heavy starting. It is used almost exclusively by AC motors.

Frequency converter from B&R

In the classic sense, a frequency inverter is basically a rotation speed setting device:

- Rotating field specification without reference to the rotor position (no position encoder)
- Slow control response, not suited for dynamic processes
- Dimensioned to rated power without overload properties

The properties described are valid for this device group in the classic sense. There are plenty of frequency converters on the market that support advanced options such as vector control and encoder feedback. The use of synchronous motors is also supported depending on the device.

Possible areas of application include:

- See "Areas of application" in Induction motors (IM)
- Winders
- Cranes
- Isolated operation without control
- Pumps, fans
- Packaging machines
- Centrifuges
- Mixers / Stirrers
- Washing machines
- Conveyors / Palletizers

3.3.3 Digital servo drives (servos)

Digital servo drives can be used to control synchronous motors in various designs with integrated positioning measurement. Here, the motor is not controlled via a specified speed value; instead it is given a set position directly that the servo system tries to reach.

Because the encoder system is directly integrated in the control loop, it is possible to maintain an achieved position and check hanging loads, for example.

ACOPOSmulti system from B&R

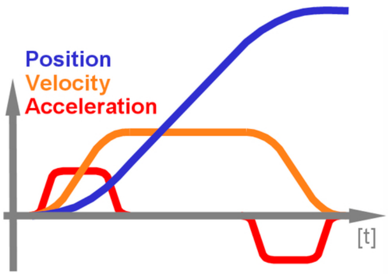
This is the basis used by compact, powerful algorithms to solve control-related tasks. The monitoring equipment and services for operating the drive (application interface) are also managed by this system:

The basic control concept consists of three cascading control loops:

- Position controller
- Speed controller
- Current controller

A corresponding manipulated variable results from the comparative values of the control loop. This is converted into the control signal for pulse width modulation. Another important element integrated here is the position encoder. It provides the value defining the current position (used to derive the speed) of the drive.

This information serves as a comparative value for the respective control loop. This also illustrates the importance of a high degree of accuracy and high-speed transfer of this information. The current is also measured at a high resolution. Intelligent algorithms ensure that the measurements are evaluated properly.



Position, velocity, acceleration, time

A servo drive is a positioning device:

- Cascading control loops
- Integrated high-resolution encoder systems
- Dynamic positioning with a high degree of target positioning and speed accuracy
- Holding torque at standstill after reaching the target position

Possible areas of application include:

- See "Areas of application" in Synchronous motors (SM)
- Packaging machines
- Handling technology
- Plastic machines

- Paper and printing
- Textile industry
- Wood industry
- Machining centers
- Variable hydraulic pump control
- Semiconductor industry
- CNC applications
- Robots

3.3.4 Comparison

The following comparison gives an overview of the specific characteristics of frequency converters and servo drives. Each system is designed for different purposes and ideally suited for driving the corresponding process, depending on what it is.

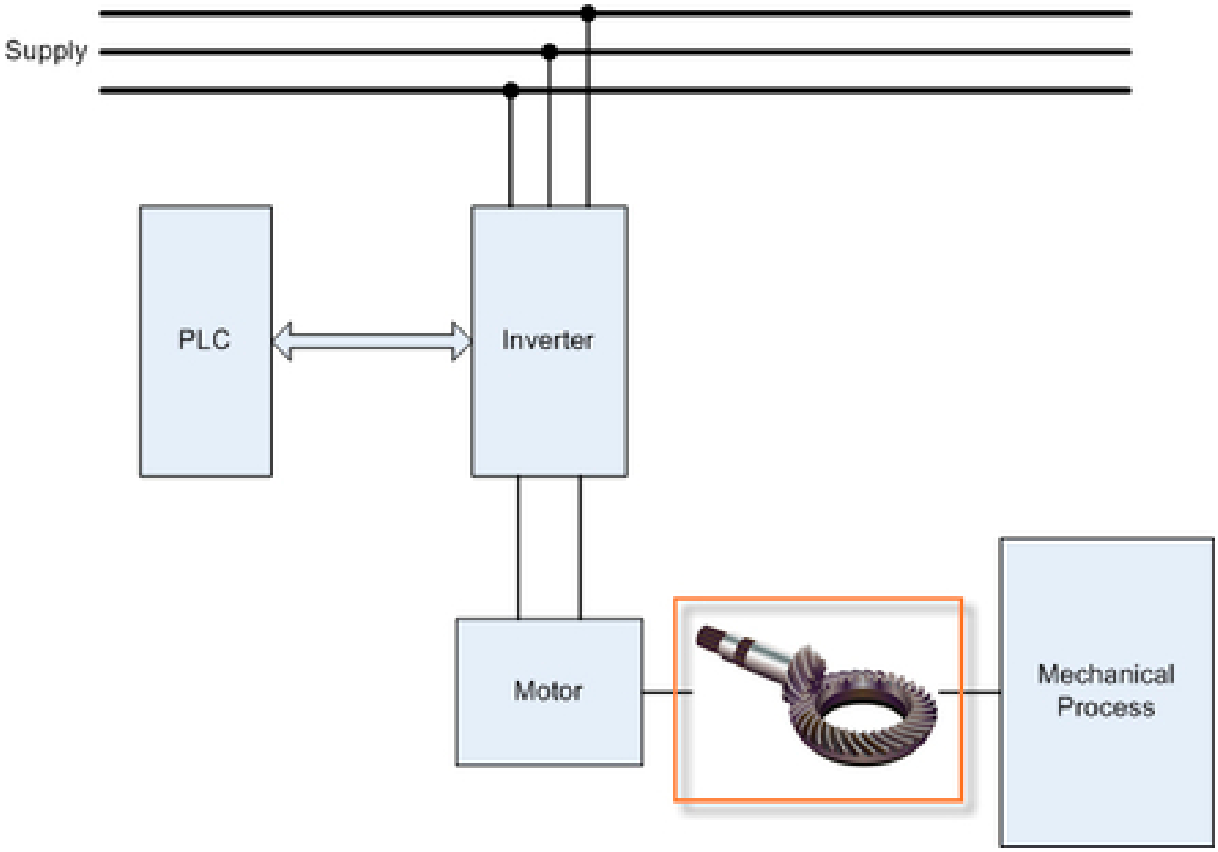
	Frequency inverters	**Servo drives**
PWM ground frequency	1 .. 16 kHz	5 .. 20 kHz
Current controller	0.5 .. 2 kHz	16 .. 20 kHz
Speed controller	4 .. 20 ms	0.2 ms
Position controller	Not present	Standard
Brake chopper	Option, usually short-circuit braking	Standard
AC motors	Yes	Yes
Synchronous motors	No / limited	Yes
Overload capacity	Low	High
Highly-dynamic movements	No	Yes
Temperature model	No	Yes
Power regeneration	Unusual	Possible
Torque at speed 0	No	Yes
Auto-tuning function	Yes	Yes
Standalone operation	Yes	No

Table: Comparison of typical characteristics

The boundaries between the main types of devices are fluid. There are also frequency inverters with integrated position controllers and elements that are typical for servo drives, but this is not the rule.

3.4 Drive mechanics and power transmission

An important aspect of drive technology has to do with power transmission. The forces generated by the motor can either be transferred to the mechanical process directly or through the use of a gearbox or similar mechanical component.



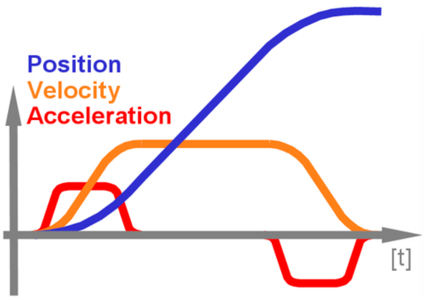
Power transmission in the drive solution

The inertia of the load, the torsion of shafts, the slip of belts or the play of gears or spindles all have to be taken into consideration when determining which gears to be used as well as when designing the drive control application itself.

The following types of power transmission will be briefly explained further below:

- Direct drives (Chapter 3.1.7)
- Rotating load
- Gearboxes
- Belt drive, belt pulley
- Spindle drive
- Toothed rack and shaft

3.4.1 General information



Motion profile with speed, position, acceleration and time

When driving machine components (also known as "load"), many forces occur that result in many different effects. For example, when acceleration is taking place or being changed dynamically or the speed or direction of rotation changes, the inertia needs to be overcome.

In power transmission, high levels of mechanical stress can occur – especially during accelerating and braking – in the form of torsion or centrifugal force. Sudden load changes ("jolt") places extreme stress on the materials and reduces the service life of mechanical components – signs of wear are the result.

The energy that is put into a mass to get it to accelerate is exerted on the one hand in overcoming static friction and the inertia of the mass, but a large majority is also stored as kinetic energy. When braking the load, the same rules apply as for its acceleration.

Complete mechanical systems also tend to vibrate at certain resonances, which can also affect drive control and overall process quality.

Before the drive components are slected, a closer look at the mechanical gears is necessary. The components themselves must be dimensioned and selected with the mechanical properties in mind. The entire system must adapted to the conditions needed to drive the load. (Drive dimensioning)

So what do we have to keep in mind? Here are a few keywords:

- Inertia
- Torque
- Acceleration
- Jolt
- Braking
- Kinetic energy
- Centrifugal force
- Rotation / Translation
- Slip
- Dynamics / Motion profile
- Resonance / Vibration tendency
- Efficiency / Performance
- Torsion / Give / Rocking
- Friction
- Wear
- Limit values of the drive components
- Emergency stop

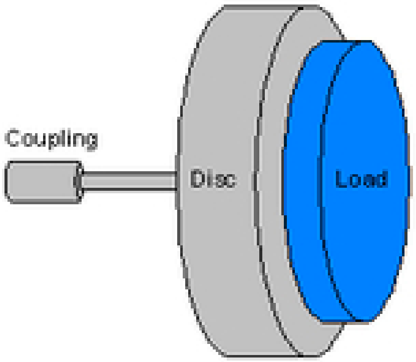
3.4.2 Direct drive

A direct drive is referred to when the electric motor is connected directly to the machine.

In this case, special attention needs to be paid to the motor since it must be capable of running at the same speed as the machine.

The major advantage of this type of drive concept is the absence of a gearbox. See Direct drive motors.

3.4.3 Rotating load



Rotating load*Servosoft / controleng.ca*)

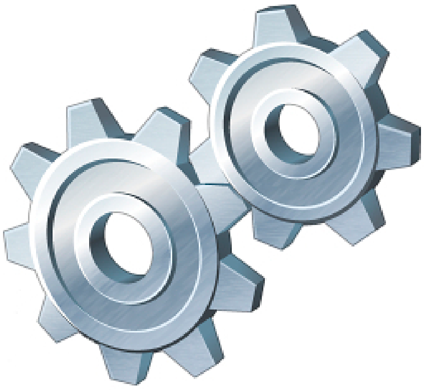
The rotating load is one of the simplest of mechanical systems. In addition to the rotating disc itself, there is often an additional load present as well. As a result, the inertia of the disc is increased and additional torque (imbalance) is generated depending on the angle of inclination and the angle of rotation of the load. The angle of rotation will determine whether this torque will be an accelerator or a decelerator. The eccentric load results in sinusoidal, pulsating additional torque if the speed remains constant.

The inertia depends on how the mass is distributed as well as the diameter of the load. This is the same as when an figure skater shifts his or her weight in order to increase or decrease the speed at which the body turns.

Typical applications:

- Turntables
- Pumps, fans
- Vibrators

3.4.4 Gearboxes



Simplified representation of toothed gears

A gearbox is an element that allows the path, speed or acceleration to be changed. It is usually mounted directly on the drive motor. A gear reduction results in a reduction of the rotational speed, but it also increases the torque. People probably talk most frequently about mechanical gears. Electronic gears refer to an axis coupling and data that is exchanged via a fieldbus.

Some features or characteristics of a gearbox include things like backlash, inertia, torsional strength and the specified permissible radial and axial forces.

Gears can be broken down according to their gear ratios:

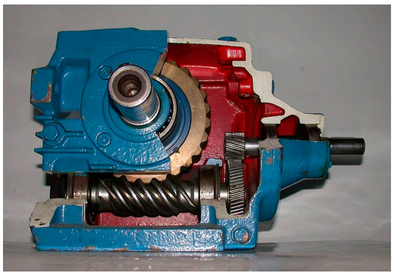
- Gears with the same ratio
- Gears with different ratios

Gears with the same linear ratio

With these, power is transmitted linearly.

They include the following types:

- Planetary gears
- Spur gears
- Bevel gears
- Helical gears
- Sliding gears
- Belt and chain gears



Spur gear combined with a worm gear
(Glenn McKechnie / de.wikipedia.org)

Gears with different ratios

With these, power is not transmitted linearly. In electric motion control, these types of gears are replaced by electronic cam profiles (see TM441 - ASiM Multi-Axis Functions).

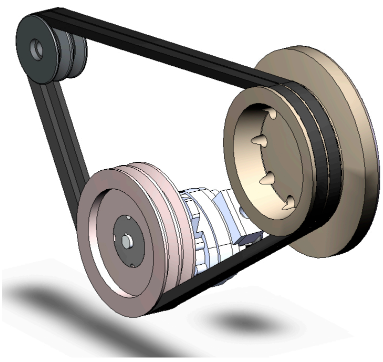
They include the following types:

- Cam mechanisms
- Coupled gears
- Stepping gears

3.4.5 Pulleys, belt drives

Belt drives are also known as belt transmissions or envelope drives. It is classified as a traction drive and is used in many different technical areas. In the early days of industrialization, the belt drive was used as a transmission.

In modern belt drives, V-belts or toothed belts are used. These belts can transfer large amounts of force with only a little amount of tension. In very simple applications, for example, belts can be used as a clutch.



Belt drive with two taut V-belts
(*Borowski / de.wikipedia.org*)

Some advantages include:

- Runs quietly
- Shock absorbance
- No lubrication required
- Affordable option for bridging large distances
- Good weight/performance ratio
- High speeds possible

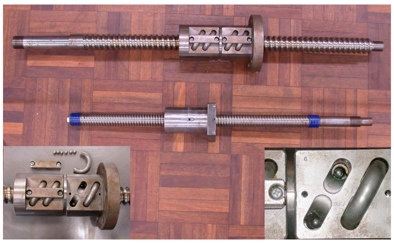
Some disadvantages include:

- Limited temperature range
- Belt stretch, tensioner needed
- Sensitive to other production equipment
- Belt slippage
- High load on the shaft

3.4.6 Spindle drive

A spindle drive is also referred to as an elevating screw. Here, a rotation is "translated" into a linear movement.

In the area of machine manufacturing, balls screws (also known as recirculating ball screws) are used. The ball screw nut grips the linear movement of the spindle. There are different open and closed nut systems whose basic function is the same, but differ in their precision.



Ball screw (*Glenn McKechnie / de.wikipedia.org*)

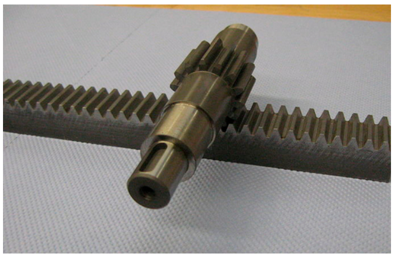
Typical applications include machine tools that are moved longitudinally or in tool carriages. In automation, complete units are offered by combining the drive motor, linear guiding and elevating screw. A robotic palletizer is a case where they are used in multiple spatial directions.

Unlike a spindle with trapezoidal thread, it is technically possible to reduce play to just a few µm. Loads of several kN are possible in addition to movements up to 200 m/min. Heat generated by high stress can cause the spindle to expand.

3.4.7 Toothed rack and shaft

A rack can be used to translate a rotation, or vice versa. Racks have been used in technical equipment throughout history, e.g. cog railroads and retaining dams have used this form of power transmission.

How it works is very simple. A cog engages the toothed rack and, depending on the direction of rotation, translates it into a linear movement going the other way.



Rack and pinion (*Dirk Gräfe / de.wikipedia.org*)

They are used in applications such as CD player trays, the rack and pinion steering system in vehicles and winches used to lift and clamp hanging loads.

4 THE B&R DRIVE SOLUTION

The range of B&R products includes all known drive technologies. Depending on the manufacturing process and technical requirements at hand, many different types of drive concepts can be used for automation. The following sections will provide an overview of the thoroughness of the products in this particular product range.

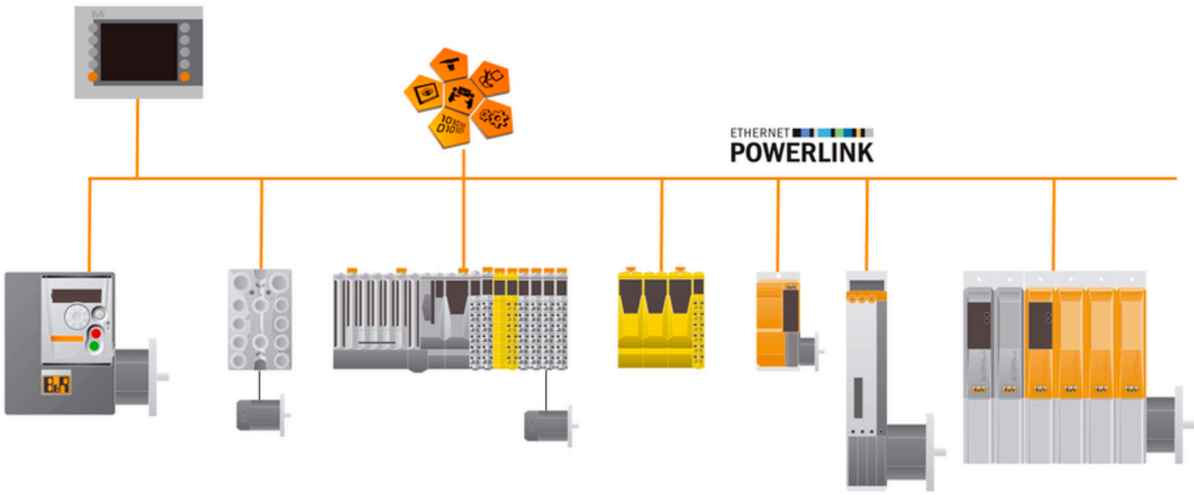
Overview of B&R drive technology

In addition to frequency converters and servo drives, control devices and motors for stepper motor and DC applications form the basic foundation. Synchronous motors and gearbox options round out the complete range of products.

Universal connectivity as well as easy configuration and programming of the drive application makes it possible to flexibly and efficiently set up complex machinery.

4.1 Typical topologies

All components contributing to machine control are connected using the same fieldbus. The controller that executes the machine application, the process visualization and the various drive technologies can be mixed homogeneously. Regardless of whether a stepper or servo motor is needed, the drive can always be connected to the other control components via POWERLINK.

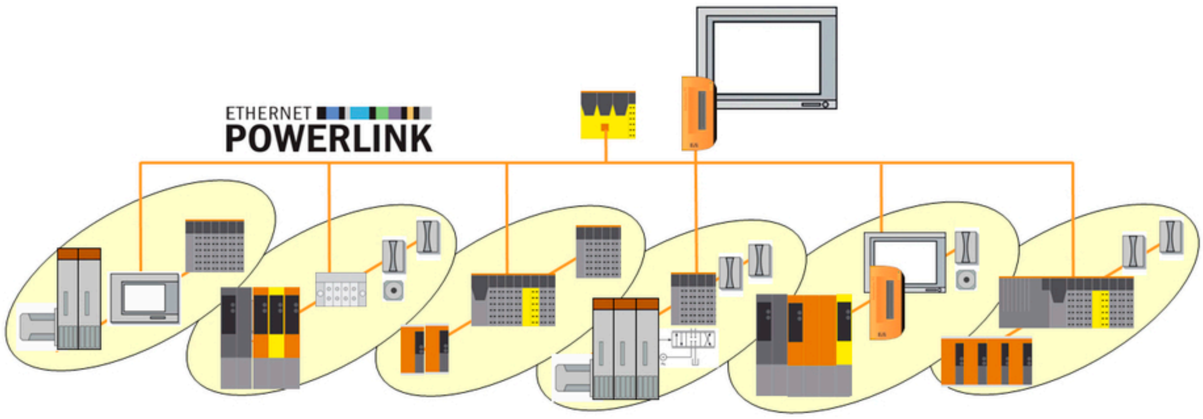


Drive solution connected via POWERLINK

Connecting mechatronic units

Large machines are often composed of mechatronic units. A mechatronic unit is a machine component that carries out a specific function; it consists of drive technology, sensors and actuators.

In the complete machine, it is important that these units are connected to each other properly.



Connecting mechatronic units to the complete machine with POWERLINK

The simplicity of networking within the machine speaks for itself and has significant advantages:

- One fieldbus can be used for the entire machine.
- A central controller networks all components.
- Applications, configurations and data can be accessed from a defined point.
- Drive parameters and module configurations are loaded directly to the devices when the system is started. This eliminates the need for additional steps when a module has to be replaced.
- The controller, drives and I/O points can be synchronized via POWERLINK, which makes it very easy to handle coupling tasks.
- The machine can be divided into mechatronic units that can be flexibly connected to each other when needed without much effort.
- All diagnostic data is accessible via the central controller, and extensive information pertaining to the overall system is collected and furnished to the System Diagnostics Manager (SDM).

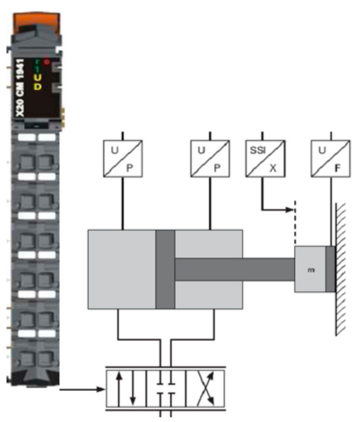
4.2 Product overview

Hydraulic control with the X20

The high performance characteristics of the X20 System make it perfect for carrying out precise hydraulic control. Fast cycle times, low jitter and the ability to read and write sensor values and manipulated variables synchronously ensure highly dynamic control.

Either analog modules or motor bridge modules can be used to control hydraulic valves.

The comprehensive hydraulics library provides simple functions for velocity, force and position control and is included in Automation Studio. The seamless integration of hydraulic systems in the automation application and coupling them to electric drive axes is thus no longer a problem.

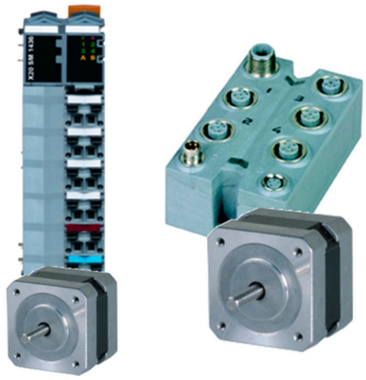


Hydraulic control with the X20 System

DC motor bridges and stepper motor controllers

DC and stepper motors are often used when inexpensive drives are needed. Using X20 and X67 modules is an optimal way to integrate these motors into the automation solution.

With DC motor bridge modules, DC motors up to 6 A continuous current can be used. Adjustable current as well as configurable dither and decay allow them to be optimally adapted to the process. Motor bridge modules include digital inputs which can be optionally configured for operation with an incremental encoder.



DC and stepper motor controllers

Stepper motors up to 3 A continuous current can be operated with X20 and X67 controllers. Even more precise positioning accuracy and quietness are achieved through its configurable microstepping mode. Optional encoder feedback makes it possible to handle high-precision positioning, while configurable rated and holding current allow optimal motor performance.

ACOPOSmicro drive system

The multi-functional ACOPOSmicro system is available in both stepper and servo designs. The two-channel variant has the option of using coded connection terminals. This allows up to 10 A continuous current and 15 A peak current per motor. A wide range of applications is made possible by the variable selection of the power supply voltage from 8-80 VDC. In addition, the ACOPOSmicro has trigger inputs and an output available to control an external brake and support different encoder systems.

Suitable stepper and servo motors are available from B&R to handle different power ranges. Optional upgrades such as a power supply module and braking resistors round out the range of functions.

ACOPOSmicro stepper motor controller

ACOPOS servo technology

Powerful ACOPOS servo drives are available in several different designs.

ACOPOSmulti is the optimal choice for combining multiple drive axes that share a common power supply and the DC bus. Three different cooling concepts mean that these devices can be tailored to the machine as needed.

ACOPOS devices have an integrated line filter, DC bus and braking chopper for individual servo axes.

ACOPOSmicro is a servo variant that offers a compact drive solution.

All of these systems have the same properties. Upgrades are easy to perform due to their modular design. The drive controller is integrated directly in the drive. All systems can be combined with, synchronized, and connected to one another. Complete diagnostics simplifies commissioning and maintenance. The system is easy to configure, and the integrated auto-tuning function helps to quickly determine necessary control parameters.

The ACOPOSmulti system also allows safety-oriented drive axes to be integrated when used with a SafeLOGIC controller. The ACOPOSmulti65 with protection against sprayed water can be used when drive control is needed in the direct proximity of the machine itself.

B & R servo technology: ACOPOSmulti, ACOPOS and ACOPOSmicro

Servo motors, stepper motors, gearboxes

B&R synchronous motors cover a very broad spectrum. Their compact designs and high quality set them apart. Motor options such as brakes, forced ventilation and a variety of connection angles for peassembled motor and encoder cables make sure that all bases are covered. Resolver and EnDat absolute encoder systems are available for these motors. The range of motors is rounded off with suitable gearbox options.

Different stepper motor designs are also available with encoder and gearbox options.

The following is an overview of the different motor types:

Synchronous servo motor, torque motor

8LV compact motors	Up to 2.7 Nm, speeds up to 6000 rpm, compact design, low inertia, three different sizes
8JS synchronous motors	Up to 53 Nm, speeds up to 8000 rpm, robust, high power density, six different sizes
8LS synchronous motors	Up to 115 Nm, speeds up to 8000 rpm, seven different sizes, highly dynamic, swivel connector

Table: Overview of servo motors

8LSN synchronous motors	Motors with increased mass moment of inertia
8LT torque motors	Different types of cooling, direct drive, with ISO mounting flange, blind hole or hollow shaft, speeds up to 1200 rpm, rated torque up to 1000 Nm
80MPD stepper motors	Stepper motors can be wired in series or in parallel, flange dimensions 56, 60 and 86 mm, holding torque up to 13.6 Nm, various encoder options, gearbox options
8GP planetary gears	Three variants: standard, economy and premium, with drive shaft, available with output flange and angular planetary gearbox

Table: Overview of servo motors

Frequency inverters

ACOPOSinverter frequency inverters can be directly integrated into the automation network. Power calculations ranging from 0.18 - 500 kW are available. Optional accessories such as braking choppers, EMC filters and regenerative power supply allow them to be efficiently integrated into the process.

As well all other B&R drive components, diagnostics can be handled centrally with Automation Studio or on site via the integrated display. Frequency inverters receive the setpoint from either the fieldbus, an analog input or the handwheel on the device. Their integrated inputs and outputs also make it possible to carry out isolated operation without a controlling CPU.

B&R frequency inverter:
ACOPOSinverter S44, X64, P84

Automation Studio

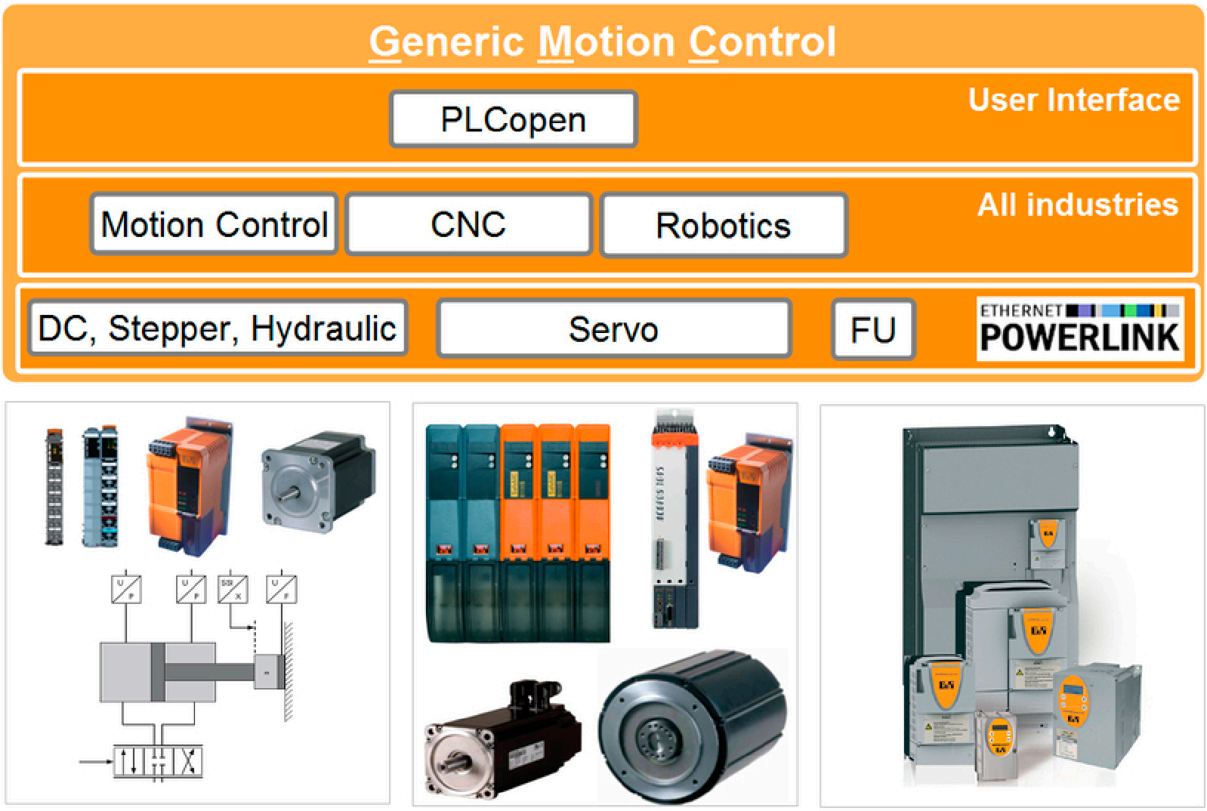
Automation Studio combines the planning and design of the logic, visualization, safety and motion application. The built-in diagnostics and commissioning interface facilitates project planning design and helps when commissioning the motion components. All settings and parameters are stored in the Automation Studio project.

Automation Studio: Simple integration of the drive solution

4.3 Implementing the positioning application

It's already possible when looking at the possible topologies to see that all of the motion components are interchangeable and can be deployed as needed. In addition, a comprehensive software tool can be used to develop all of the different types of motion applications.

Various electrical properties of the drive system and requirements such as an easy speed setting, position setting and axis couplings are the basic demands.



Generic Motion Control

This is made possible through the use of **G**eneric **M**otion **C**ontrol, or GMC. All axis movements are coordinated using **PLCopen** function blocks. The underlying layers control the specific characteristics of the different drive systems.

This allows the same positioning tasks to be handled using the same user program, regardless of whether an electric drive axis with a stepper motor, frequency inverter or servo drive is being used. Hydraulic drive axles can be integrated in the same way.

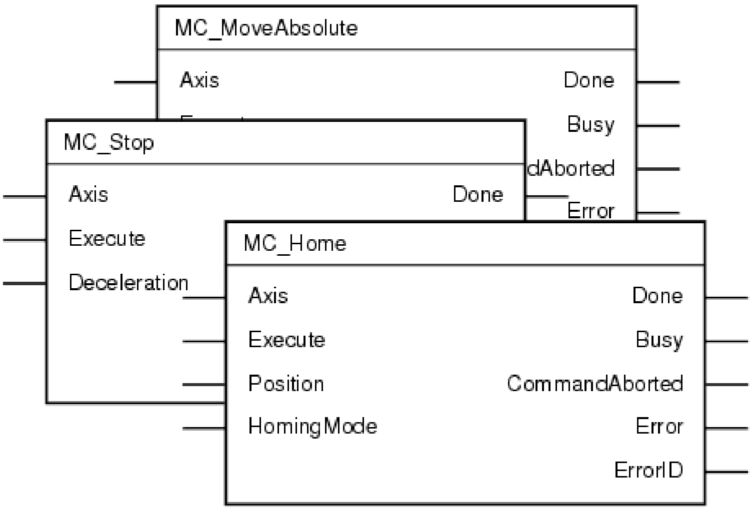
PLCopen motion control

PLCopen

PLCopen is an organization of industrial manufacturers who have taken it upon themselves to increase overall efficiency in the area of software development. The result of their efforts can be seen in the specification and standardization of motion and safety-related function blocks. They can be used across different platforms and notably incorporate the use of programming languages specified in the IEC 61131-3 standard. (**http://www.plcopen.org/**)

ACP10_MC - PLCopen Motion Control library

In addition to PLCopen function blocks, the ACP10_MC library also includes advanced functions blocks that implement functionality relevant to B&R systems. This makes it possible to utilize simple drive functions such as **basis movements** and drive preparation as well as **more demanding functions** such as implementing axis couplings with cam profiles.



PLCopen basic functions

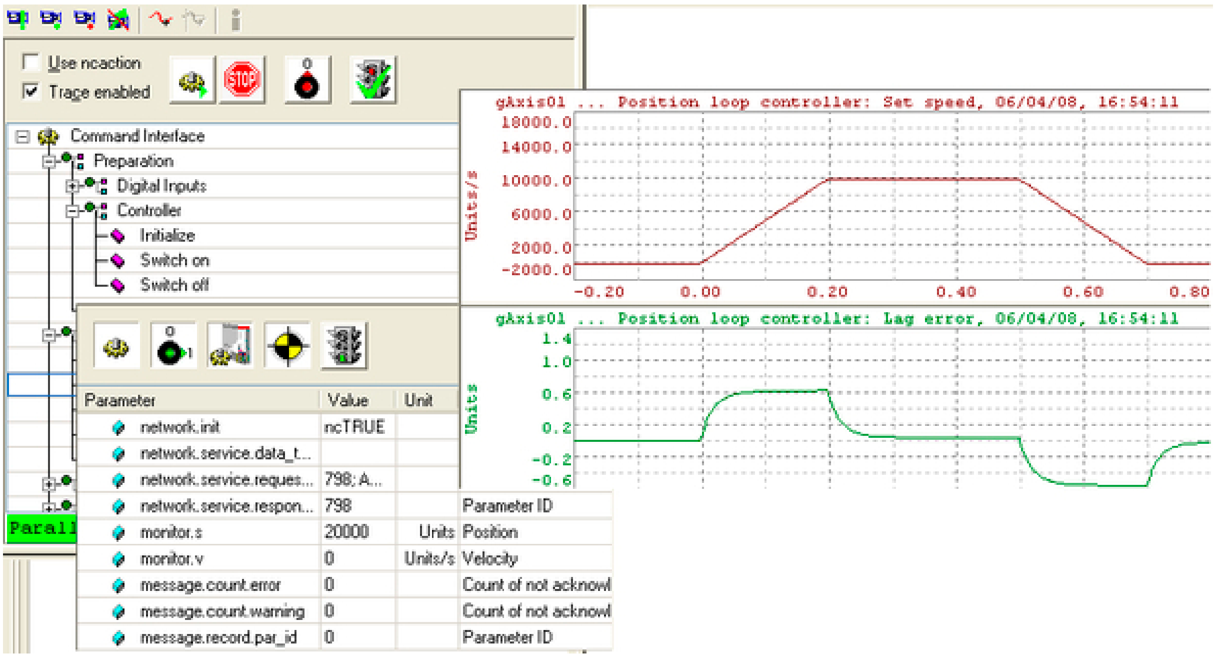
Integration in Automation Studio

In Automation Studio, a drive configuration is added from the Physical View. All necessary configurations and links are inserted directly from the **Motion Wizard**.

Several **sample programs** for basic movements as well as fundamental information about **commissioning** a drive axis can be found in the Automation help documentation here:

> ? Automation Software \ Getting started \ Create a motion application in Automation Studio
>
> Programming \ Examples \ Motion

A testing and commissioning environment is included right in Automation Studio. In NC Test, all axis commands can be executed even before a drive application exists. The integrated auto-tuning function can also considerably reduce commissioning times. In addition, axis movements can be recorded using NC Trace. Complete **motor** and **drive simulation** is also available and allows testing without even needing a physical drive.



NC Test with NC Watch and NC Trace

Additional information concerning programming and optimizing the complete system can be found in the Automation Studio help documentation:

?

Programming \ Libraries \ Motion libraries

Programming \ Libraries \ Closed loop control and mathematics

Motion \ Project creation

Motion \ Commissioning

Motion \ Diagnostics

Motion \ Reference manual

4.4 Selecting the right technology

It is not always easy to keep track of the wide variety of motors and drive types.

Therefore, the following section provides an overview of motor types, their areas of application and the corresponding solution from B&R.

Technology	Properties, areas of application	B&R solution
Stepper motor	Low torque, torque at low speeds, good standstill behavior, inexpensive, compact (power density), usually without an encoder, not very dynamic Variable speed drives, transport of small objects, positioning, smaller winders	⇨ ACOPOSmicro ⇨ X20SM ⇨ X67SM ⇨ B&R stepper motor
DC motor	Not typically used in positioning applications, energy efficient, maintenance (brushes) Small auxiliary drives	⇨ X20MM ⇨ X67MM
AC motor	Inexpensive, robust, maintenance-free, not very efficient, control without encoder possible Transport, conveyor belts, pumps, fans	⇨ ACOPOSinverter ⇨ ACOPOS ⇨ ACOPOSmulti
Synchronous motor	High dynamics (low inertia), can be positioned (precision), long service life, more expensive, passively cooled, high power density Positioning applications, dynamic speed changes, start-stop applications	⇨ ACOPOSmicro ⇨ ACOPOS ⇨ ACOPOSmulti ⇨ ACOPOSmulti65 ⇨ 8LV, 8LS, 8JS motors
Direct drive motor • Torque • Linear	High torque, custom design, lower speeds, no gearbox (precision, noise, maintenance) Winders, printing presses, weaving machines, machine tools	⇨ ACOPOSmicro ⇨ ACOPOS ⇨ ACOPOSmulti ⇨ 8LT motors
Hydraulic drive	High performance, high torque, all environments, power density, low velocity, poor energy balance Casting, presses, stamping, printing, metal-cutting machines	⇨ X20 ⇨ X67

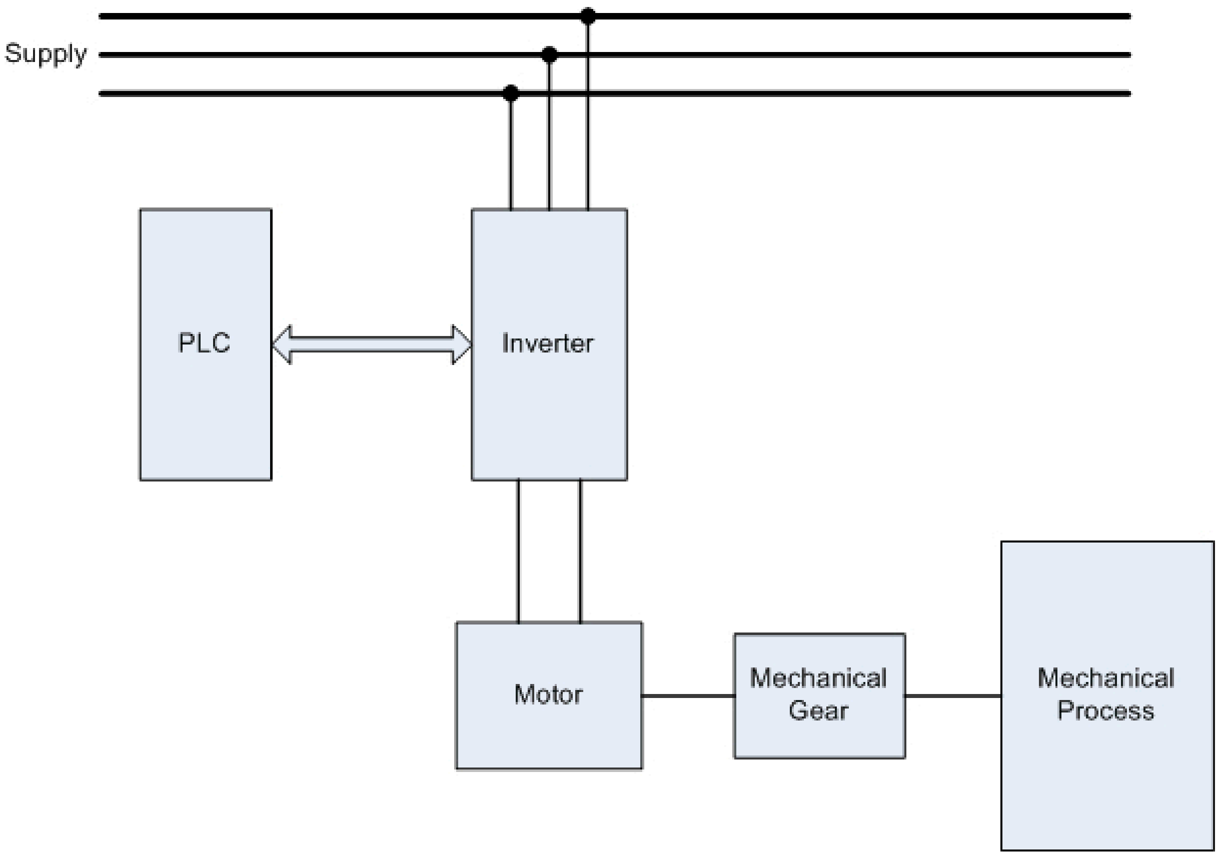
Table: Motors, properties, areas of application, B&R solution

5 DRIVE DIMENSIONING

In order to select the right motion control system, it is necessary to understand the entire drive sequence and the machine that it will be driving. All components of the system need to be taken into consideration when dimensioning the drive. Drive components that are incorrectly dimensioned can lead to big problems, especially if they're not discovered until the machine is being commissioned. For example, it may not be possible to achieve the expected dynamics or level of efficiency. The quality of the units produced will be affected. Or the drive mechanics could become damaged.

The following diagram illustrates all of the components that are important when dimensioning the drive:

- The mechanical process
- The mechanical gear (power transmission)
- Motor and system for detecting positions
- Inverter
- Energy supply



Drive system

Designing a drive system is a repetitive process – the individual steps involved may have to be carried out more than once depending on the circumstances.

Procedure:

- Select the type of drive (linear, rotary, direct, etc.).
- Select the motor according to the required speed and torque curves.
- Check the thermal capacity of the motor.

- Select the physical motor options.
- Select the encoder system.
- Select the inverter.
- Check the efficiency and viability of the drive solution and repeat the steps if necessary.

In this context, there are additional aspects that need to be considered. These include both country-specific characteristics as well as local conditions.

The following questions need answers:

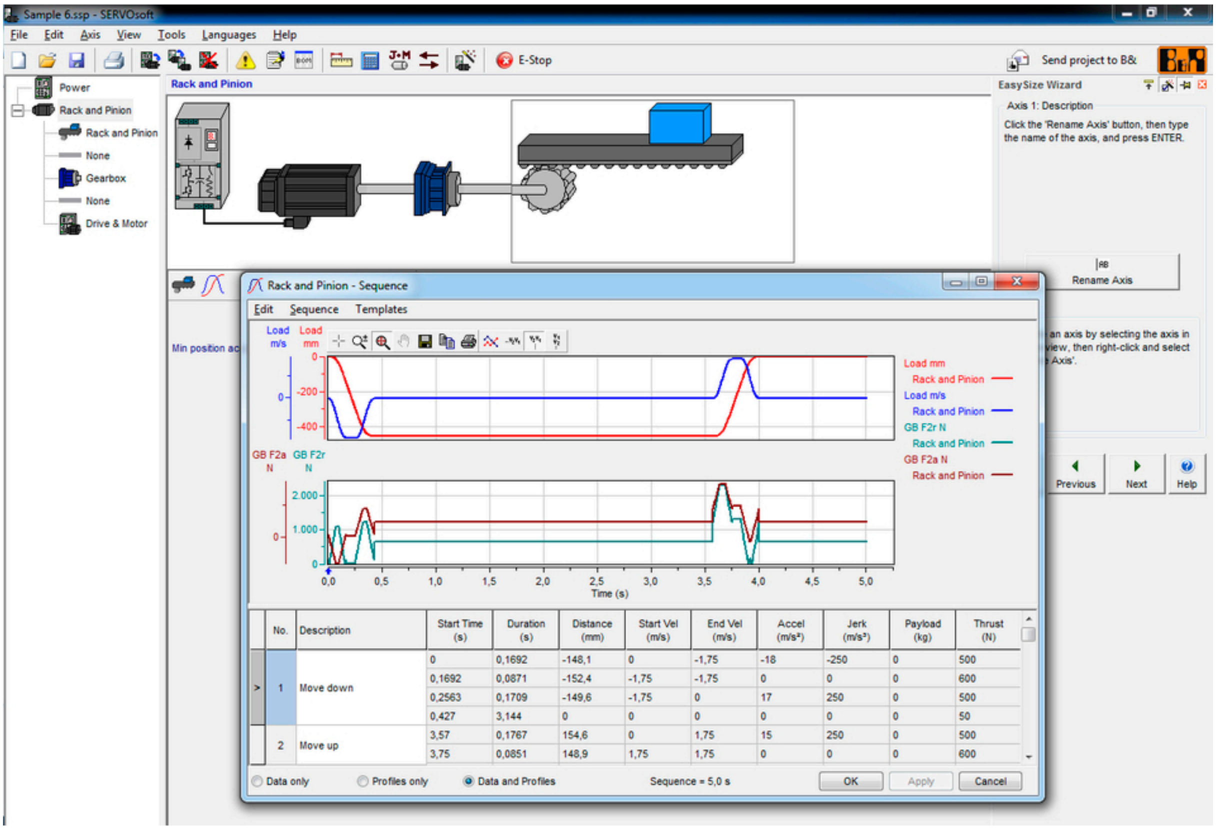
- What kind of power grid is available on site?
- How constant is the power grid?
- At what altitude will the machine be operated (sea level)?
- Are country-specific guidelines and standards being adhered to?

5.1 Drive dimensioning with Servosoft

To dimension a drive properly, a number of calculations need to be made that involve how the mechanics are designed. The values calculated in this way can be used to determine the necessary motor, inverter and subsequently the required power supply.

The drive dimensioning software "SERVOsoft" can be used to simplify this process. A free version of this software is included on the Automation Studio installation DVD and can be registered free of charge from the manufacturer.

SERVOsoft logo



SERVOsoft displaying a rack and motion profile

The following components can be entered in the full version for calculation:

- Up to 20 axes in a shared bus
- Rotating and linear drive axes
- 12 different pre-configured drive mechanisms
- Motors, gear boxes, load couplings, positioning accuracy
- B&R components (motors, inverters, gearboxes) selected from the SERVOsoft database
- Infeed, bleeder and capacitor modules
- Mass moment of inertia for all components
- Motion profiles with up to 5,000 segments per axis
- User-defined reserves for all components

The following data can be calculated:

- System check whether the drive configuration is realistic
- Torque, moment of inertia, current
- Overall efficiency
- Power for power modules, DC bus
- Energy costs
- List of materials necessary
- Motor and gearbox combinations

Drive dimensioning

A selection of sample projects for common drive configurations makes it easy to learn how to develop projects with SERVOsoft. It also provides a first impression of the importance of drive dimensioning.

6 SUMMARY

The level of performance exhibited by modern drive systems has improved significantly thanks to technological advancements in the area of power and signal electronics.

Mechanical, electrical and IT-related components are combined to automate a process. Making sure that this mechatronic system is optimized as much as possible is decisive for meeting high demands.

The B&R ACOPOS and servo motor product family

Closely coordinating everything to match the requirements of the process starts with selecting the right drive system components. When doing so, it's the specific characteristics of the system components and their effects on the entire system that take on the main focus.

Basic knowledge of the components, technologies and procedures being used in the system is very helpful for the software developer.

This is the necessary basis for adapting, configuring and optimizing the mechatronic drive system as needed into a function unit that can be used repeatedly.

TRAINING MODULES

TM210 – Working with Automation Studio
TM213 – Automation Runtime
TM220 – The Service Technician on the Job
TM223 – Automation Studio Diagnostics
TM230 – Structured Software Development
TM240 – Ladder Diagram (LD)
TM241 – Function Block Diagram (FBD)
TM242 – Sequential Function Chart (SFC)
TM246 – Structured Text (ST)
TM250 – Memory Management and Data Storage
TM261 – Closed Loop Control with LOOPCONR
TM400 – Introduction to Motion Control
TM410 – Working with Integrated Motion Control
TM440 – Motion Control: Basic Functions
TM441 – Motion Control: Multi-axis Functions
TM450 – ACOPOS Control Concept and Adjustment
TM460 – Initial Commissioning of Motors
TM480 – The Basics of Hydraulics
TM481 – Valve-based Hydraulic Drives
TM482 – Hydraulic Servo Pump Drives
TM500 – Introduction to Integrated Safety
TM510 – Working with SafeDESIGNER
TM530 – Developing Safety Applications
TM540 – Integrated Safe Motion Control
TM600 – Introduction to Visualization
TM610 – Working with Integrated Visualization
TM630 – Visualization Programming Guide
TM640 – Alarms, Trends and Diagnostics
TM670 – Advanced Visual Components
TM810 – APROL Setup, Configuration and Recovery
TM811 – APROL Runtime System
TM812 – APROL Operator Management
TM813 – APROL XML Queries and Audit Trail
TM830 – APROL Project Engineering
TM890 – The Basics of LINUX

TM400TRE.00-ENG / V1.0.2