ABB drives

Technical guide No. 9
Guide to motion control drives

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Contents

Chapter 1 - Introduction

This guide aims to give users an overview of high performance drives and motion control. Although written in a simple style to make it relevant to most applications, readers need to have a basic understanding of AC drive technology to benefit from this guide.

When considering a motion control application it is important to consider all elements in the system including drives, motors, mechanical power transmission components, software, etc.

A high performance system has one or more of the following characteristics:

– high dynamic performance
– high accuracy reference following and repeatability
– high accuracy motion functions
– capability to run different motor types

1.1. Motion control versus speed control

Standard variable speed drives normally control the motor by giving a speed command. The system typically has no feedback and speed reference is preset speeds, 0 to 10 Volts, 4 to 20 mA, or fieldbus.

With motion control, there is always feedback of the real position. This is compared to the reference value and the difference is corrected continuously by the motion controller's profile generator.

Positioning is a good example that highlights this difference. If a standard drive is used for positioning, the motor normally runs at high speed, then decelerates to a lower speed and stops. Alternatively, the drive can follow an analog signal. Either way, no reference profile is followed, compared for errors or corrected. This results in low accuracy.

Accuracy can be improved if the controller is a high performance motion controller but in this case, the dynamics and the sample time (generally several milliseconds) of the standard drive become limiting factors.

1.2. Decentralized or centralized control

In a system with centralized control, one unit contains all the software and the drives just follow the reference value. There is no intelligence within the drive.
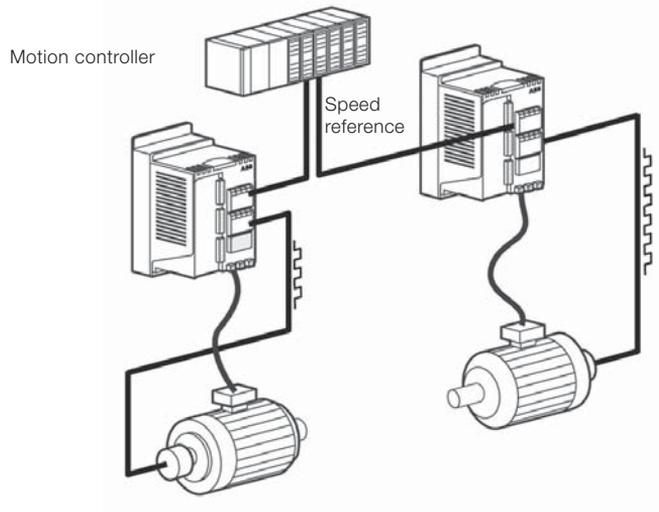

Figure 1.1 Simplified centralized system.

In a decentralized system, the field devices also have intelligence. This means that the cost of the control unit is reduced, as far less performance is required centrally.
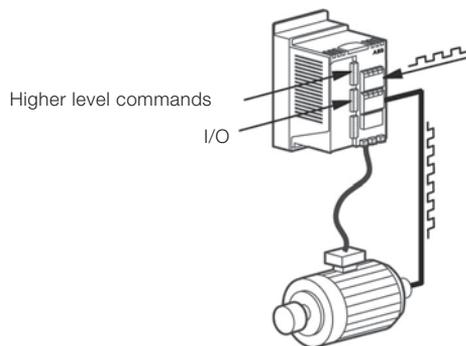

Figure 1.2 Simplified decentralized system.

1.3. Comparison between decentralized and centralized systems

Feature	Decentralized	Centralized	Benefits of decentralized control
Number of control wires	Low	High	Less cabling – lower cost Fewer potential faults wires
Cabinet	Less components, smaller size	More components installed	Labour and material cost saving
Programmable Logic Controller (PLC)	Control distributed	All control, additional hardware cost	Cost saving in PLC hardware
Time levels	Motion loop is closed in drive*	Motion loop is closed in controller	Good cost/ performance ratio
Drive-to-drive communication	Fast drive-to-drive communication improves communication	Not used	Less hardware

*This means that feedback is connected directly to drive. It does not go to PLC or motion controller for calculation which might cause delay.

More detailed information of motion control in chapter 7.

1.4. Main functional parts of machine

Machines using motion control and/or high performance drives consist of the following, all of which have a deciding influence on the performance of the system:

– Motion control hardware: this controls the operation of the system; it can be centralized or decentralized
– Motion control software: determines the functions of the machine by receiving input data and handling this according to the instructions set out in the software code
– Drive or amplifier – receives commands from the motion control software
– Motor – provides mechanical energy with the required speed and torque to drive the load in the specified way
– Mechanical power transmission components – belts, gear-boxes, clutches, ballscrews etc.
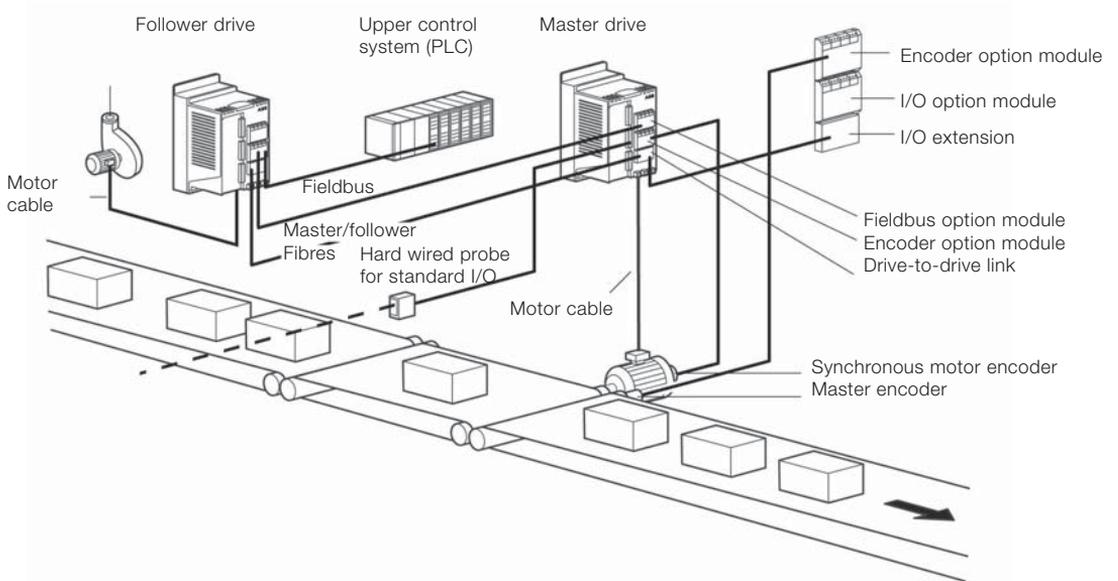
Figure 1.3 Constant gap maintaining.

1.5. Machine components

Figure 1.3 shows a basic setup. The distance between boxes on the conveyor belt varies and the purpose of the motion control software is to accelerate or decelerate the belt and space the boxes equally.

Main components:

– Drives and cables (power, feedback, control)
– Overriding control by PLC
– Motor encoder monitoring closed loop motor control and position information for cyclic correction
– Master encoder, giving speed reference of production line
– Fibre optic cable for communication between drives
– Fieldbus, encoder and drive-to-drive link
– Sensor giving 24 V on/off information to drive
– Synchronous encoder

Chapter 2 - Drive and motor combination

The drive and motor are normally supplied as a package to suit the application. The main drive, motor types and features are described here.

2.1. Brush-type DC

The basic principle is the same as in industrial high power DC drives, the main difference being that there is no magnetizing circuit. Instead, the motor carries permanent magnets on the stator side. Rotor current and voltage is supplied by brushes and a commutator.

Normally, it is not possible to use the supply voltage. Instead, a transformer is used to reduce the voltage. Some drives have a rectifier circuit, while others need an external voltage rectifier.

The electronics are relatively simple and only speed feedback is required for the speed controller. Brush-type DC drives is one of a small number of control platforms that actually use a tacho as a feedback device for the speed reference.

When this type of drive and motor combination is used in motion control, a pulse encoder is quite often fitted to the motor shaft. Pulses are sent to the motion controller for calculating the position.

The benefit of brush-type technology is the simple and inexpensive controller. The drawback is that the commutator and the brushes are mechanical components and have limited lifetime. Especially in applications where the motor always stops in the same position, the commutator gets worn in one particular place, thereby reducing its life even more.

The main players in the drives industry do not use this technology anymore. Typically these kinds of products are based on old analogue platform.

2.2. Brushless DC

The power circuit of a brushless DC servo drive is similar to that of an AC drive. Input current is rectified and filtered in a diode bridge with associated DC-link capacitance. The inverter unit consists of six power devices.

However, with a brushless DC drive the output voltage is not modulated to form sinusoidal current, unlike in an AC drive.

Instead, six possible switching combinations are used to form a trapezoidal vector diagram. Typically, hall sensors (hall sensor is a device that senses magnetic field are used to identify rotor position) and a tacho generator gives feedback to the speed controller.
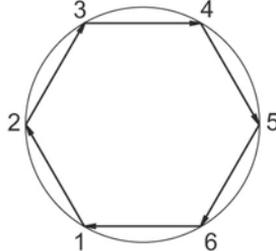

Figure 2.1 Rotational voltage vectors in trapezoidal control.

In the AC drive, the motor's back EMF (electro magnetic force) tends to be sinusoidal, while brushless DC servo motors have a trapezoidal back EMF.

The brushless DC servo control algorithm does not need as much computing power as a sinusoidal drive. The tacho also provides fast input to the speed controller.

However, with faster, more powerful and reasonably priced processors, very high performance drives with sinusoidal output has been developed.

The main problem with trapezoidal control is torque ripple, especially at low speeds. There are ways to improve the performance but it seems that this technology is disappearing from the main marketplace.

2.3. Asynchronous servo

The amount of slip forces current to the rotor determines the torque. This motor type has a light and small diameter rotor to minimize inertia. This means that the inertia, which is inversely proportional to acceleration, is lower than in induction motors, although it is higher than in permanent magnet servo motors.

Suitable control methods are closed loop vector or DTC control. This method gives performance equal to that of drives with asynchronous servo motors. The main limiting factor is the motor.

This drive can often be referred to as a servo drive, due to the nature of the motor or a closed loop control for standard AC induction motors.

However, feedback from an incremental encoder, resolver or SinCos encoder is always needed.

2.4. Synchronous servo

This type of motor is quite often called AC brushless servo. Synchronous servo motors have a rotor with permanent magnets and a stator for three phase supply. The rotor has very low inertia and can achieve fast dynamic performance. The motor operation is synchronous and the feedback device has to be able to deliver continuous position and speed information to the amplifier.

In chapter 3 (page 15) the AC synchronous servo motor is explained in more detailes.

Chapter 3 - Synchronous technology

The drive or amplifier delivers a sinusoidal output modulated from the DC-link voltage (traditional modulator or an advanced method like DTC). This makes the power circuit identical to that of a conventional drive. Using permanent magnet motors, the basic algorithm only needs to produce current for the torque - no magnetizing current is needed.

Servo motors, like induction motors, are manufactured with different numbers of poles. Taking a 6-pole motor as an example, the name plate states 940 rpm nominal speed (standard induction) and therefore the synchronous speed is 1000 rpm. This is achieved at 50 Hz input frequency and at higher speeds, the motor operates in its field weakening area. This is slightly simplified because some asynchronous servo motors are designed to run at other than 50 Hz field weakening point.

Synchronous motors use sinusoidal wave form and constant torque up to nominal speed but in such a way that the frequency at nominal speed is, for example, 150 Hz for the motor at 3000 rpm nominal speed (six pole winding).

3.1. Measuring performance

The key performance indicator is the bandwidth of different control loops.

Typical good speed control loop has bandwidth of 100 Hz and torque loop has 800 Hz.

Increasing the frequency means that the amplifier tends to loose its ability to respond. Normally, the bandwidth is measured up to a level where the output is 3 db less than the reference level. Bandwidth of a signal is a measure of how rapidly it fluctuates with respect to time. Hence, the greater the bandwidth, the faster the variation in the signal may be.
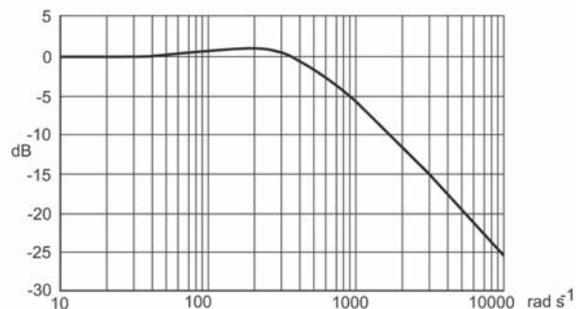

Figure 3.1 Amplifier's response variation as a function of frequency.

The other problem is phase delay in the amplifier circuit. As the frequency increases, the amplifiers tend to loose the original phase.
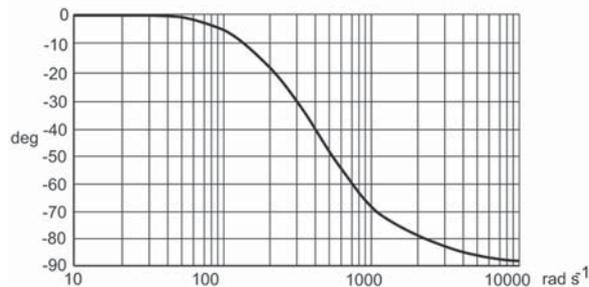

Figure 3.2 Amplifier's phase delay as a function of frequency.

3.2. How synchronous servo motors differ from induction motors

The main difference between synchronous servo motors and induction motors is in the motor shaft performance. With synchronous servo motors, rotor mass and diameter are minimized, leading to low inertia which in turn means the rotor does not need much torque to accelerate. Most of the torque produced can be used to run the load.

Typical features of synchronous servo motors:

– The motor efficiency is typically over 95% at full power.
– The motor has high power density – there is no rotor current and thus no build-up of heat in the rotor.
– The motors can run with high temperature rise, for example, at 40 degrees ambient, temperature rise/class H=125 °C is allowed.
– IP65 is the typical protection degree, compared to IP54 for standard induction motors.
– Standard AC induction motors are inexpensive. But for higher performance, additional feedback devices are needed and these can be costly.
– Other costs include encoders, fans making asynchronous servo motor a more attractive choice.
– High torque overload capability depends on the basic motor design and its magnetic materials. Generally, synchronous servo motor motors can deliver up to 2-5 times or more overload during short periods.
– Resolver, incremental encoder with commutation channels or various types of SinCos encoders can be used as feedback devices. Full digital feedback systems are also available.
– Recent development of drives and motion control systems, along with lower cost magnetic materials, has increased the market and number of applications for synchronous servo motor rapidly.

Chapter 4 - Synchronous servo motor – principle of operation

The synchronous servo motor does not have commutator or brushes. The drive (amplifier) maintains correct current distribution at the right vector angles and the right angular speed.

The rotor of synchronous servo motor is not symmetrical but has a magnetic polarity. The stator provides the three-phase sinusoidal current. The stator current forms the composite flux vector.
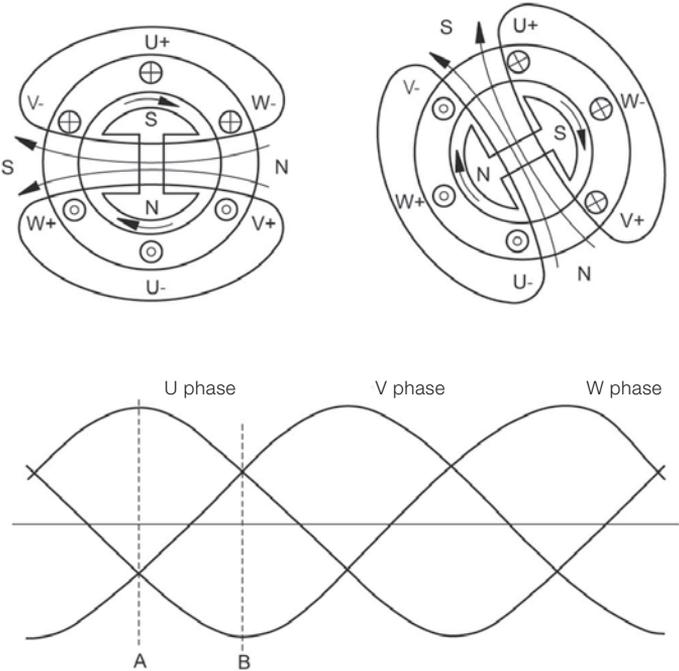
Figure 4.1 Magnetic fields at two positions.

The flux produced by permanent magnets and the flux produced by stator currents must be at exact opposites to maximize the repulsive and attractive forces of the magnetic fields.

These are the forces that build up torque and cause the motor shaft to rotate. This operation needs a feedback device that senses angular position of the shaft at all times, enabling the amplifier to setup sine output to the right angles.

4.1. Special conditions during startup

New motors can sometimes have a difference between the actual rotor position and that given by the feedback device. This needs to be corrected, otherwise inaccurate feedback results in the motor not being able to produce full torque and optimum performance.

The phase error can be resolved in different ways:

Initial startup:

– The drive features phasing error software which identifies the error during the commissioning run and uses its control algorithm to compensate for the error
– Error information from the motor manufacturer is entered as a parameter into the drive. This becomes important if a spare motor is installed and a non-load trial run is difficult to perform
– Some motor producers build in zero phase error during manufacture – this is the preferred option as it avoids the above tasks

Startup after power down:

– When powering up, the rotor position is known if the feedback device (such as resolvers and some SinCos encoders with communication bus) can give absolute position within one revolution.
– However, if an incremental encoder is used, then commutation channels are required. At startup, the motor is controlled in the trapezoidal manner, as long as the position is identified using the commutation signals. See also chapter 6, page 21 for feedback devices.

4.2. Traditional speed and current control

Figure 4.2 shows the basic principle of speed and current control.
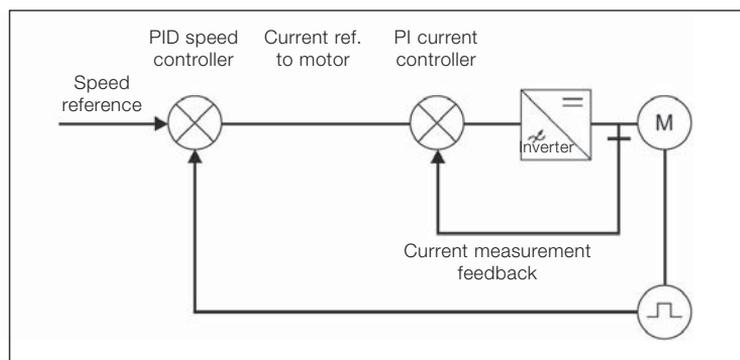
Figure 4.2 Speed and current control loop.

The role of the servo drive or amplifier is to make sure that the motor speed and torque follows the reference value. The motor´s feedback gives actual speed to the speed controller. The speed controller is typically a PID controller comparing reference and feedback signals.

The error signal is passed to the current controller. The current controller, typically a PI amplifier, sets up the correct current so that the right torque is available to keep the speed at the reference level.

Chapter 5 - Typical servo motors data

5.1. Torque constant

The torque constant is an important measure given to the synchronous servo motor. It is expressed as Nm/A and determines how much torque is produced per ampere.

5.2. Back EMF

The permanent magnet motor acts like generator and builds up back EMF voltage which is related to angular speed. Back EMF is opposite to the supply voltage and is in direct relation to the angular speed.

Ke is voltage constant and is typically expressed in V/1000 rpm (voltage rms value).

5.3. Torque curve
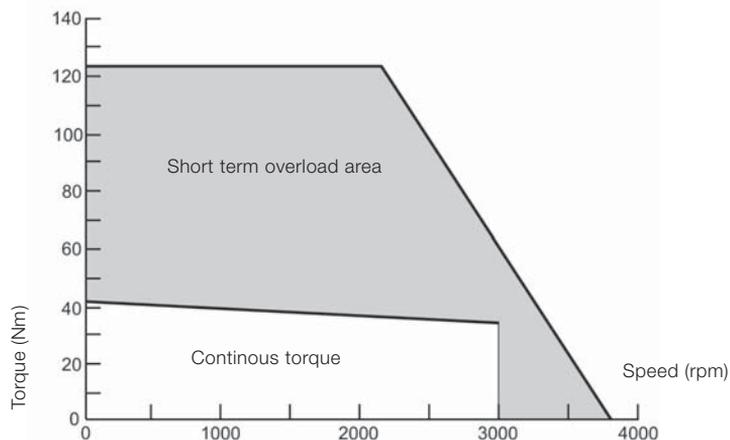
Figure 5.1 Torque curves of a synchronous servo motor.

The picture shows a typical torque curve of an synchronous servo motor. It consists of a continuous torque curve and a short term overload curve. Typical values given as part of the motor data are:

– T stall which is nominal torque at zero speed
– T nominal which is nominal torque at nominal speed
– T peak which is maximum torque which is typically 2 to 5 times nominal torque.

Synchronous servo motors are normally selected so that the highest running speed is close to the nominal speed. One important limiting factor is back EMF.

When the speed increases, the back EMF increases. This means there is a limit where the back EMF would be equal to or higher than the drive's maximum output voltage.

Synchronous servo motors normally run at a voltage which is far lower than the drive's maximum output voltage. For example, 560 V may be used for the DC link drive and 300 V nominal for the motor. The reason is that the motor has to be able to recover from peak loads very quickly.

On the other hand there are technical solutions that make it possible to run synchronous motors in field weakening area.

This means that motor needs more current to the motor windings. This is achieved by increasing the voltage and thus there must be margin between nominal and maximum voltage. This is also the reason why maximum torque output starts to decrease when the speed becomes closer to nominal speed.

Synchronous servo motors do not typically have cooling fan. Some suppliers offer cooling fans as option. It increases the nominal and thus RMS torque, but not peak torque.

5.4. Typical motor data

This is a summary of typical nominal values and other motor data. The reference values are for ABB Servomotors series 8C.

Type	Continuous torque zero speed M_0 [Nm] (3)	Current at continuous torque I_0 [A] (1) (2) (3)	Rated torque M_N [Nm] (3)	Rated current I_N [A] (1) (2) (3)	Rated speed n_N [revi/min]	Mechanical rated power P_N [kW] (3)	Peak torque M_{max}	Current at peal torque I_{max} [A] (1)	Motor current limit I_{limit} [A]
8C1.1.30	1.3	2.1	1.2	2	3000	0.38	4.6	8.1	13.8

Type	Torque constant K_{t0} [Nm/A] (1) (2) (3)	B.e.m.f. between phases at rated speed V [V] (1) (2) (3)	Resistance at terminals R_{UV} [W] (1) (3)	Inductance at terminals L_{UV} [mH] (4)	Moment of inertia of rotor J_m [revi/min]	Weight m [kg]	Curves (5)
8C1.1.30	1.05	190	20.8	47	0.9	3.1	501000

Chapter 6 - Feedback devices

High performance drives often use rotational feedback devices to give:

– speed feedback to the amplifier's speed controller
– position information to internal/external position control
– shaft position to the amplifier
– position information when acting as second encoder
– absolute position after black out

6.1. Resolver

A resolver is a rotational transformer. The most common type is a brushless resolver.

The resolver has a three coil arrangement. The reference signal, for instance an 8 kHz sine wave, is connected to the rotating part of the device via a transformer. This enables the coil carrying reference to rotate at the same speed as the shaft.

Two other coils are placed in 90 degrees phase shift. The rotational coil induces voltage in these coils. Output signals are fed to the amplifier and the speed and the position of the rotor is resolved by using these signals.

Frequently, resolver signals are converted to a pulse train for an external motion controller. In other words there is output that emulates encoder channels A, B and Z pulses. Read also encoder information.
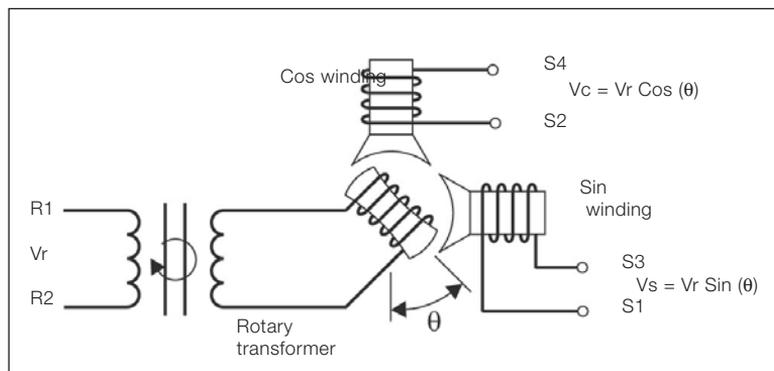

Figure 6.1 The principle of a resolver.

6.2. Incremental encoders

Incremental encoders are widely used in various machine building applications.

The basic operation is based on a light source, a disk and a photo cell (sensor). The disk is installed between the light source and the sensor. The disk has a very fine mesh, enabling light to be visible or obscured to the sensor. The sensor output is digitized to form a square pulse when light is seen. When the disk rotates, the sensor produces a pulse train. The frequency of the pulse train is in relation to the speed of the axis and the receiving end can calculate this.

There are various specifications for encoders, but for motion control, two channels plus a zero channel is the most commonly used. Each channel is typically differential so that the output is A, A inversion, B, B inversion and Z, Z inversion.
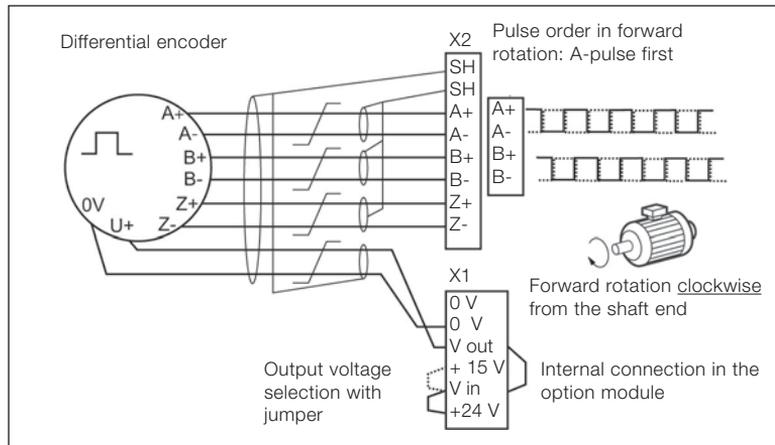

Figure 6.2 Typical circuits and cables

6.3. SinCos encoder

The SinCos encoder operates in a similar way to the incremental encoder. It typically has three channels, A, B and Z. While the output from an incremental encoder is a digitized square wave, the SinCos encoder output is a number representing the full sine and cosine waves. The number of cycles can be, for example, 1024 full cycles, often also called "increments". The receiving circuit of the drive calculates the increments and interpolates between these signals to improve the resolution. The interpolation depends on the sample time of the drive. For example, if the sample time is 250 us, a sample of sinus and cosine is taken every 250 us; the lower the speed, the higher resolution can be achieved (and visa versa). From a mathematical point of view, the angle is arctan $(\sin\alpha/\cos\alpha)$.

Typically, the drive hardware outputs a quadrate signal of sine/cosine signals, so that what is seen is a pulse train input for calculation. The rising and falling edges of both channels can be utilized, giving four signals per cycle. This results in a number of signals that is four times higher than the number cycles specified in the encoder data.
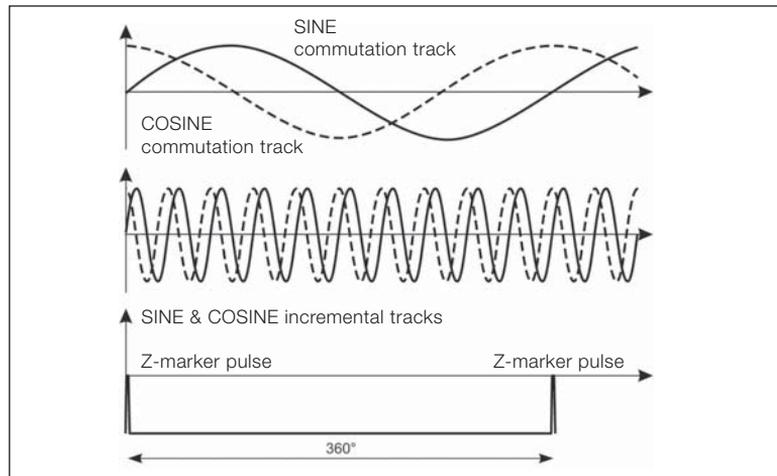

Figure 6.3 Output of SinCos encoder with commutation channel.

The absolute position of the rotor is also needed at startup. This can be established by using a data link (next chapter) or by an additional sine/cosine channel. This channel provides one full sine and cosine cycle per revolution and makes it possible to find the rotor position. The Z-pulse position can be checked by ensuring that the Z pulse is "high" when the sine/cosine channels show zero position.
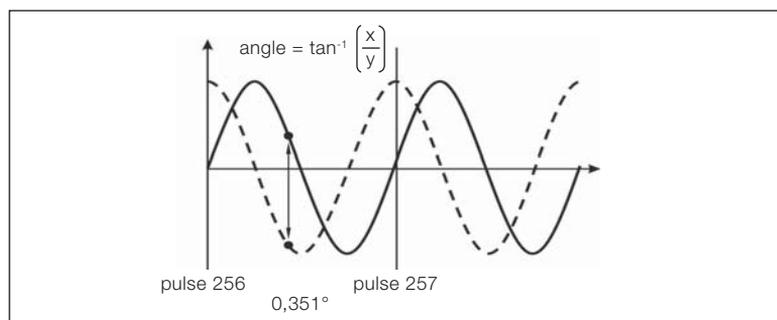

Figure 6.4 Interpolation within one cycle in SinCos encoder (1024 cycles per revolution)

SinCos encoders are also available with data bus. A data bus can give absolute position after power-down, a common requirement in today's applications. This eliminates the need for homing routines after power-down. This makes the machine design simpler and increases the machine's production time. Data of absolute position is also used at startup to identify the rotor position.

Chapter 7 - Motion control

7.1. General

Motion control covers many different functions. This chapter deals with basics of speed and motion and functional differences.

7.2. Motion control – basic blocks

Speed controlled drives change speed mainly in steps and the response is not very fast. Speed reference commands are given in certain levels and the drive frequently has its own ramp to move from one level to another. The drive does not follow a continuously changing reference track.

In motion control, the situation is different. The motor follows a continuously changing reference. The reference is created in a profile generator and this profile is compared to the feedback. P-amplifier compares signals and feeds the reference to the speed controller.
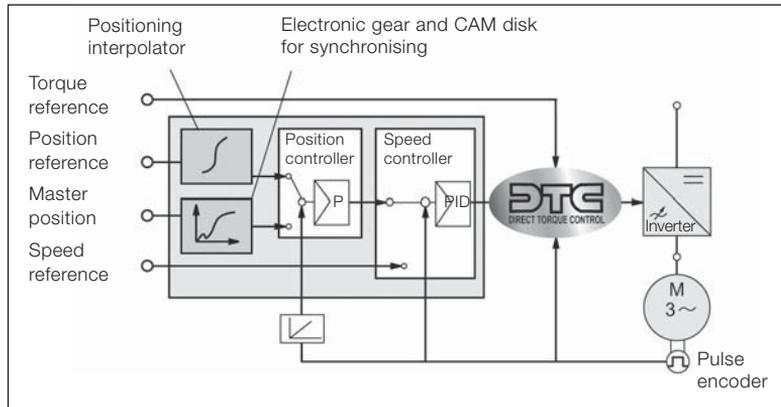

Figure 7.1 Motion control loop.
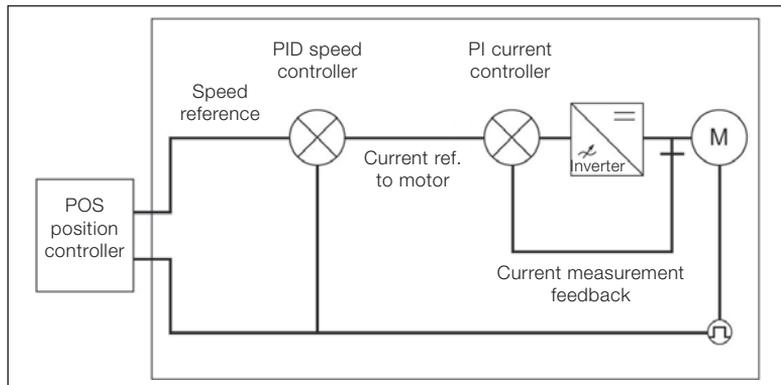
Figure 7.2 Position, speed and current control.

7.3. Motion control formulas and profiles

The following formulas are the key motion parameters.

Distance (θ) = velocity x time
= $\int v \cdot dt$ (integral of velocity x time)

Velocity (v) = distance/time
= $d\theta/dt$ (rate of change of distance)
= $\int \alpha \cdot dt$ (internal of acceleration x time)

Acceleration (α) = velocity/time
= dv/dt (rate of change of velocity)
= $\int \gamma \cdot dt$ (integral of jerk x time)

Jerk (γ) = acceleration/time
= $d\alpha/dt$ (rate of change of acceleration)

7.4. Motion profile

The illustration shows how the position advances against a set target. It also shows the velocity profile and the corresponding acceleration and deceleration rates.
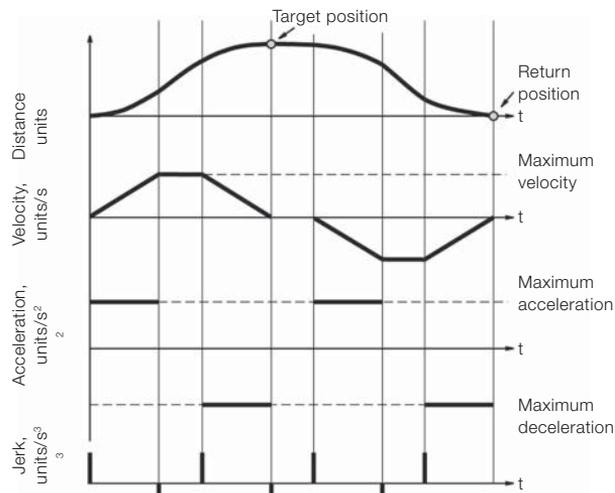

Figure 7.3 Positioning motion profile references.

7.5. Position interpolator

The position interpolator calculates the speed from which the drive can decelerate to a stop within the target distance, using the defined deceleration reference. The calculated speed is used to generate an optimized position reference, which guides the drive to its target position. The illustration refered to shows how the position interpolator generates a position reference.

The typical parameters that are set by the user are
– Acceleration
– Run speed
– Deceleration
– Target position

Chapter 8 - Typical motion functions

8.1. Positioning

Positioning is one of the most frequently used motion functions. It is used when moving material from point A to point B along a pre-defined track, then on to point C and so on.

Positioning can also be divided into linear and roll-over positioning. Roll-over positioning means position calculation within one revolution.

Linear positioning is used for linear movement. There are two main principles in positioning, absolute and relative positioning.

8.2. Absolute positioning
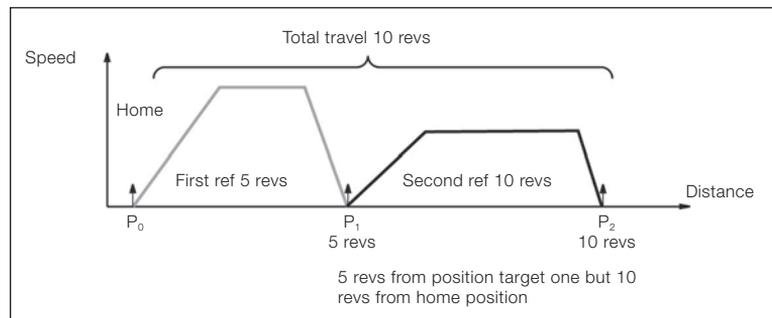
Figure 8.1 Positioning absolute.

## 8.3. Relative positioning
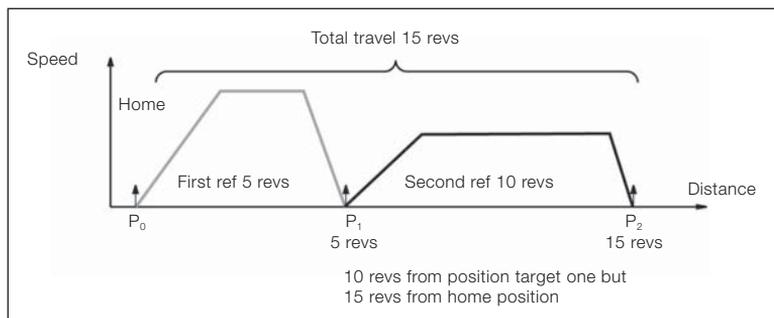
Figure 8.2 Positioning relative.

8.4. Synchronization

Synchronization means that a follower drive reads speed and positional reference from an external encoder or from the other drives. The gear ratio can normally be adjusted to suit the application. Synchronization can be absolute or relative and works for linear/rollover axes.
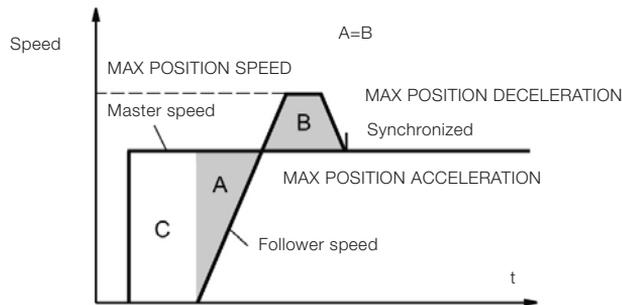
Figure 8.3 Relative synchronization.

Linear axis (Figure 8.3), relative synchronization: The follower drive starts to accelerate and continues to increase the speed to catch up with the speed of the master. When areas A and B are equal, the follower has caught up.
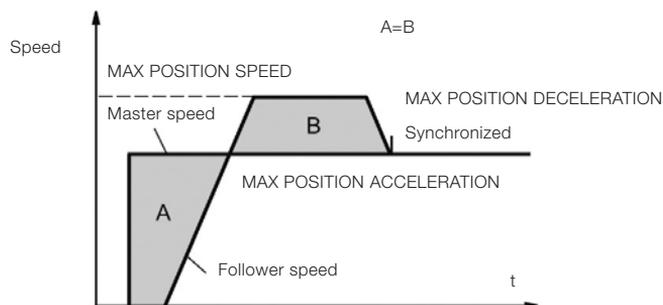
Figure 8.4 Absolute synchronization.

Linear axis, absolute synchronization: In this case, the reference is the total travel distance the master drive has to complete. The follower drive will run at a higher speed for long enough to catch up with the position of the master drive.

## 8.5. Rollover axis

Rollover axis mode is such that only one revolution is calculated and then calculation starts all over again.

Speed

MAX POSITION SPEED

MAX POSITION DECELERATION

Synchronized

MAX POSITION ACCELERATION   Master speed
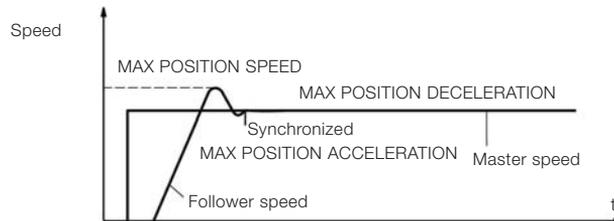
Follower speed   t

Figure 8.5 Rollover synchronization.

The illustration shows how the follower drive catches up with the master drive's position.

8.6. Dynamic limiter

The picture shows a situation where the master speed is so high that a synchronization error is built up between the master and the follower drives. In this example, the error is corrected when a stop command is given. A dynamic limiter controls the speed of the follower until the positioning speed is reached and the follower runs to the position it should have according to parameter settings.

Speed   A=B

Master speed   STOP

A   Follower speed

MAX POSITION SPEED   POSITION SPEED

Master speed   B   t

POSITION DECELERATION
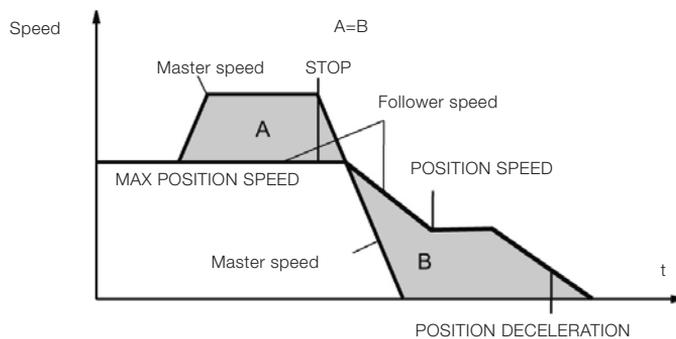
Figure 8.6 Dynamic limiter controls follower's speed.

8.7. CAM disk

Cam functions used to be achieved by mechanical means in the past. Traditionally, this method incorporates a rotational, non-symmetrical tool that forms a reference to another tool.

This type of system is not very flexible and contains mechanical parts that loose accuracy with wear.

In most cases these mechanical systems can be replaced by electrical CAM systems. The CAM profile is created in a CAM table where the user enters the values. Each master position has corresponding slave position.

The cam function is very useful in for example flying shears.

CAM disk table	
Master position	Follower position
0	0
20	20
40	20
60	40
80	40
100	60
120	90
140	120
160	150
180	180
200	150
220	120
240	90
260	60
280	40
300	40
320	20
340	20
360	0
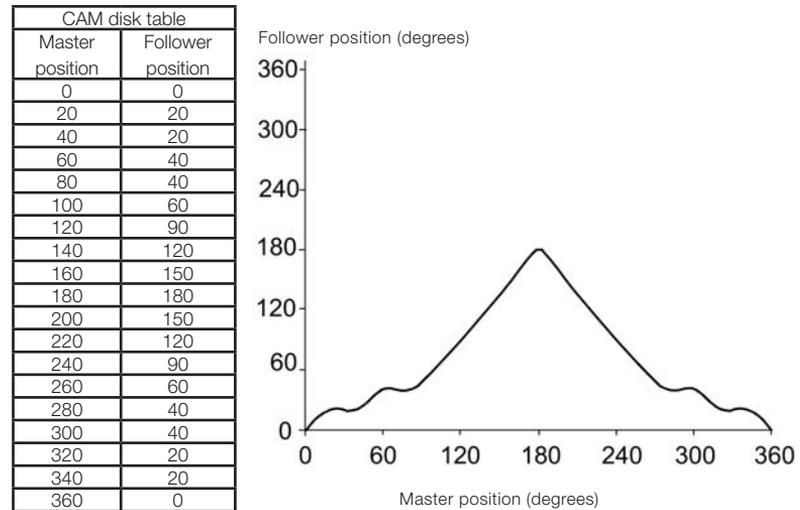
Figure 8.7 CAM disk table values vs CAM profile.

8.8. Homing

Homing is required at startup and if position is lost due to power loss of system. If absolute encoder is used the real position is known as soon as power comes back. One way around is to use auxiliary power supply (typically 24 V).

What ever the system is home position has to be determined at startup. Following discuss applications without absolute encoder and explains some typical homing routines.

If there is only homing limit switch, software checks the status of switch. If switch is on the load must move towards positive speed until switch turns off and then load is at home position.
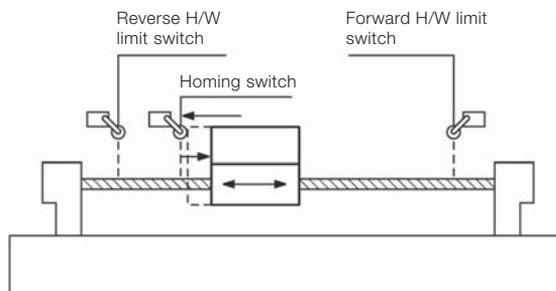
Figure 8.8 Homing started with homing switch on.

Vice versa if switch is off load must drive to negative direction until switch turns on and then back up slightly until switch turns off again.
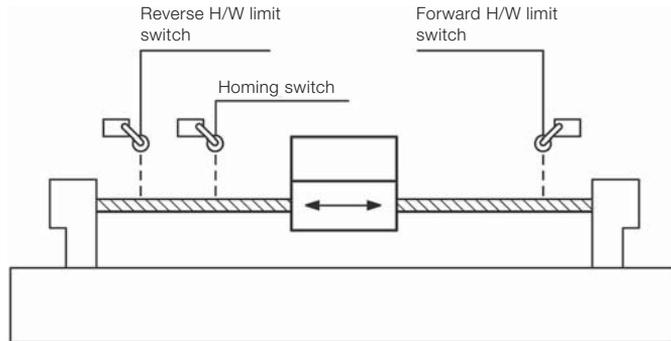

Figure 8.9 Homing started with homing switch off.

The better result or say accuracy can be achieved by using zero pulse and pre latch function. This works in the following way:

– At commissioning the absolute position of zero pulse is know or can be setup
– The distance between proximity switch and zero pulse must be within one revolution
– As soon as proximity switch becomes active software starts to seek zero pulse and stops at zero pulse or to determined distance from it. The idea is that mechnical switch might be inaccurate, due to mechanical stress for example and thus gives rough positional information. Zero pulse is then very accurate and free of drift.
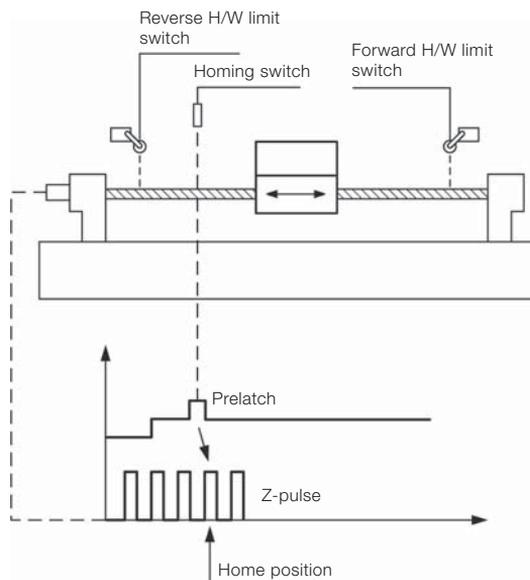

Figure 8.10 Homing with prelatch and zero pulse.

8.9. Cyclic corrections

Cyclic corrections are used in many applications where, due drift or material misplacement, the position needs to be corrected. This is valid for both roll over and linear movement.

Cyclic corrections always need latch information of position. This could come from an external sensor or Z-pulse of the encoder.

A few examples are the best way to show functionality.
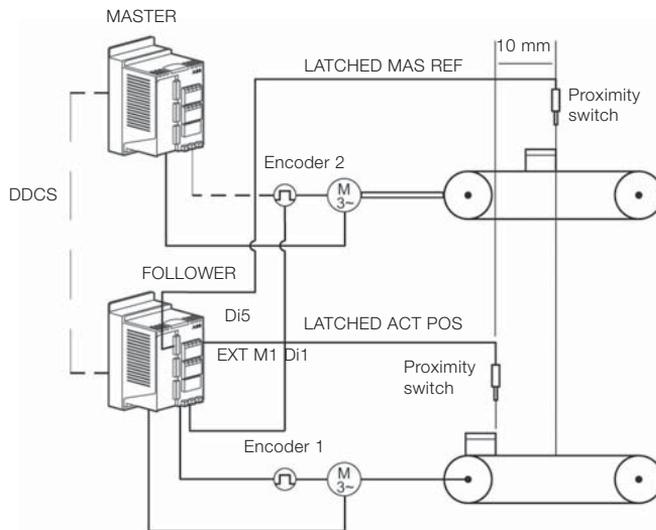
Figure 8.11 Master/follower conveyor lines

In Figure 8.11, a master/follower setup is described. The purpose is to make sure that cans on two conveyors have the correct distance between each other, 10 mm in this example.

The follower needs to know the speed of master. There are two ways to set this up:

1. Read the master´s speed from the encoder. This means that the follower has connections for two encoders. The master is running in open loop mode.
2. The other solution is to use communication between drives like fibre optical DDCS link. The master has a feedback connection (encoder) and this information is fed via optical link to the follower.

What ever the communication method, proximity switches are connected to the follower's (programmable) digital I/O. The follower compares the distance difference seen by the sensors and corrects the distance, in this example to be 10 mm.

8.10. Encoder gear functions

Motion control applications always need feedback. This can be connected to the motor, the load or both.
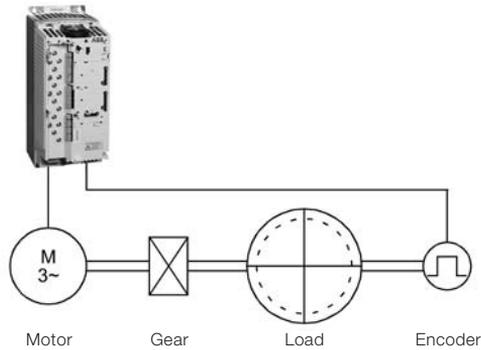

**Figure 8.12 Motor encoder gear ratio to be used.**
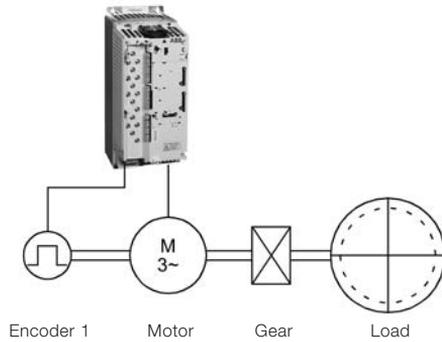
Figure 8.13 Load encoder gear ratio to be used.

If there is no encoder on the load side, load gear ratio has to be setup according to gear ratio, as the drive must control the actual position of the load, using feedback from the motor.
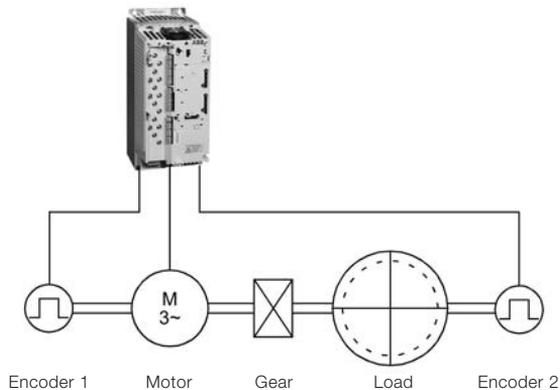
Figure 8.14 Both motor and load have an own encoder.

8.11. Virtual master/axis

Virtual master means that the reference values are applied to a model of a rotational axis that runs in the software. The virtual axis gives its speed reference to all its followers. The virtual axis gives full noise-free speed and positional signal in applications where two or more drives are synchronized.

Virtual axis is also very useful during system commissioning, as parts of machines can be tested without running the whole process.

Chapter 9 - Application examples, distributed control

This chapter briefly describes some typical motion control applications. Most of illustrations include a PLC the role of the PLC is to handle overriding control information. The control actions are executed in the distributed controlled drives.

9.1. Cyclic correction for material handling.

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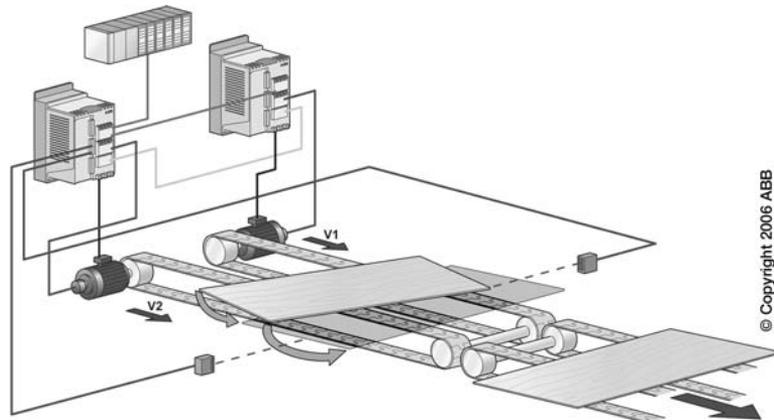
The purpose of this machine is to correct any angular error of the material. Two drives are used in a master/follower setup. The master determines the main line speed. The follower receives a speed reference. Two sensors are connected to digital inputs. The follower calculates the error distance in number of pulses between two sensor signals. This error is corrected by increasing or decreasing the speed of the follower.

Depending on the application, different types of motors can be selected. Feedback will always be required.

9.2. Constant gap maintaining

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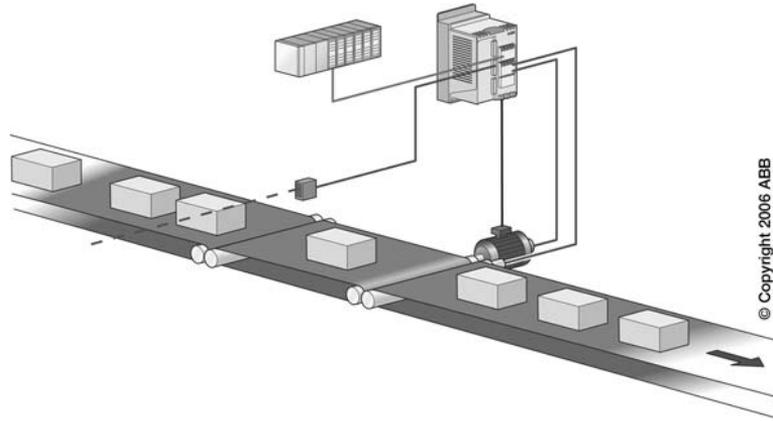
This conveyor has a feed belt, an adjusting belt and a receiving belt. The boxes arrive with random spacing. The drive receives the line speed reference from the encoder. The sensor follows the rises and falls of the top line of the boxes. When the sensor detects a box, it follows the top edge of the box until length of the box is run. The dropping edge is seen by the sensor and the distance to the next rising edge is the actual gap between boxes. This is compared to the required gap and the software makes the necessary correction by altering the speed of the adjusting belt.

9.3. Cut to length
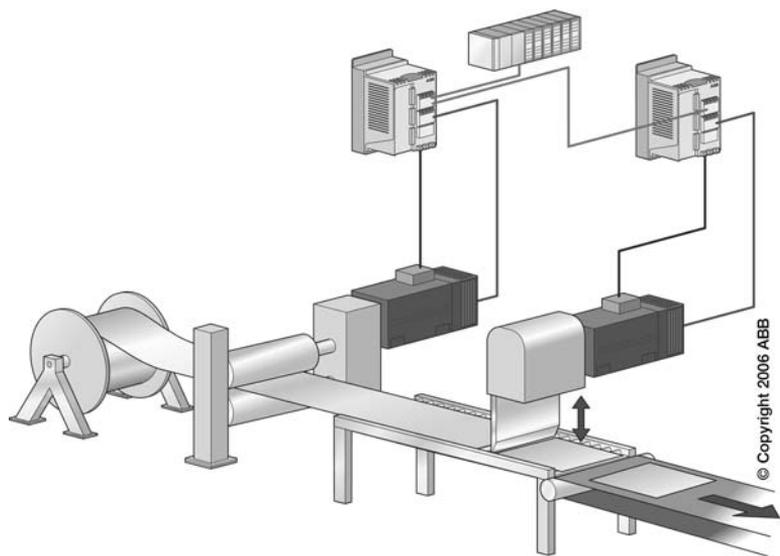
There are many methods to cut different materials to the required length. Here, we cover the most common methods. These are examples only; there are many other configurations.

In applications where the line is stopped to make the cut, both axes use the positioning feature of drive. The drive that is fed the material first runs a determined number of revolutions corresponding to the required material length. When the target position has been reached, the drive signals to the PLC that it is in the required position. The cutting motor runs the required number of revolutions to execute the guillotine operation. Its drive the gives the feed motor permission to run. As in other applications, the dynamic performance requirements of the system have to guide the motor selection.

9.4. Rotary knife

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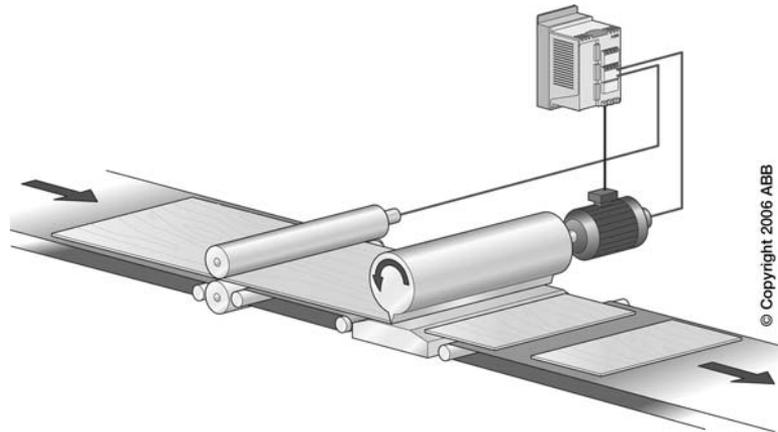
A rotary knife is used to cut material into required length or cut off unwanted material. The simplest rotary knives are synchronized to the line speed using an electrical gear. However, in many applications, this will not give satisfactory performance.

There are a number of considerations to take into account for rotary knife operations. Firstly, if the cutting length varies, it must be decided whether the tool should be at standstill or rotate continuously. Secondly, when the tool hits the material, it will in most cases need to have the same speed as the line. Thirdly, it is important to determine where to place the cut.

For more sophisticated applications, the knife must form a motion profile during the cycle. When the knife is at standstill and a cut command is given, it has to accelerate to reach the position and then decelerate to cutting speed. After cutting, the tool should return to the home position as fast as possible to be ready for the next cut.

In some cases, the tool may not be able to stop but has to start another cut "on the fly". This means using two profiles that are added together. Cam profiles with flexible parameter setting are normally used in these situations.

9.5. Cyclic correction, packing application

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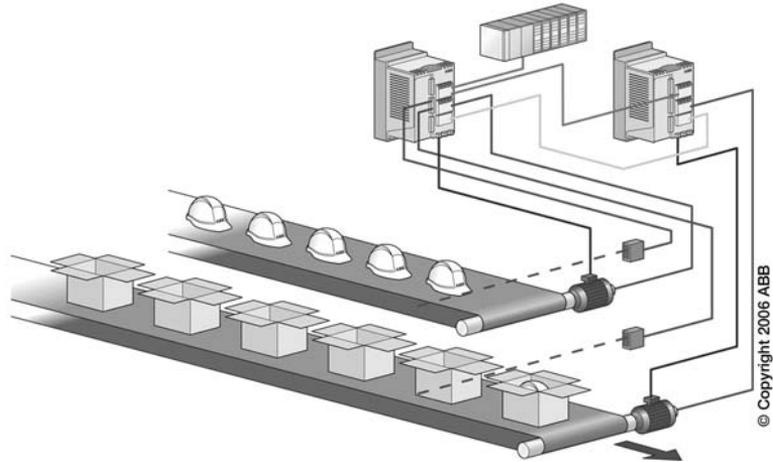
From a software perspective, this is same operation as example 13.1, "Cyclic correction for material handling". The difference is the physical setup. In both examples, there is master-follower setup and sensors for actual position checking and software correction. The system has two feeding conveyors. The items on them must be arranged to the correct distance between each other.

9.6. Flying shear, angled

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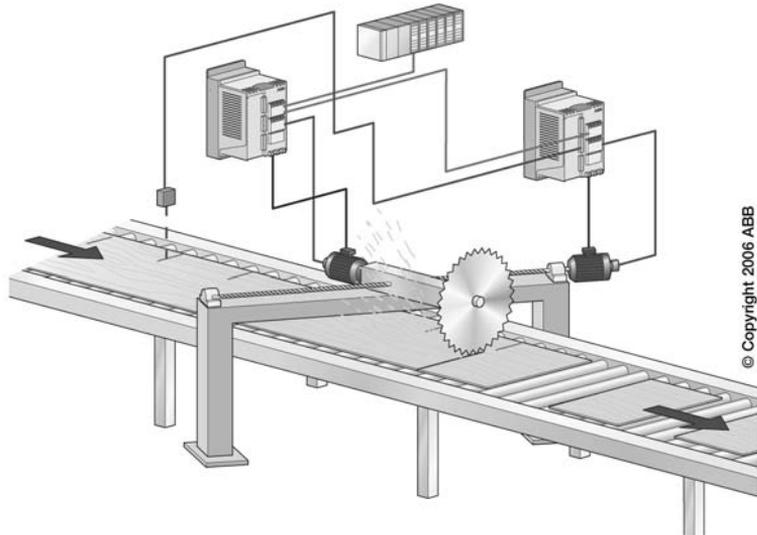
A flying shear is a cutting machine that allows constant material flow during cutting. It is base on right-angle trigonometry. When the speed of the line and the speed of the saw are known, the angle of the cut can be calculated and adjusted accordingly. In this illustration, the angle means that blade moves in the direction of the line when the saw operates. Saw speed control is not critical; even an uncontrolled motor can be used; however the most practical solution would be to use a general machinery drive.

The cutting point can be indicated by a mark on the material or through rotational measurement by encoder. Typically, synchronizing or CAM functions are used.

This setup is often used in applications where the material must be cut by a saw rather than a knife/guillotine.

9.7. Flying shear, parallel

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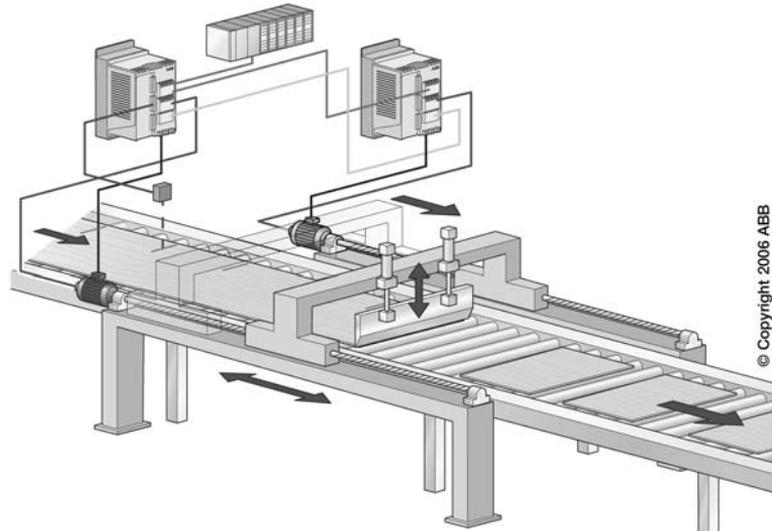
This is another version of the flying cut. As described earlier, the cut point is read from a mark or an encoder. The carriage waits for a "cut" command. When the command is given, the carriage accelerates to line speed whilst synchronizing itself to the cutting point. Typically, synchronizing or CAM functions are used and a guillotine performs the cutting. The illustration shows a system with two motors. Both drives run at synchronous speed using the master/follower function. There are also systems using only one motor.

9.8. Lathe
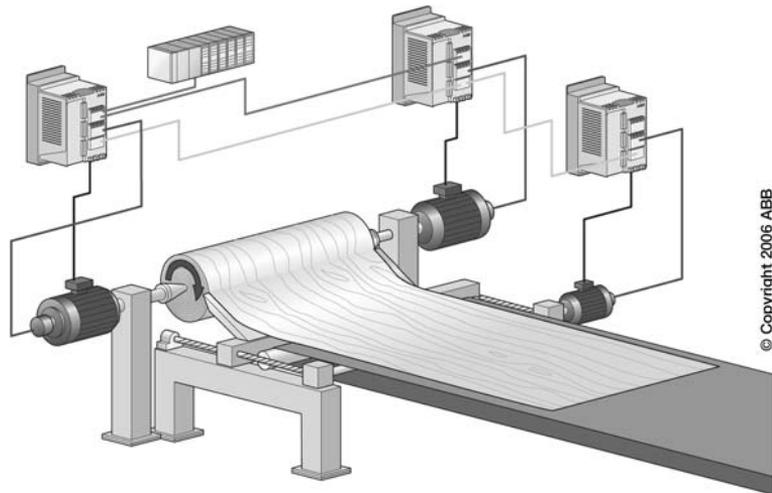
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Although this illustration is very simplified, it shows the three main motion functions of a lathe.

The line speed must be constant. This means the speed of the spindle motors must be controlled and adjusted in relation the changing diameter of the material. This can be controlled by a PLC or distributed to a drive with winding software.

The two main motors run as master at master follower setup. This is particularly critical in plywood manufacturing, where the spindle heads are connected to the material on a screw thread. If the motors run at different speeds, one of two screw heads will begin to open until eventually, the log flies off.

The carriage with the blade is running in synchronous mode. The gearing ratio is setup in relation to the material thickness. It is very easy to setup the required thickness just by adjusting the gear ratio parameters; these are typically converted so that user can specify units in millimeters from the HMI.

9.9. Material filling

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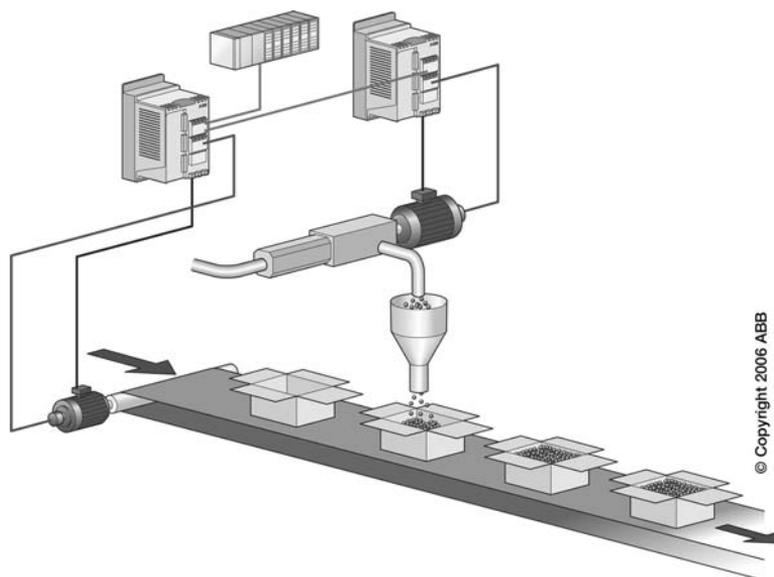
This application is very similar to the one described in chapter 13.3, "Cut to length", although in this case, the follower drive runs dosing unit.

This is only one of many possible configurations; there are several other ways of filling packets and bottles.

9.10. Slitter

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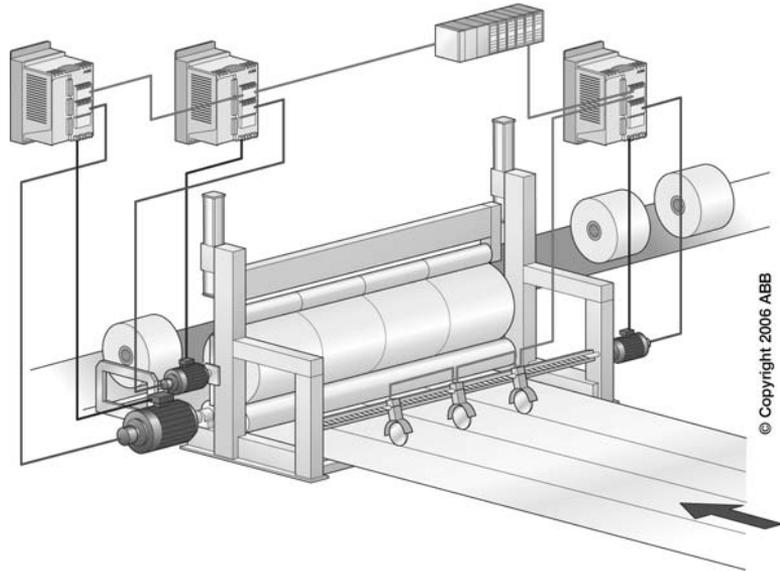
This illustration describes the cutting and winding part of a slitter, showing the operation of the cutting tools. Each tool is individually connected to the screw. When a tool is engaged, the PLC sends the address to the drive. The distributed control system ensures correct positioning.

9.11. Picking and stacking

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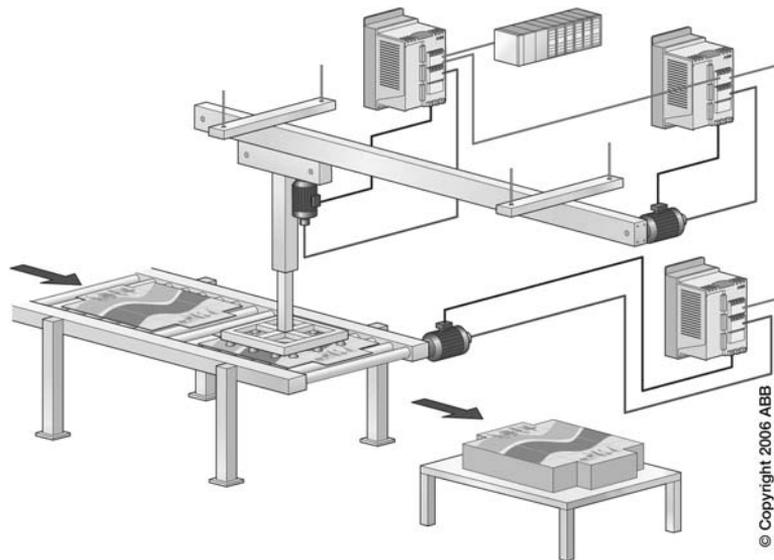
This application uses distributed control in three shafts. The overriding controller gives commands to each shaft to make the material flow of the plates fluent. The plates are picked up with the picking tool using position control. The plate, still in position control, is moved forward to the stacking place. Finally the plate is positioned down to build up the stack. The plates feeding conveyor can run in continuous speed or position control mode.

9.12. Warehouse automation

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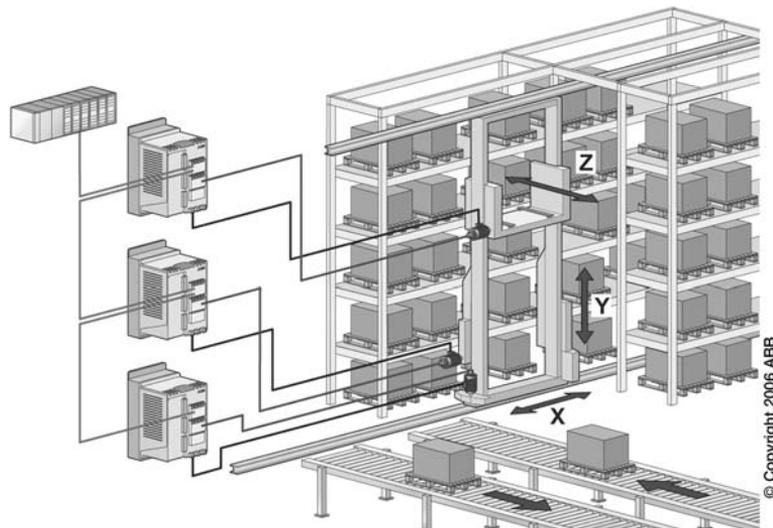
Warehouse automation applications can be configured very cost-effectively using distributed control. The overriding control system is part of the full factory automation system and knows where the pallets need to go.

In most cases, high speed and torque performance is needed at and from zero speed. This means that closed loop control is required.

System dynamic requirements differ between applications and motor selection ranges from standard AC motors with feedback to AC brushless induction or permanent magnet servo motors.

This type of systems can have large physical dimensions and motor feedback will not be sufficiently accurate for position control in all cases. This is overcome by using a second encoder that monitors the actual position.

9.13. Winding

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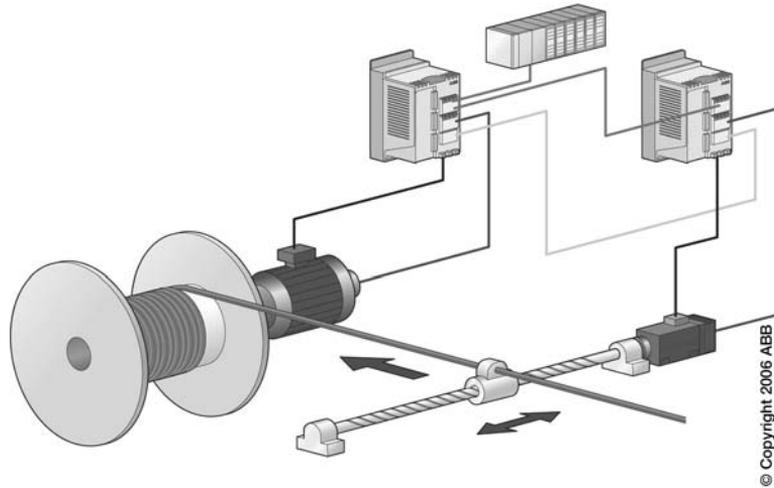
The application picture here is much simplified. The purpose is to show the main principle of traverse control. Traverse control is an electronic gear function where the gear ratio is setup so that traverse linear movement is locked to the build-up of material. The illustration does not show the limit switches that typically control the turning point action.

Winding and unwinding are well-established applications and there are many dedicated software packages commercially available.

9.14. Wrapping

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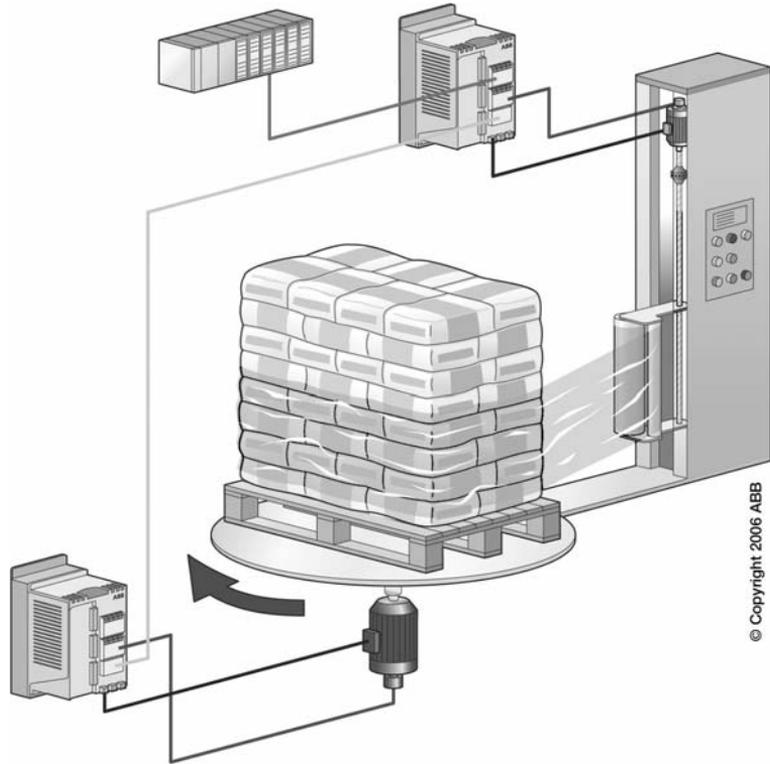
The illustration shows a simple packaging application. The electrical gear is formed between two motors.

Chapter 10 - Motion control – *Glossary of terms

Acceleration

The rate of increase of velocity, usually expressed as meters per second per second, or meters per second^2 (m/s^2).

Accuracy

The measured value compared to the desired value. In motion control, this will most often refer to a position description, defined in terms a plus or minus deviation from the commanded value, or in terms of a range of values around the set point.

Active front end

A front end processor which receives data from both upstream and downstream equipment and makes changes without reference to external controls.

Actual position

The position of an axis compared to the desired position. This can be either the final position at the end of the move or the lag between the commanded position and the measured position at any point during the move. The latter is commonly known as following error.

AC servo

A motor drive that generates sinusoidal shaped motor currents.

Alarm

A warning that a parameter has moved out of acceptable or defined limits or an indication that a component has failed or is malfunctioning. It can either warn or advise an operator or be in the form of an output signal that can initiate corrective action or switch a process off.

Analog servo

Most commonly found in hydraulic and similar systems, an analog servo uses analog control and feedback systems such as voltage variation and changes in pressure.

Analog signal

A signal that varies in step with the parameter being measured. Typical examples include a 0-10 volt motor control signal and a pneumatic control pressure.

Axes of motion

The major directions along which controlled movement of a machine part or component occurs. These axes are usually defined as follows:
X: Linear motion in positioning direction
Y: Linear motion perpendicular to positioning direction
Z: Vertical linear motion
A: Angular motion around X (roll)
B: Angular motion around Y (pitch)
C: Angular motion around Z (yaw)

Axis

The main directions along which a tool, component or workpiece will move.

Brushless servo

A servo drive which uses electronic commutation of the current rather than achieving it through mechanical brushes and a commutator.

Bus

A series of conductors acting as path to send information between control elements and components.

Centralized control

A system with the software located in one physical unit. All input information from sensors and feedback devices are connected to this unit and control commands are sent from it.

Circular interpolation

A process of moving a component in a circle by moving along two axes in a series of straight lines generated by software.

Close motion loop

The reference signal is compared to the feedback signal and the discrepancy is corrected in an amplifier circuit.

Collision detection

Describes the process of using sensors to detect a possible collision between parts or components. The sensors can produce alarms to stop the movement or slow it to produce a low speed mating of the components.

Commutation

Ensuring that the correct motors phase receive the correct currents or voltages. It can be done electromechanically via the brushes and commutator as in brush type motors, or electronically as used in brushless motors.

Converter

Changing AC to DC or DC to AC, most often with a diode rectifier or thyristor rectifier circuit. The term "converter" may also refer to the process in an adjustable frequency drive. This consists of a rectifier, a DC intermediate circuit, an inverter and a control unit.

Co-ordination

Integration two or more axes of motion to produce an otherwise impossible motion. Sensors and other internal or external commands may also be used to assist the movements.

Current controller

An electronic function which gives the proper instant current needed by the load. The current is controllable to limit the maximum current and reduce the danger of overloads damaging the motor.

Cut to length

An algorithm that feeds material a set distance so that a process can be performed on a correctly sized length. Feedback systems are usually used to ensure that the selected length is repeated accurately.

DC bus

A common communications circuit that uses a DC voltage as reference. The term may also refer to a power distribution system shared by several components.

Deceleration

The rate of decrease of velocity. Usually measured in units of velocity change for each unit of time, ie, meters/sec/sec or, meters/sec^2.

Decentralized control

A control method made up of separated control elements distributed over an area or process. The individual elements are essentially independent of each other, although they will have some means of communicating.

Deterministic scan time

The frequency at which a Programmable Logic Controller (PLC) executes a Program. Normally measured in milliseconds this will include the time required to read a specific set of instructions and return to the initial instruction.

Device level network

A common network cable that eliminates individual links between the PLC and each device.

Diagnostic code

A code displayed on an operator interface or in a program, used to indicate a fault condition as well as usually its position.

Digital motion control

A motion control system that uses binary code for calculating.

Digital servo

A servo motor that uses binary code for all calculations and feed back.

Digital signal

A signal in the form of binary pulses if information, based on voltage levels that represent the values 0 and 1.

Drive

An electronic device that controls the electric current supplied to a motor.

Efficiency

The efficiency of a motor compares the mechanical output to the electrical input and is a measure of how well the motor turns the electrical energy it receives into a useful mechanical output.

Electronic cam profiles

A technique that replaces mechanical cams with electronics to perform non-linear motion.

Electronic clutch

A method of using electronic cams or gearing functions to produce a slave profile based on a master position.

Electronic gearing

Simulating mechanical gears by electrically synchronizing one closed loop axis to a second.

Electronic line shaft

A virtual axis which synchronizes other axes either through using electronic gearing or camming profiles.

Encoder

A feedback device that translates mechanical motion into electrical signals that indicate position. Incremental and absolute encoders are used to indicate incremental or absolute changes of position respectively.

Encoder resolution

The number of electrically identified positions in a 360 degree rotation of a shaft.

EnDat

A standard interface for serial data transfer, particularly for position and parameters.

EMC/CE

European Directive that sets standards and limits for conducted and radiated emissions. Drives may need line filters or other components to conform to the directive.

Emergency stop

An emergency stop function must meet all of the following requirements:
– It must override all other functions and operations under all conditions
– Power to machine actuators that can cause hazard must be interrupted as quickly as possible without creating other hazard
– Reset must not initiate a restart
– The emergency stop shall be either a Category 0 or a Category 1 stop. The choice of emergency stop must be decided in accordance with the requirements of the application

Ethernet

A very widely used open networking standard. Normally used for office automation and operating at a communications speed of 1.5 megabits/sec, newer versions are capable of up 100 megabits/sec.

Event

When an input parameter changes state, such as at the triggering of a limit switch or proximity sensor.

Fault

A condition a drive or control is in having attempted an illegal process and becoming disabled.

Feedback

When a controlled machine sends a signal to inform that it has responded to a control signal.

Feedback device

Give information of the actuators' real speed and position to the motion controller.

Feed forward

A method that compensates for known errors in a control loop. It depends only on the command, not the measured error.

Fiber optic

A glass or plastic fiber guide that transmits light that is translated into current or used to determine the open/close state of a current path.

FieldBus

A local area network, as defined by ISA standard S50.02 and which is used to connect control elements and sensors to each other.

Flying restart

When a motor is restarted while spinning, normally done by sampling the motor speed, encoder input, or back EMF.

Flying virtual master

The ability of a motion controller to switch from one virtual encoder to another instantaneously. This feature makes it possible to use advanced synchronizing features.

Following error

The difference between the commanded position of an axis and its actual position, a difference that varies with the speed of the axis.

Frameless motor

A motor consisting of only the stator and rotor. This allows a manufacturer to incorporate it into a machine directly, cutting the need for any shafts or other mechanical transmissions.

Gantry

An overhead framework that can move in the X, Y, and/or Z axes, carrying a variety of tools or devices to perform tasks.

G code

Software used for programming machining processes, such as 3-axis milling and 2-axis wire cutting.

Hard, real-time control

The ability of a controller to respond to an event immediately. PLCs are designed for this, though PCs pose more of a problem.

Hardware limit switch

A switch that alters the electric circuit associated with the machine or equipment and which is operated by some part or motion of a power-driven machine or equipment.

Holding brake

A friction device which sets a brake when power is removed.

Home position

A position which acts as a reference for all absolute positioning movements. It is normally set at power-up and remains valid as long as the control system is operational.

Homing

The act of calibrating axes by finding a unique reference position, usually at power up.

Human-machine interface (HMI)

A console which displays data and receives commands, allowing the operator to control the drive.

IGBT insulated-gate bipolar transistor

The IGBT is usually used in switching power supplies and in motor control applications and forms the basis of the most modern and capable variable speed drives.

Inching

Advancing a motor in small steps through repeated closure of a switch.

Indexer

An electronic device that allows a PLC to control the movements of a stepping motor.

Indexing

An axis or axes moving to a pre-programmed position.

Inertia

A property of matter in which a body continues in a state of rest or uniform motion unless acted on by an external force.

In position window

A range of acceptable positions around the commanded position point.

Interpolation

When two or more axes move in a co-ordinated way to produce a linear or circular motion.

Inverter

A device that converts DC power to AC power. Typically used as a part of the frequency converter.

Jerk limitation

A feature that limits the rate of change of acceleration with the aim of eliminating mechanical jerking during speed changes.

Jitter free synchronization

The process of matching the acceleration and deceleration of a driven slave drive to the master drive to provide a smooth transition.

Jog

An axis moving at a fixed velocity and acceleration/deceleration rate, in a chosen direction, but with no specific destination.

KP

Velocity Loop Proportional Gain. Determines how much velocity error the servo system will allow during a move. See also: Tuning

KV

Position Loop Gain. Determines how much positioning error, or following error, will be allowed by the servo system during a move. See also: Tuning

Length units

The linear units for programming and configuring an axis, often defined in inches, feet, meters, or millimeters.

Linear

Where the output varies in direct proportion to the input.

Loop update times

The time required to calculate the process variable from the following error.

Motion control

Any tool or actuator controlled by motion software. The system can be hydraulic, pneumatic, electronic or any combination of these. Whatever the system, the profile for movement is written into the software code and the actuator has to follow this as accurately as possible. The actual movement and the reference are always compared by feedback devices and the motion controller aims to minimize the discrepancy.

Modulo Value

The position increment at which a rotary axis position returns to 0, ie, 360 degrees.

Noise

An unwanted electrical signal, usually the result of radio frequency or electromagnet ie, interference from devices such as AC power lines, motors, generators, transformers and radio transmitters.

Offset

Distance between the actual zero reference point and a programmed zero reference point.

Open architecture

Hardware and/or software with standard features that numerous vendors can incorporate into their own products, which can then connect to each other and work together easily.

Open loop/close loop

Open loop control is where a control system has no external references with which to govern its speed or position. A closed loop control system is one which uses signals fed back from external sensors in order to correct the position or velocity and make it conform to the commanded value.

Overcurrent

A current above the rated current of the drive, applied to maintain a set position or move to a new position.

Override

The act of forcing an axis to move during a fault condition. It is often used to force an axis to move away from an overtravel limit switch.

Overshoot

Where the output of a system goes beyond the desired value.

Over temperature

A warning or alarm that indicates that a motor or drive is too hot, most often the result of too high current demand.

PC

Personal Computer

Phasing

Adjusting the position of one axis with respect to others, to correct for small registration problems, usually done while the axes are moving.

PLC

Programmable Logic Controller. A computer that uses fast, repeatable deterministic scan times to control equipment.

PLS

Programmable Limit Switch. A device that converts the rotary motion of a shaft into digital signals. It is typically used to improve positioning accuracy.

Point-to-point wiring

Wiring each drive directly to the PLC. The method cuts out the communication delays introduced by a network.

Position error

Error caused when the difference between the actual position and the command position is greater than a set amount.

Positioning

When a move is specified by target position, velocity and acceleration. The target position can be an absolute position, or one relative to the current position.

Position loop

Signals that generate position information based on position feedback.

Printmark synchronization

A method of controlling speed by comparing the position of a mark on a product with its expected position and then compensating for the difference.

Profile

A graphical representation of movement, with axes of position vs. time, velocity vs. time or torque vs. time.

Programmable Limit Switch

See PLS

Programming language

A stylized communication method for controlling the behavior of a machine.

Protocol

A specified method of encoding information for transmission.

Pulse width frequency

The switching rate of an IGBT.

Pulse-width modulation

A switch-mode control method based on varying on/off times of the voltage pulses applied to the transistors.

Quadrature

A technique used to detect direction of motion based on separating signal channels by 90' (electrical).

Ramp function generator

Device or mathematical model that produces a square, triangular or sinusoidal wave output.

Rated speed

The maximum speed at which a motor can rotate.

Real master

Feedback that provides position information for a synchronized axis.

Rectifier

A device that converts AC power into DC for use by converter drives.

Referencing

The setting of a feedback device relative to the real world.

Regen

A motor /drive system can produce regenerative power during deceleration, power that can be fed to other machines on the network.

Resolver

A type of position transducer that uses magnetic coupling to measure absolute shaft position.

Rollfeed

A function that keeps the linear speed of the feed material constant as the diameter of the rotary axis changes.

Rotary

Moving in a circular way, with measurement of position based on degrees.

Safe off

A method of ensuring that power will not travel from the drive to the motor.

SCADA-Supervisory Control & Data Acquisition.

A system of software and hardware that controls a production process and collects data on its efficiency.

S curve

A way of accelerating and decelerating a motor slowly to reduce mechanical shock. Although more sophisticated than linear acceleration, it does not have the performance of camming.

Sequence of operation

A series of steps that causes a machine to perform an action.

SERCOS

Serial Real-time Communications Standard. An open communications protocol for motion-control networks, with transmission speeds over a fiber-optic cable of up to 4 megabits/sec.

Serial communications

The transmission of digital 1s and 0s in a series over a single cable.

Servo mechanism

An automatic, closed-loop motion control system that uses feedback to control a desired output, for example position, velocity, or acceleration.

Servo motor

A motor that can be precisely controlled. The drive that powers it gets accurate feedback on the motor's position from a resolver or encoder.

Shielded cable

A cable that has a metallic sleeve encasing the conductors at its centre The metal sleeve is grounded to prevent electrical noise affecting the signals on the cable.

SinCos

An encoder used in servo control. It outputs both digital and high resolution analog signals.

Software limit switch

A switch based on software rather than a physical object. It is used to turn physical outputs on and off, depending on the level of a particular input, from devices such as servo motors, resolvers or encoders.

SSI

Acronym for Serial Synchronous Interface. A type of multi-turn absolute encoder that sends position information as a serial string in Gray code format.

Synchronization
When several functions of a machine follow a common control signal.

Tachometer
An electromagnetic feedback transducer that provides an analog voltage signal proportional to the rotational speed of a motor.

Task
A software system control that determines the execution rates and priority levels for software modules running in a drive or PLC.

TCP/IP
Transmission Control Protocol/Internet Protocol. A method of encoding data into a series of "packets" for transmission over a network, initially designed for the Internet but now often used in production control.

Teach position
The position of an axis that is "taught" into the motion control program. Once the axis is moved to the desired position, the "teach position" is entered into the motion program automatically by the control.

Telegram
A data packet used to communicate between controller and device.

TeleService
A feature that allows a controller or PLC to be serviced.

TN
Velocity Loop Integral Action Time. Associated with KP. When the measured velocity moves beyond the tolerance value set in KP, TN determines how quickly the drive will bring the velocity back within the specified tolerance. See also: Tuning

Torque limitation
A servo function that allows the current supplied to a servo motor to be monitored and limited.

Tuning
Adjusting the servo drive's internal characteristics to give it the ability to control the reflected inertia and give the axis a smooth position/velocity profile.

Twisted pair

Two wires twisted together with the aim of eliminating electrical noise.

VxWorks™

VxWorks™ is a real-time operating systems that guarantees an absolutely deterministic response. Its benefits include real-time behavior, stability, operating time and an efficient memory efficiency.

Velocity

The speed at which a motor or mechanical system runs.

Velocity loop

A servo control function that adds a velocity command signal to a speed feedback signal. The resultant signal is output as a torque command signal.

Virtual master

An encoder signal created in software of a motion control to allow several servo systems to be synchronized.

Warning

An error condition received from a drive or a controller, indicating that a fault will occur if the problem is not rectified.

Wintel

Microsoft's Windows™ operating system running on Intel's microprocessors, an industry standard for PCs.

Zero point of feedback

The point at which the encoder position and the physical position of a servo motor line up.

* Glossary of terms resource list:
OMAC Motion for Packaging Working Group, Education Subcommittee, Glossary of Motion Control Terms, August 2001.

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