VLT 2800 Series - Precise Stop

Introduction

This note will give you the information you need to use the functions of precise stop, speed compensated stop and counter stop with VLT 2800 frequency converters. This document is to be used as a suggestion only. Users must ensure that installations meet national standards and are suitable for the existing conditions.

The functions described are highly advantageous in applications requiring high precision, for example in food and beverage industries.

Examples of advantages:

- High repetition accuracy
- Speed independence
- Cost optimised solution
- Increased flexibility
- Less waste
- Uniform quality

Typical applications and instructions how to use the functions are described in the following.

This note is intended for personnel familiar with the VLT 2800 hardware and programming procedures necessary to operate the VLT 2800. Your local Danfoss Company shall of course be pleased to give you any further explanation you may need.

Precise Stop

Why precise stop?

Packing or filling of containers are often done at high speed with many start and stop sequences. It is thus very important that you can rely upon that the conveyor belt stops exactly where it should to ensure that the container always has the right position when assembling, filling etc. If that is not the case, much waste and downtime of your plant could be the costly result. If you use a standard frequency converter the accuracy is determined by the internal task time. That is not the case when you use the precise stop function of the VLT 2800; it eliminates the task time dependence and increases the accuracy substantially. The precise stop function is an open loop control.

The frequency converter, however, is not the only component that limits the system capacity. For the best possible solution it is important to take a look at the whole system, both the mechanical part and the electrical part.

■ Typical application

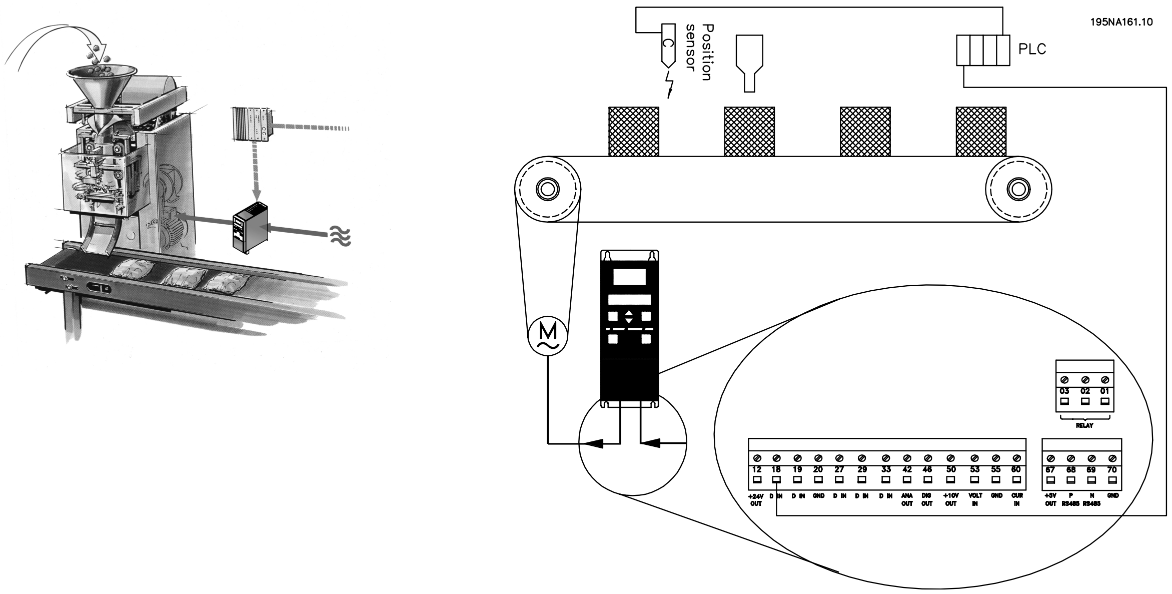

Figure 1 Typical use of precise stop function

In Figure 1 a conveyor belt takes a number of boxes to a filling station. The conveyor belt is driven by an asynchronous motor controlled by a VLT 2800. The PLC gets a signal from a proximity sensor when the next box is on its way. Then the PLC gives a stop command to the frequency converter, and the next box is brought forward. In this situation you are not dependent on a constant distance between the boxes, there will always be a box under the filler. Precise placing of the box, however, depends on the system.

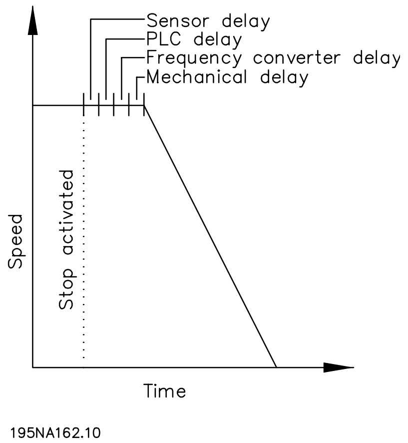

Figure 2 Typical delays at precise stop

All components from the proximity sensor over the PLC to the frequency converter cause delays. A proximity sensor typically gives a delay between 0.5 and 10 ms depending on sensor principle and type. The PLC delay is typically between 1 and 10 ms depending on program size and structure. If the delays are constant you can move the proximity sensor until you have achieved an acceptable result. However, it is important to consider any delay tolerance value that should be kept as low as possible.

Example 1:
A conveyor belt runs at 1.0 m/s. The total delay of the system has been measured to be 20 ms with a tolerance of 10%. What is stop length and accuracy? The belt runs 20 mm from the stop signal has been given until standstill. This distance can be adjusted by moving the proximity sensor 20 mm. The tolerance is 10 % equal to 2 mm. The 2 mm inaccuracy can only be eliminated by using a positioning system like a VLT 5000 with Sync/pos option.

The frequency converter tolerance is normally given by its task time. For a VLT 2800 it is 13 ms. However, by using its special precise stop function the tolerance is independent of the task time because the stop signal immediately interrupts the execution of the frequency converter program. The precise stop function gives a highly reproducible delay of 20 ms from the stop signal is given until the ramping down starts.

Guidelines

In this section we go through the various factors to be considered when using precise stop.

Ramps

To achieve the optimal precise stop it is important to set the ramps correctly. If the ramping down is done too quickly there will be very few ramp stages resulting in a relatively high error contribution as shown in Figure 3. To ensure optimum accuracy there should be at least 10 cycles during ramping down. Achievable VLT 2800 expressed in shaft accuracy in degrees as function of ramp length is indicated in table 1.

Ramp [ms]	50	150	3000
Accuracy [°]	33	23	9

Table I Accuracy at different ramps

The ramps of VLT 2800 refer to the rated motor speed. Running at other speeds the system can be further optimised by modifying the ramps according to actual maximum speed.

Example 2:
A 50 Hz motor runs at maximum 30 Hz. What must the ramp of the frequency converter be programmed for to ensure 10 cycles during ramping down considering that the task time of the frequency converter is 13 ms? As from 30 Hz the ramping down must be done in at least 130 ms, so the ramping down time of the frequency converter must be programmed to be at least 5/3*130 = 217 ms.

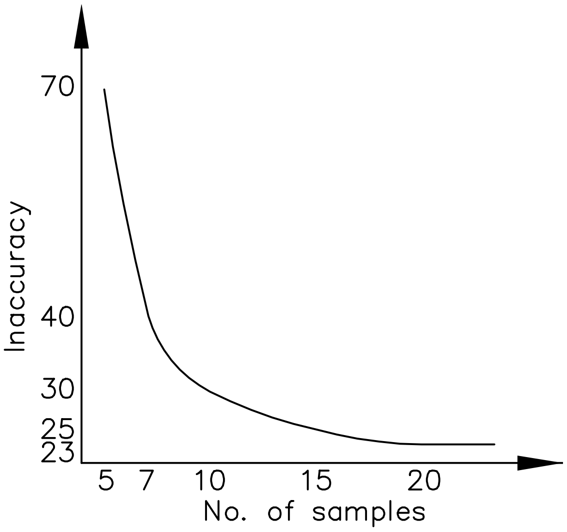

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Figure 3 Ramp inaccuracy

Tolerances

The tolerance or the accuracy indicates how precisely the frequency converter can stop the motor. This is illustrated in Figure 5. In transport applications the accuracy is normally given by a length tolerance. For example, the conveyor belt must stop within ± 2 mm. This accuracy is partly influenced by the frequency converter's ability to stop the motor and partly by the mechanical gear ratio from motor shaft to conveyor belt. This ratio can either increase or reduce the inaccuracy. In most cases, however, the inaccuracy will be reduced by the gear ratio. See example 3 below.

The shaft position accuracy in degrees gives the best indication of the basic accuracy of the frequency converter and motor, as illustrated in Figure 6. When the precise stop function of VLT 2800 is used the motor shaft accuracy is typically better than ± 23°. Table II shows the typical tolerance intervals for a VLT 2800 with precise stop at ramp times of minimum 150 ms. The tolerance will decrease with increasing ramp times, see Table I above. The tolerance intervals are a measure of the variance. This means that the shaft will in average stop outside these intervals in 4.56 %, 0.26 % and 0.003 % (30 ppm) of the cases respectively.

	Tolerance intervals
2σ (95.44%)	± 23°
3σ (99.74%)	± 37°
6σ (99.997%)	± 82°

Table II Tolerance intervals

If the mechanical gear ratio, and pulley diameter is known the accuracy can be converted to length accuracy for the conveyor belt. See example 3 below.

A frequency converter with a task time of 2 ms will give an inaccuracy of ± 1 ms corresponding to a theoretical tolerance of ± 9° for a 4 pole asynchronous motor at rated speed (1500 RPM).

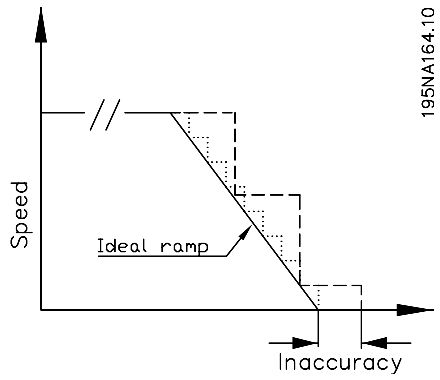

Figure 4 The accuracy is dependent on the number of samples.

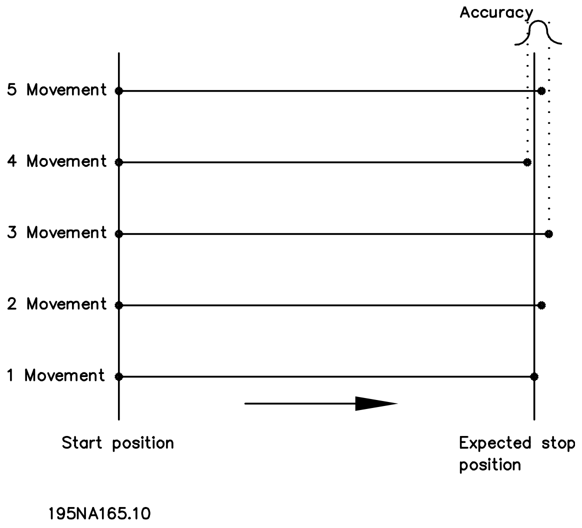

Figure 5 Position accuracy

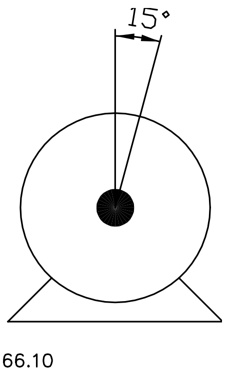

Figure 6 Stop accuracy for motor

Example 3:
A VLT 2800 is connected to a gear motor with a gear ratio of 3:1. The gear is connected to a conveyor belt running 100 mm per revolution. How precisely can this conveyor belt be stopped at 3σ accuracy? The ± 37° from tabel II is converted to length accuracy as follows:

37/360 x 1/3 x 100 mm = 3.5 mm.

This means that the belt will stop within ± 3.5 mm in 99.74 % of all cases.

Precise stop inverted versus precise start/stop
With VLT 2800 precise stop can be used in two different ways. You can either choose *Precise stop inverted* or *Precise start/stop*.

The start signal must be active during the entire ramping up.

Precise stop inverted:
If terminal 18 or terminal 19 is programmed for *Precise stop inverted* you can use a signal source (sensor or PLC) with positive logic.

Precise start/stop:
If it is important also to have a precise start signal you choose *Precise start/stop*. This could for example be in applications where one movement must be synchronised with another action, filling dough on plates /putting cheese on pizzas for instance. You can also use *Precise start/stop* if you want to start and stop the frequency converter with only one control wire.

Creep speed contra precise stop
In some applications the stop accuracy can be improved by using a creep speed. In such cases a proximity sensor is passed when 95% of the distance is completed. Then the belt is ramped down to a considerably lower speed, e.g. 5% of normal speed, then another sensor is passed and the motor is stopped. This is illustrated in Figure 7.

Figure 7 shows the effect of using creep speed. The hatched fields of Figure 7 show the stop length at high and low speeds. The stop length and the tolerance is much higher when ramping down from full speed than when ramping down from creep speed. It is thus possible to minimise the influence of sensor and PLC delay tolerances by using a creep speed.

The disadvantages of using creep speed are that two proximity sensors are required and that the total stop time and length are longer than at direct stop. This means that the cycle time is increased and that the efficiency of the machine is reduced. VLT 2800 with precise stop can often make it unnecessary to use creep speed.

Example 4:
The conveyor belt is the same as that used in example 1. In example 4 a creep speed is used that is 5% of rated speed. What is the stop length and what is the accuracy? After having passed sensor 1 the belt runs 0.05 m/s. With a delay of 20 ms ± 10% this gives a stop length of 1 mm and a tolerance of 0.1 mm. The stop length from the first sensor is not considered. – Note the considerable improvement compared to example 1.

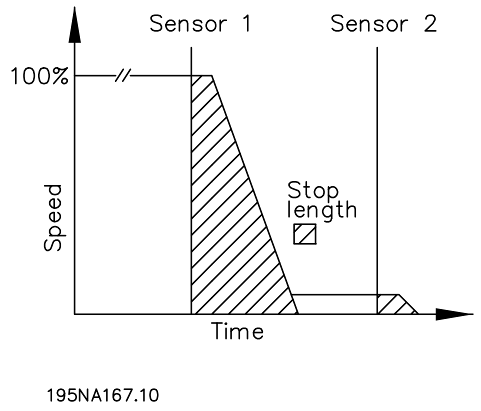

Figure 7 Precise stop using creep speed

Braking

Dynamic braking:
When braking loads of high inertia are used it may be necessary to use a brake resistor with the frequency converter. This makes it possible to dissipate the surplus energy that arises during braking. For further information about brake resistor applications we refer to instruction MI.50.D2.

DC braking:
To optimise precision you can use DC- braking. This function is integrated in the frequency converter. As a DC voltage is applied to one motor winding there will be a brake torque making it possible to brake the motor at low speed (below 8% of rated speed). The parameters to be programmed are shown in Figure 8.

Using this function the conveyor belt can be brought to standstill without help from the friction of the application. This means higher accuracy, especially if the natural friction is low.

122	**Function at stop**
	(FUNCTION AT STOP)
123	**Min.frequency for activation of function**
	at stop
	(MIN.F.F.FUNC.STOP)
126	**DC brake time**
	(DC BRAKING TIME)
127	**DC brake cut-in frequency**
	(DC BRAKE CUT-IN)
132	**DC brake voltage**
	(DC BRAKE VOLTAGE)

Figure 8 Relevant DC braking parameters

Speed compensated stop

Why speed compensated stop?
Precise stop is only optimal when the operational speed of the conveyor belt is constant. If you use the same line for different products you will often have to change the belt speed. In such cases you cannot rely on the precise stop function to ensure that work pieces are placed correctly. The reason is that the stop length varies with the original speed. To solve this problem it is necessary to compensate for the actual speed. With VLT 2800 that is done by using the function *speed compensated stop*. At speeds below maximum speed the stop signal is delayed internally before speed is reduced by the programmed ramp. This is illustrated in Figure 9 where the stop length is the same at the two speeds if the size of area 1 is the same as the sum of areas 2 and 3. Speed compensated stop utilises the precise stop function of VLT 2800.

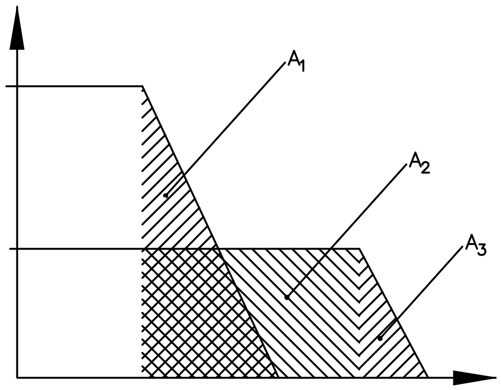

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Figure 9 Speed compensated stop

Typical application

Figure 10 shows a typical speed compensated stop application. Dough is placed on the conveyor belt, a belt takes the dough to a belt oven and from the oven the belt leads the cakes through the packing procedure. A flexible production plant that can handle different types of products requires speed changes of the conveyor belt. The time in the oven depends for example of the cake size and type and therefore the belt speed must be adjusted accordingly. Without speed compensated stop the distance between the cakes and capacity of the plant will vary from cake type to cake type and it will be necessary to move or adjust the proximity sensor mechanically. Such mechanical adjustments reduce the efficiency and flexibility of the plant. The speed compensated stop function ensures that the distance between the cakes is the same at all speeds.

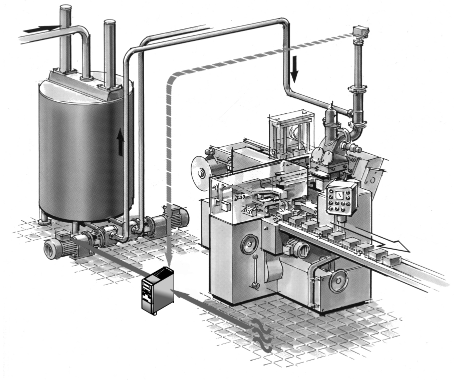

Figure 10 Typical speed compensated stop application

Guidelines

In this section we go through the factors that must be considered for speed compensated stop applications. Please also consider the factors mentioned under precise stop.

Speed reference

The delay is calculated on the basis of the reference speed of the frequency converter and not on the basis of the actual speed. Please therefore make sure that the frequency converter has ramped up before you activate the speed compensated stop. The ramp delay is calculated relative to the maximum output frequency programmed in parameter 202.

Setting of ramp up time

The ramp up time may affect the accuracy of speed compensated stop. Much too short ramps may result in overshoot or ringing of the mechanical system, as shown in Figure 11, or current limit in the frequency converter. Such instability will of course give rise to high inaccuracy. Increasing the ramp up time can reduce overshoot and the risk of resonance.

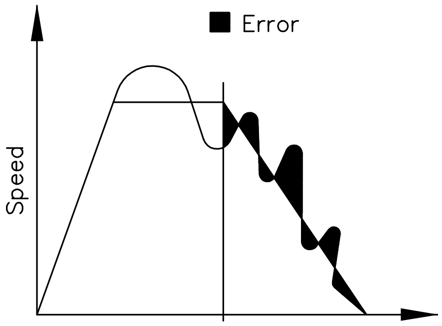

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Figure 11 The ramp time is too short

If the frequency converter runs into current limit it will try to increase the ramp time and this can have the consequence that the belt has not reached the desired speed when ramping down, and thus introduce an inaccuracy. Appendix A gives more details about this and a way to calculate the required power as a function of the ramp time.

Sensor and PLC delay

The frequency converter can only compensate for the inaccuracy that arises because of different stop lengths during ramping down. Before the frequency converter starts ramping down the belt runs a distance, how long depends on the speed. The time depends on the delay of the sensor and the PLC, before the braking starts. To compensate for this you can program parameter 349 for a total delay in ms enabling the frequency converter to compensate for this delay as well.

Speed compensated stop for commissioning

Commissioning is often done at a lower speed for safety reasons. This makes it easier to see what is going on. However, in some applications, for example where the distance to be done must be precise, it is not directly possible to use a lower speed. In such cases the speed compensated stop could be of great help by making commissioning possible at low speed.

■ Counter stop

Why counter stop?

The VLT 2800 frequency converter can be controlled via a pulse train. The frequency converter counts the number of pulses, typically from an encoder and generates a stop signal after a pre-programmed number of pulses. The advantage of using counter stop is that you get a direct feedback from the process, for example from the conveyor belt. In this case backlash and other mechanical variations will not affect the accuracy. The control is done in a closed loop. This is a one-way control meaning that the motor will not be reversed if it should run too far.

Typical application

VLT 2800 with counter stop is typically used in applications requiring strict monitoring of the distance done. Figure 12 shows an example of such an application. A frequency converter controls the feeding forward of paper, plastic foil etc. The material is automatically cut in fixed lengths. On the material there is a measuring wheel with an incremental encoder. The output of the encoder is connected with the counter input of the VLT 2800 frequency converter. This reduces waste and makes the quality uniform.

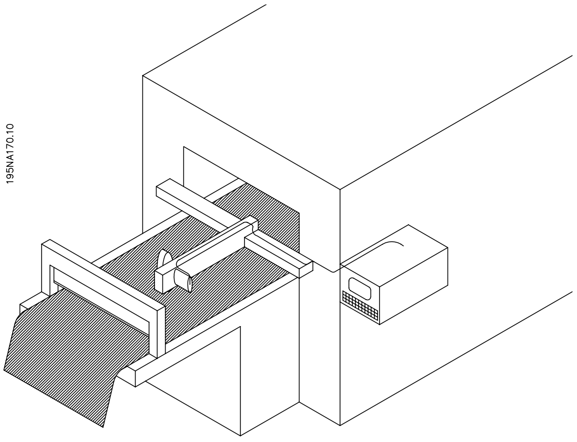

Figure 12 Paper cutter

Guidelines

In this section we go through the factors to be considered for counter stop applications.

Start/stop and ramps

As counter stop works with the precise stop function the VLT 2800 must be programmed for precise start/stop as start input for the digital inputs (terminal 18 or 19). The start signal must be active on the digital input during ramping and be removed before the end value is reached.

With this function the ramp should also consist of at least 10 cycles (130 ms).

Counter with or without reset

The desired counter value is programmed in parameter 344. The maximum value is 100000.

You can choose whether you want the counter to reset so that it starts from zero each time. If you choose without reset the overrun value is stored in the memory of the frequency converter and next time the counter starts from this value. You can for example use this function to compensate for the extra distance done during ramping down and to reduce the impacts of gradual wear of mechanical parts.

PLC counter module

One of the advantages of using the built-in counter is that a simpler and cheaper PLC without high frequency input can be used.

Via the digital output the VLT can inform the PLC whether it runs or has stopped. Such information is for example required if one movement must be synchronised with other events.

Choice of encoder

Different types of encoders are available. Primarily we distinguish between absolute and incremental encoders. Absolute encoders give a specific digital value for each individual position of the shaft, whereas an incremental encoder gives a number of pulses per revolution (typically 512, 1024 or 4096 per revolution).

The output signal from an encoder is either of an open collector or of a push-pull type. Open collector outputs can be used up to 20 kHz with VLT 2800 frequency converters. If the pulse signal has a higher frequency it is necessary to use a push-pull output. The VLT 2800 accepts pulse inputs up to 67 kHz. The voltage level is either 5 VDC (TTL levels, line driver) or 10-30V DC (HTL levels). For VLT 2800 encoders with HTL levels must be used.

The minimum frequency, the VLT 2800 can detect on the pulse input, is 5 Hz.

Example 8:

In an application like that shown in Figure 12 a resolution of 0.5 mm is required. The measuring wheel has a diameter of 100 mm. How many pulses must be chosen for the incremental encoder? The perimeter of the measuring wheel is 100 x π = 314 mm. The number of pulses must therefore at least be: 314/0.5 = 628 pulses corresponding to an encoder with 1024 pulses/revolution. If the forward speed for the paper is 1 m/s, what type of output should be selected? The wheel will rotate 1000/314 = 3.18 revolutions/s. This means that the frequency of the encoder signal will max be 3.18 ·1024 = 3256 Hz. An encoder with open collector output will thus be sufficient.

Actual counter value

You can read the actual counter value in parameter 544 to check whether the frequency converter registers the correct number of pulses on the pulse input.

During commissioning it is also often useful to know the counter value, for example, if mechanical adjustments are based on the counter value.

Parameter 544 can be programmed into the user defined quick menu so that the counter value can be read directly from the frequency converter display. Please consult the VLT 2800 Design Guide for further information about how to program the user defined quick menu.

Appendix A

Calculation of motor size

The output power available to accelerate the load is often the limiting factor when motors are used in applications with frequent starts and stops. The frequency converter limits the applied output to 160% of rated motor output. However, a special high torque mode can be programmed so that the torque can be 180% for a short period of time (up to 0.5 s). With the VLT 2800 we have made this limitation to protect the output of the frequency converter against overload and the motor against reaching the pull out torque.

When the frequency converter reaches the current limit it will limit the ramp and try to ramp up at a lower speed. This means that the conveyor belt does not reach the required speed within the programmed time. In connection with speed compensated stop this can give rise to faults. Contrary to expectation it could in such cases help to increase the ramp time to make the belt reach the expected speed, without reaching the current limit.

For the time t_0 the belt will travel the distance:

$$S_0 = \frac{V_{max} \cdot t_0}{2}$$

The ramp of the frequency converter is limited so that it will need a ramp of $t_1 = k \cdot t_0$ to reach V_{max}, where k is a constant. This is illustrated in Figure 13.

The stop signal will come at the same distance as the proximity sensor position is fixed. The acceleration of the belt with the new ramp is:

$$a = \frac{V_{max}}{t_1} = \frac{V_{max}}{k \cdot t_0}$$

The distance done at any time, t, during ramp up can then be calculated as:

$$S_1 = \frac{1}{2} a \cdot t^2 = \frac{1}{2} \frac{V_{max}}{k \cdot t_0} t^2$$

The proximity sensor is reached when $S_0 = S_1$:

$$\frac{1}{2} \frac{V_{max}}{k \cdot t_0} t_1^2 = \frac{V_{max} \cdot t_0}{2} \Leftrightarrow t_1 = \sqrt{k} \cdot t_0$$

And the speed at t_1 will be:

$$v_1 = a \cdot t_1 = \frac{V_{max}}{k \cdot t_0} \sqrt{k} \cdot t_0 = \frac{V_{max}}{\sqrt{k}}$$

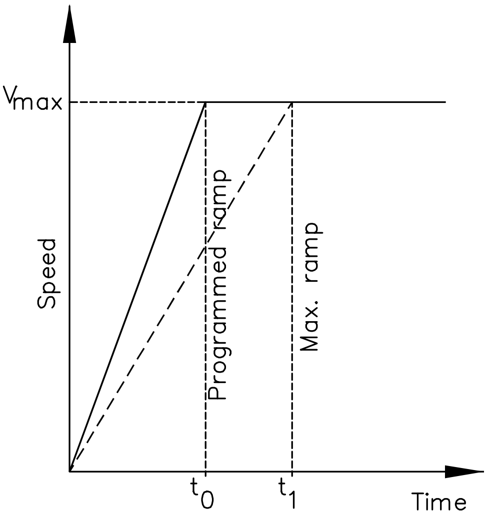

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Figure 13 Current limited ramp

Example:
If the ramp is extended to the double the speed will only be 71% of the expected speed when the work piece passes the proximity sensor, which is a significant deviation.

In the following we go through how the necessary motor output can be calculated in a typical horisontal conveyor belt application. The distance done and the material on the conveyor belt will vary from application to application. The ramp time is typically determined by the processing time, e.g. expressed as a cycle time, whereas the maximum belt speed is often limited by mechanical factors.

The conveyor belt has a total length of L, and between the rolls there is a distance of dL. Each roll weights M_r, and has a radius of R. The total mass on the conveyor belt is M and the belt/mass must move the distance L_0 within the time t_0, see Figure 14.

Max. speed belt, acceleration, force on the box, and the maximum angular velocity of the rolls can be calculated as follows:

$$V_{max} = \frac{2L_0}{t_0}; \qquad a = \frac{4L_0}{t_0^2};$$

$$F = M \cdot a = \frac{4L_0M}{t_0^2}; \qquad \omega_{max} = \frac{V_{max}}{R}$$

The frequency converter output to the motor/gear shaft is: $\eta \cdot U \cdot I$, where η is the total motor and gear efficiency, $\eta = \eta_{motor} \cdot \eta_{gear}$.

The energy delivered to the conveyor belt during acceleration is:

$$E_{out} = \int_0^{\frac{t_0}{2}} \eta \cdot U \cdot I \cdot dt = \eta \cdot U \cdot I \cdot \frac{t_0}{2},$$

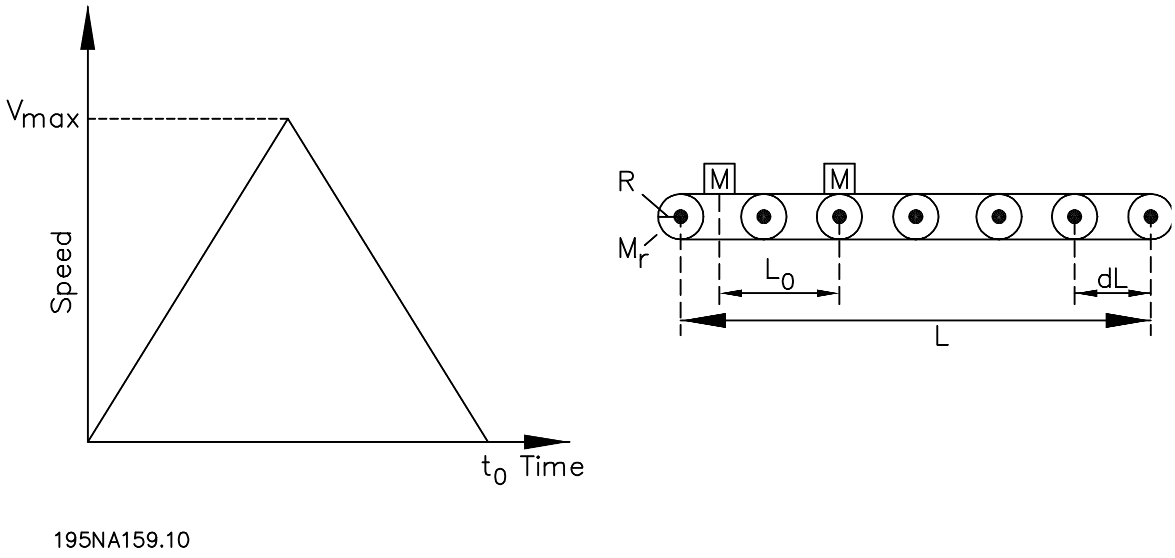

Figure 14 Typical conveyor belt application

To accelerate the belt and the material on the belt the following energy is required:

$$\begin{aligned}
E_{mass} + E_{conveyor} + E_{motor} &= \int_0^{t_0/2} (P_{mass} + P_{conveyor} + P_{motor})\, dt \\
&= \int_0^{t_0/2} \left((F + F_{fric}) \cdot R \cdot \omega + I_{conveyor} \cdot \dot{\omega} \cdot \omega \ + I_{motor} \right) \cdot \dot{\omega} \cdot \omega \ \ dt \\
&= \int_0^{t_0/2} \left(4 \frac{ML_0R}{t_0^2} \omega_{max} \ \frac{t}{t_0} + \left(\frac{1}{2} + \sum M_r R^2 + I_{motor} \right) \cdot \frac{\omega_{max}}{t_0} \cdot \omega_{max} \cdot \frac{t}{t_0} \right) dt \\
&= \left(8 \frac{ML_0{}^2}{t_0^4} + \left(\frac{1}{2} + \sum M_r R^2 + I_{motor} \right) \cdot \frac{\omega_{max}}{t_0} \cdot \omega_{max} \cdot \frac{t}{t_0} \right) \left[\frac{1}{2} t^2 \right]_0^{t_0/2} \\
&= \left(8 \frac{ML_0{}^2}{t_0^4} + \left(\frac{1}{2} + \sum M_r R^2 + I_{motor} \right) \cdot 4 \frac{L_0{}^2}{R^2 \cdot t_0^4} \right) \frac{1}{8} t_0^2 \\
&= \frac{ML_0{}^2}{t_0^2} + \left(\frac{1}{2} \sum M_r + \frac{I_{motor}}{R^2} \right) \cdot \frac{1}{2} \left(\frac{L_0}{t_0} \right)^2
\end{aligned}$$

As $E_{out} = E_{mass} + E_{conveyor} + E_{motor}$, and the frequency converter can supply 160 % torque for up to 60 s. the following calculation can be made:

$$E_{out} = E_{mass} + E_{conveyor} + E_{motor} \iff$$

$$1.6 \cdot \eta \cdot U \cdot I \cdot \frac{t_0}{2} = \frac{ML_0^2}{t_0^2} + \left(\frac{1}{2} \sum M_r + \frac{I_{motor}}{R^2} \right) \cdot \frac{1}{2} \left(\frac{L_0}{t_0} \right)^2 \iff$$

$$U \bullet I = P_{nom} = \frac{1}{1.6\,\eta} \frac{L_0^2}{t_0^3} \left(2M + \frac{L}{2dL} M_r + \frac{I_{motor}}{R^2} \right)$$

As it will appear from the above the necessary output power is highly dependent on the ramp time, t_0.

Example:

A conveyor belt of 2 m, a roll distance of 10 cm and a roll radius of 2.5 cm and a mass of 200 g per roll transports a mass of 5 kg over a distance of 20 cm within a given time. If it must be done as described above in Figure 1 with a total motor and gear efficiency of 0.85 and a moment of inertia of the motor and gear of 0.02 kgm^2, the frequency converter must supply the motor with an output power as shown in Figure 15. It can be seen that the output is very high for short ramps compared to the output you would normally expect for such a conveyor belt in steady state.

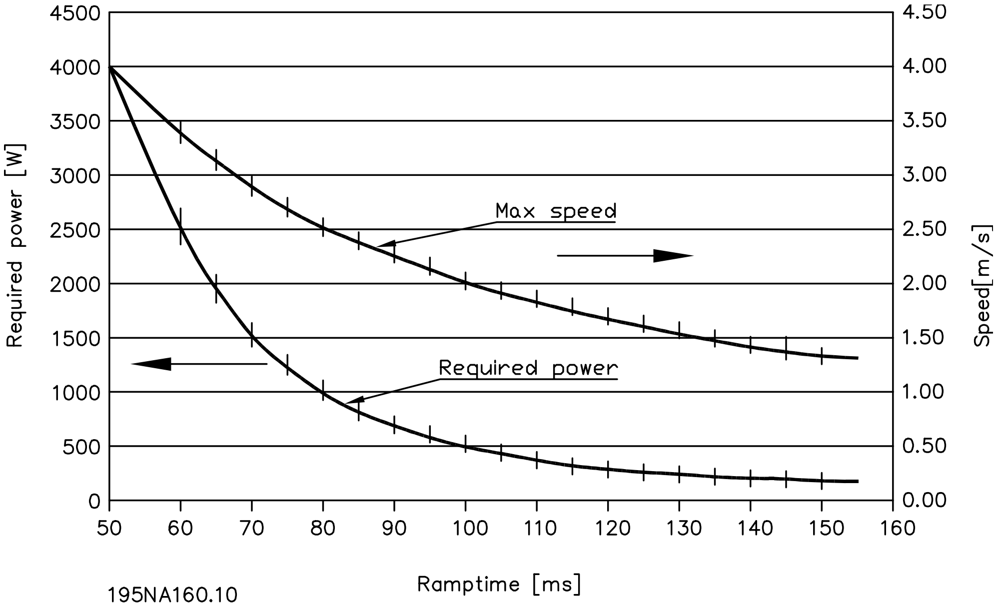

Figure 15 Output required to accelerate a conveyor belt

The frequency converter may thus reach the current limit during acceleration if for instance a 0.75 kW frequency converter and motor are used. One solution is to choose a frequency converter one size larger than the motor to enable a higher power. Caution should be paid not to exceed the pull out torque of the motor.